



INTELLIGENCE TO SHAPE YOUR TOMORROW

Status of the Camera Module Industry 2023

Market and Technology Report



GLOSSARY



- ADAS Advanced Driver Assistance System
- AF Auto Focus
- AR Augmented Reality
- ASP Average Selling Price
- BSI Back Side Illumination
- CAGR Compound Annual Growth Rate
- CCD Charge Coupled Device
- CCM Compact (or CMOS) Camera Module
- CFA Color Filter Array
- CIS CMOS Image Sensor
- CMOS Complementary Metal Oxide Semiconductor
- COB Chip On Board
- CRA Chief Ray Angle
- CSP Chip-Scale Packaging
- CT Computed Tomography
- DMS Driver Monitoring System
- DOE Diffractive Optical Element
- DOF Depth Of Field
- dToF Direct Time of Flight
- EB Event-Based
- FF Fixed Focus
- FPA Focal Plane Array
- FPC Flexible Printed Circuit
- FSI Front Side Illumination
- HDR High Dynamic Range
- HMD Head-Mounted Display
- HMI Human-Machine Interface
- IoT Internet of Things
- IR Infrared
- ISP Image Signal Processor
- iToF Indirect Time of Flight
- LCV Light Commercial Vehicle
- LiDAR Light Detection And Ranging
- LDAF Laser Detection Auto Focus
- MEMS Micro Electro-Mechanical System
- MLA Micro Lens Array
- Mp Megapixel
- NIL Nano Imprint Lithography
- NIR Near Infrared
- OEM Original Equipment Manufacturer
- OF Optical Format
- OFP Optical FingerPrint
- OIS Optical Image Stabilization
- OLED Organic Light-Emitting Diode
- OMS Occupant Monitoring System
- PCB Printed Circuit Board
- PDAF Phase Detection Auto-Focus
- QE Quantum Efficiency
- RIE Reactive Ion Etching
- RGB Red/Green/Blue
- ROIC ReadOut Integrated Circuit
- SL Structured Light
- SMT Surface-Mount Technology
- SNR Signal-to-Noise Ratio
- ToF Time of Flight
- TSV Through-Silicon Via
- TTL Total Track Length
- VCM Voice Coil Motor
- VR Virtual Reality
- WLG Wafer-Level Glass
- WLO Wafer-Level Optics
- WLP Wafer-Level Packaging
- XR eXtended Reality
- YoY Year-over-Year

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REPORT'S OBJECTIVES

1. Provide market data on key CCM metrics and dynamics

- CCM forecasts, by revenue, shipments, and components
- Market shares, with detailed breakdown by player and components
- Application focus on key growth areas for CCM

2. Deliver an in-depth understanding of the CCM value chain, infrastructure, and players

- Who are the CCM players (CIS manufacturers, CCM manufacturers, optics and actuators manufacturers, etc.), and how they are related?
- Who are the key suppliers to watch - and more generally, how will the camera module industry evolve?

3. Present key technical insight and analysis regarding future technology trends and challenges

- Manufacturing technologies
- Device technologies: CCM applications across markets
- Technology focus on game-changing areas and emerging technologies



SCOPE OF THE REPORT

Yours needs
are out of the
report's
scope?

Contact us for
a customized
inquiry



MOBILE & CONSUMER

Mobile

Front
camera



Rear camera



3D sensing
camera



Other consumer

Personal robotic
camera



AR/VR/MR
camera



Home
surveillance



Smartwatch/
AloT camera



Action/drone
camera



Smart
assistant/Game
station camera



AUTOMOTIVE

AD
camera



ADAS
camera



Viewing
camera



In-cabin
camera



INDUSTRIAL

Barcode
reader



MEDICAL

"Chip-to-
the-tip"
endoscope



Computing

Tablet and
computing
camera



Non-compact cameras are out of this report's scope:

- Consumer DSLR & DSC cameras
- Medical Xray and PET applications
- Infrastructure security cameras
- Industrial machine vision, professional & broadcast cameras
- Defense & Aerospace cameras

METHODOLOGIES & DEFINITION



Yole's market forecast model is based on the matching of several sources:

Comparison with existing data
Monitoring of corporate communication
Using other market research data
Yole analysis (consensus or not)

Comparison with prior Yole reports
Recursive improvement of dataset
Customer feedback

Top-to-bottom approach
Aggregate of market forecasts
@ System level

Bottom-up approach
Ecosystem analysis
Aggregate of all players' revenue
@ System level

Top-to-bottom approach
Aggregate of market forecast
@ Semiconductor device level

Bottom-up approach
Ecosystem analysis
Aggregate of key players' revenues
@ Semiconductor device level

Market
Volume (in Munits)
ASP (in \$)
Revenue (in \$M)

Semiconductor foundry activity
Capacity investments and equipment needs

Preeexisting information

Primary data

- Reverse costing
- Patent analysis
- Annual reports
- Direct interviews

Secondary data

- Press releases
- Industry organization reports
- Conferences

Information Aggregation



ABOUT THE AUTHORS



Zine BOUHAMRI

Team Lead Analyst
Zine.bouhamri@yolegroup.com



Anas CHALAK

Analyst
Anas.chalak@yolegroup.com



Axel CLOUET

Analyst
Axel.clouet@yolegroup.com



Florian DOMENGIE – Lead Author

Senior Analyst
Florian.domengie@yolegroup.com



Raphaël MERMET-LYAUDOZ

Analyst
Raphael.mermet-lyaudoz@yolegroup.com



Jérôme MOULY

Division Director
Jerome.mouly@yolegroup.com

COMPANIES CITED*



AAC Technologies, AGC, Alibaba, Alps, Amazon, Ambu, Ams OSRAM, Analog Devices, Apple, Aptiv, Asia Optical, ASM, Awaiba, BAE Systems, Baidu, BL, BMW, Bosch, Brigates, BYD Semiconductor, Calin Technology, Cambridge Mechatronics, Cammsys, Canon, CEA Leti, Chicony, Cirrus Logic, Coherent, Continental, Corephotonics, Corning, Cowell, Curve-one, Dahua, Denso, DJI, Ecovacs, Ficosa, Foxconn, Fujifilm, Fujitsu, Galaxycore, Genius Optical, Goodix, Google, Gopro, Gpixel, Haesung Optics, Hamamatsu, Hikvision, Himax, Holitech, Honeywell, Honor, Hoya, Hozel, Huixin, Huawei, IM Co, Immervision, Infineon, Intel, iRobot, Jabil, Jahwa, JBL, Kantatsu, Kappa, Kinko Optical, Kolen, Kura Technologies, Kyocera, Largan, LCE, Leica, Lenovo, LG Innotek, Lumotive, Luxvisions, Magna, Materion, Mcnex, Medigus, Melexis, MEMS Drive, Meta, Metalenz, Microsoft, Mitsumi, Moxtek, Neato Robotics, New Shicoh, Nextlens, Nidec, NILT, NTK, Ofilm, Olympus, Omnivision, Oneplus, Onsemi, Oppo, Optotune, Panasonic, Panasonic Automotive, Parrot, Partron, Pixart, Pixelplus, Pmd, Polight, Powerlogic, Primax, Prophesee, Q Tech, Rayprus, Realme, Ricoh, ROHM Semiconductor, Samsung, Samsung Electro-Mechanics, Schott, Sekonix, Sharp, Sheba Microsystems, Shinetech, Silicon Dynamix, Silina, SK Hynix, Smartsens, Softkinetic, SOInc, Sony, SPY, STMicroelectronics, Sunex, Sunny Optical, Sunwin, Suss Microoptics, Synaptics, Tamron, TDK, Teledyne, Tesla, Toshiba, Toyota, Transsion, Truly, Tunoptix, Valeo, Veoneer, Viavi, Vivo, Volvo, Waymo, Xiaomi, Xperi, Zeiss, Zeon, ZET, ZF, ZTE, and more.

*non-exhaustive list

WHAT WE GOT RIGHT, WHAT WE GOT WRONG



What we got right

- Automotive cameras are booming, on path of 10% volume CAGR by 2028 as expected, driven by the takeoff of new electric vehicles and the pursuit of higher automation levels to meet new safety regulations. The new growth cycle from the industrial and automotive markets has been confirmed.
- After strong growth in 2021, computing markets started to decline following the end of the “stay-at-home” policies.
- Investment in capacity expansion is running, also in China, and overall market competition is increasing.
- The introduction of new CIS technologies, such as those related to sensing or three-wafer stacking, is happening.



What we got wrong

- Mobile imaging market slowed due to the lower smartphone sales in the current uncertain economic context. We overestimated the growth in smartphone optical fingerprint image sensors, so we corrected downwards its penetration rate.
- Following the impact of the COVID-19 crisis, we overestimated the DMS/OMS camera volume.
- We corrected and increased the ASP for computing tablets and barcode readers CCM that had been underestimated.
- We made a complete re-assessment of the CCM cost breakdown: slightly decreasing actuator (-1% to -2%), and increasing lens set (+1%) and CIS contributions (+3 to +7%).



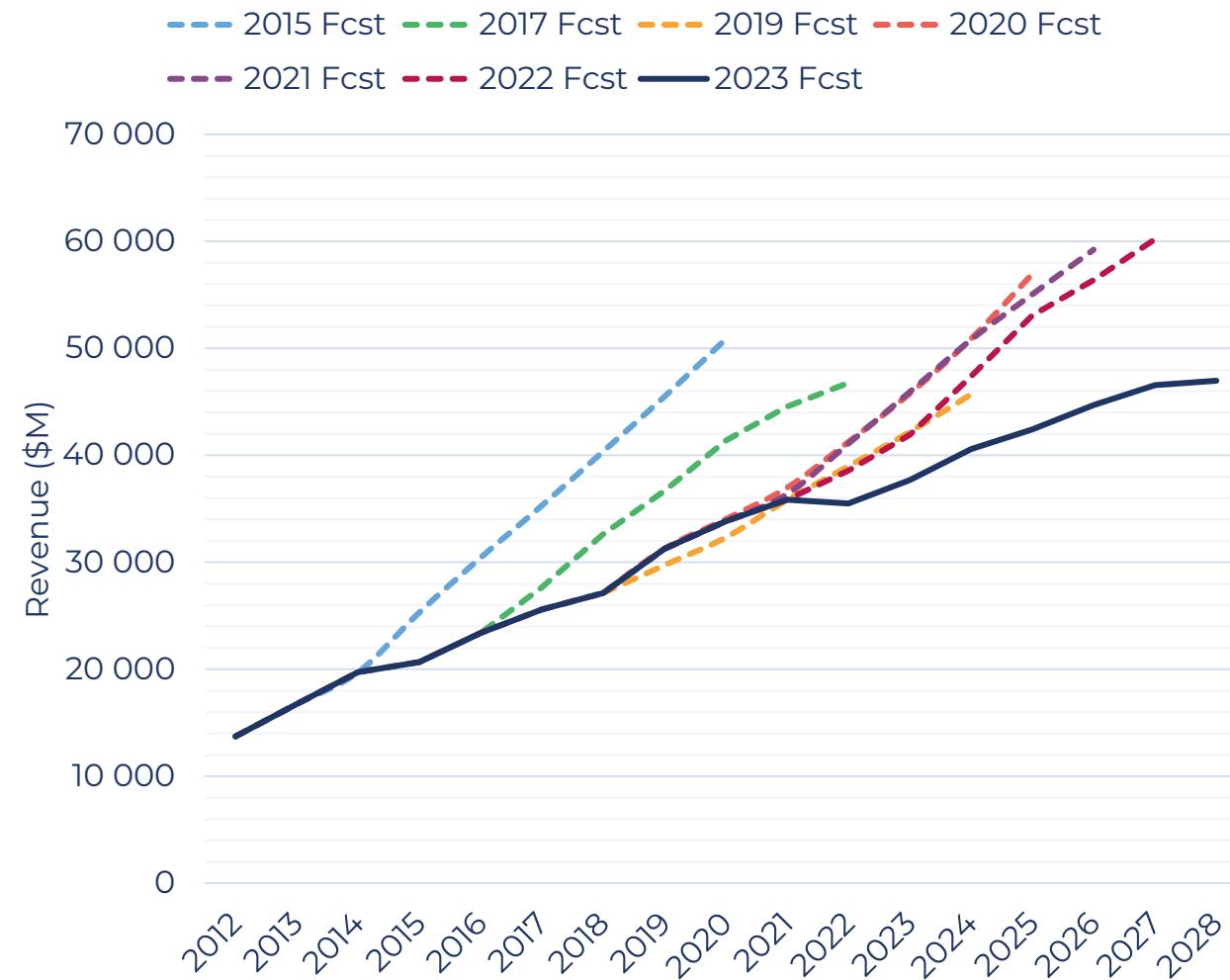
WHAT WE GOT RIGHT, WHAT WE GOT WRONG

CCM revenue forecast over the past years

Growth momentum is maintained but slower for CCM.

- Since mobile imaging has reached a certain maturity, Yole intelligence has revised downwards its camera module (CCM) forecast these past few years.
- Overall, the growth potential expected in early 2022 for the 2021-2027 period has been affected, mainly due to the economic context that negatively impacted the mobile and consumer markets.
- This results in about a 20% long-term revenue decrease versus last year's estimation:
 - Decrease of long-term smartphone volume shipments by 14% and slowdown of multi-camera trend
 - Review of the Automotive CCM volume forecast, adjusted by 20% downwards
- Still, we should expect a sustained but slower growth for the next six years.

Yole historical CCM revenue forecast (in \$M)





CMOS image sensor, optics, actuators and camera module vendors:

- Evaluate the market potential of future technologies and products for new applicative markets
- Screen potential new suppliers for the introduction of new disruptive technologies
- Monitor and benchmark your competitors' advancements

CMOS image sensor foundries:

- Spot new opportunities and define diversification strategies
- Position your company in the ever-changing CCM value chain

Assembly and test service companies:

- Understand the strategy of top CCM players

Equipment & materials manufacturers:

- Recognize CCM evolution and ecosystem dynamics
- Discern the differentiated value of your products and technologies in this market
- Identify new business opportunities and prospects

Electronic module makers & original equipment manufacturers:

- Weigh the benefits of using these new technologies in your end-system
- Filter and select new imaging suppliers

Financial & strategic investors:

- See the potential of new imaging technologies
- Obtain a list of key emerging start-ups



3 PAGE SUMMARY

Soft landing before a new take-off at 4.8% CAGR by 2028



- The CMOS compact camera module industry were continuing to grow until 2021 thanks to the massive volume of mobile phones, booming new energy vehicle adoption, and the temporary high demand for PC & tablet devices. Then, revenue decreased slightly to \$35.5B in 2022. The CCM market should resume growth in 2023, with a progressively slowing growth year-over-year rate from 2024, and we expect a 4.8% CAGR over the 2022-2028 period. The natural decline expected for computing product shipments (tablets, laptops..) is confirmed. All the other market segments are promised to grow at different rates. **The decrease of long-term smartphone volume shipments by 14%, the slowdown of multi-camera trend, and the review of the Automotive CCM volume forecast, adjusted by 20% downwards, is resulting in an about 20% long-term revenue decrease versus last year's estimation.**
- In 2022, the camera module market generated \$35.5B in revenue, Mobile and Consumer applications representing nearly 96% of the shipments with more than 6.3B units: Mobile only accounted for more than 5.1B units, Computing cameras (tablets, laptops, optical mice) for nearly 1B units and about 0.2B units camera modules have been shipped for other consumer applications (drones, consumer robotics, home security cameras, etc.). Automotive represented 3% of the total shipments, with 218M camera modules for viewing, ADAS and emerging in-cabin or exterior access applications. **This resulted in 6.6B units shipped, a -5.4% decline in 2022 vs. 2021.**
- 3D imaging and sensing camera module solutions accounted for 12% of the total CCM market in 2022, and are expected to increase to 14% by 2028.
- Over the 2022-2028 period, CCM shipments should increase from 6.6B units to 8.2B units, with the corresponding CAGR adjusted from 6.5% to 3.6% versus our last-year forecast. Beyond mobile, which will still drive CIS volumes, computing, automotive, and other consumer products camera modules are also sustaining the growing trend. Indeed, our long-term prediction has been reviewed downwards significantly: **smartphone sales are expected to reach 1.2B units instead of 1.4B units, and with a deceleration in the increase of the average number of cameras per smartphone**, that will limit the primary source of growth for CCM volumes (by about -1.5B units).
- In the mobile market high-end photography is transitioning to larger resolution and size image sensors with higher ASP. The Automotive CCM price surged further in 2022, as a soft-landing situation from the previous shortage and supply chain issues, and also due to the growing adoption of higher resolution including the 8Mp ADAS solutions. This results for the whole CCM market in a slight average ASP increase at 1.2% CAGR from 2022 to 2028, as the consequence of a slightly increasing ASP for Mobile applications that represent most of the volume shipped.
- After being on a decreasing trend, the module assembly contribution part should start to retake more percentage value from 2023 as modules are becoming more complex, diversification and new sensing cameras are rising, and larger formats are coming to Mobile. As new technologies are adopted, AF & OIS penetration will also demonstrate an increased value share, spreading into more camera modules in the mobile and consumer market. Overall, image sensors and optics will grow at a slightly slower pace than actuating and module assembly contributions. The trend to replace some plastic lenses with glass ones in Mobile should remain limited, and some efforts are being conducted to simplify the optics module. **Module assembly could still benefit from the diversity of cameras, from imaging to sensing applications, and from the growing share of higher-value Automotive applications in the camera module assembly.**
- Despite a decline in 2022 and lower longer-term expectations of smartphone shipments of about 10%, and a slowdown in the increase of the average number of cameras per smartphone, higher-end products and new sensing opportunities will sustain the Mobile CIS market in the coming years. Automotive cameras are experiencing large growth enabled by in-cabin, viewing, and ADAS applications. Safety regulations and increasing demand for car automation encourage car OEMs to integrate more imaging technologies. **Automotive is now one of the segments with the biggest growth potential for CIS and in more general imaging solutions providers. Factory automation is the main driver for the growth of the Industrial imaging, requiring high-end industrial cameras; logistics automation with matrix code readers is still the high-volume industrial application.**



SUPPLY CHAIN SUMMARY

Slowing mobile and consumer market reshuffling the camera module ecosystem

- CCM revenues have slightly decreased in 2022 from \$35.6B to \$35.5B, as a soft landing after the largely inflated growth from the previous years. The general inflation worldwide in 2022 resulted in a significant slowdown in consumer product sales, such as smartphones (-10%). In this context CCM manufacturers continued to experience different fortunes and previous revenue trends have been exacerbated in 2022: **LG Innotek**'s continued on its tremendous growth, with 24% YoY, and could outperform its competitors, still supplying all rear triple-camera and sensing cameras to Apple and getting new opportunities in Automotive. **Q Tech** continued to grow until 2021 due to increased high-resolution cameras in its product mix and being a supplier for Xiaomi, Oppo, and Vivo camera modules. However, **Sunny Optical** and **Ofilm**, show decreasing revenue. The main reason for this has been the past restrictions on Huawei. **Foxconn (Sharp)** and **Semco** have been quite stable in revenue these past few years, the latter getting more diversified in Automotive.
- For CIS, 2022 has been a transition year with similar revenues to the year before and a slight decline in overall volumes. However, a significant transformation is underway in the CIS market structure, as evident in the growth of the Automotive segment and the increase in CIS average selling price. **Sony** is again increasing its commanding position while **Omnivision** has retreated to close to its pre-COVID market share. **Samsung** also reduced its footprint, apparently to the benefit of **SK Hynix**. **STMicroelectronics** has kept its share, while **Onsemi**, which had been sliding for a few years, saw an exceptional 2022 boosted by the Automotive and Industrial markets. **Galaxycore** and **Smartsens** have retreated, apparently due to the disinflation of the low-end Mobile and Security camera markets. The geographically competitive CIS landscape is marked by the economic conflict between the U.S. and China.
- More than 90% of the optics lens set revenues are generated by leading companies based in Greater China, with lens set revenues that have decreased in 2022 from \$5.31B to \$5.25B. Interestingly **Largan** could not pass the \$2.0B milestone as challenged by its competitors and had to share its growth with **Sunny Optical**, **Genius Optical**, **LCE**, **AAC Technologies** and other smaller players, that have experienced a solid and continuous growth. For the lens market, the update speed of new camera modules has slowed down, which has led to a decline in the income of the two top players these past three years. AAC is the leader in WLO glass manufacturing, advocating for glass-plastic hybrid lenses.
- CCM actuators revenues have imperceptibly decreased in 2022 from \$2.57B to \$2.56B. Interestingly Japanese actuator leading companies: **Alps**, **Mitsumi**, **TDK** had outperformed the Korean ones: **Semco**, **Jahwa**, **LG Innotek** in terms of revenue growth from 2015, except TDK that encountered a large decline from 2020 due to its high exposition to its major declining customer, Huawei, following the ban imposed by the U.S. Among the AF and OIS actuator supply chain, new entrants have mastered the simpler AF technology, reduced costs, and gradually gained some market share. However, high-end OIS actuators are still concentrated among the top players.
- With the slowdown in the Mobile and Computing market, there are ongoing investments to secure capacity, develop in-house technologies or license them as a strategic vision to get further market share. CCM manufacturers and CIS giants are dominating the revenue ranking: **LG Innotek**, **Sony**, **Sunny Optical**, **Samsung**, **Foxconn**... In the race to build and strengthen an alternative supply chain, major investments are announced in CCM production capacity in Vietnam factories, with more than \$6B investment since 2022. Finally, even if there was an evolution in the market share rankings caused by the slowing growth of the Mobile and Consumer market and the thriving of Automotive, the leaders are still there, and there is only a small space for new entrants to gain a foothold.



TECHNOLOGY SUMMARY

Rising innovation activity to support higher value products

- In the climate of Consumer market stagnation, most imaging leaders are working to increase their product value and performance, targeting new product developments. Zoom has always been a key differentiator for high-quality imaging and smartphone OEM competition. From the first commercial cameras in 2019 released by Huawei and Oppo, there has been a folded optics camera adoption wave from Android OEMs from 2020 to 2021. Lastly, in 2023, Apple introduced a periscope camera in its iPhone 15 Pro Max series for the first time, which has given additional momentum to the expected growth. It should get more adopted in flagships and mid to high-end phones in the future thanks to module cost reduction. Jahwa collaborated with Semco to develop ball-guide actuators, a highly desired actuating technology for larger cameras, including periscopes, to bring further speed, reliability, and accuracy over spring-type actuators. However, some critical patents cover these ball-type actuators and their associated OIS system.
- The CMOS image sensor industry is animated by a profusion of technological innovations that aim to continue improving sensor performance and integrability and unlock new sensing capabilities. In general, the industry is still seeking smaller pixels, higher signal-to-noise ratio, and higher dynamic range while decreasing power consumption and the physical footprint of the sensor. Sony is introducing its first triple-stack sensor with pixel transistors on a separate layer for its Xperia 1 V smartphone, while Omnivision and STMicroelectronics are also investigating such architectures. Not only are pixel architectures changing, but it is also the case for logic, with smaller technology nodes. Another critical challenge is to increase device sensitivity, especially for low-light or 3D sensing applications. A low-cost SWIR imaging segment is emerging, leveraging a CIS basis to address Consumer applications (tracking cameras, 3D sensing, multispectral imaging). Event-based imaging is emerging as a solution for high-speed, low-latency, and low-power imaging as it ensures a reasonable data load.
- The manufacturing of individual camera modules is becoming more mature, but new types of modules, such as the periscope camera, require more effort because of their optical complexity. Mobile phone imaging has given rise to the widespread use of plastic lenses, which were previously made of glass. The optics lens industry has largely moved from Germany and Japan to South Korea and China. However, as the height needs to be minimized, the increased number of lenses makes the assembly of the lens very complex. A high-resolution CIS requires a high-quality lens, that does not necessarily mean increasing the number of lenses; another approach is adding glass to the lens set, as the hybrid approach. A new paradigm, such as a free-form or liquid lens, has risen, and metalenses are coming to the market as an ultimate evolution of flat optics to bring further the performance and improve the compactness of the camera modules. WLO plastic lenses have made good progress, and their small size gives them an advantage in medical applications such as endoscopy. Another way to resolve the problem of CIS with a large number of pixels is not to increase the number of lenses but to use lenses with a high refractive index material, the quest for these materials with sufficient levels of quality and reliability is still ongoing.
- VCM technology has matured, while the SMA actuator is coming to bring progress in lightweight, energy and power efficiency, allowing to move the large, heavy lens modules necessary for large-format CIS. While emerging technologies such as piezo motors, MEMS actuators, and liquid lenses have been brought to market, their use has remained somewhat niche, while most products are based on the more conventional VCM technology. Recently, Alps Alpine announced the mass production of an SMA actuator for camera modules. This SMA technology offers precise and rapid actuation with superior compactness and energy efficiency compared to traditional VCM technology. Additionally, the immunity to magnetic interference makes SMA actuators an ideal solution for foldable smartphones. OIS technology has clearly moved on from lens shift to sensor shift and even module shift.
- The camera module industry has evolved offering more complex modules, bringing actuator, larger resolution, larger formats, etc., then transitioning to multi-camera trends and now opening the way for new multi-sensing modalities with even more intelligence brought closer to the sensing module.

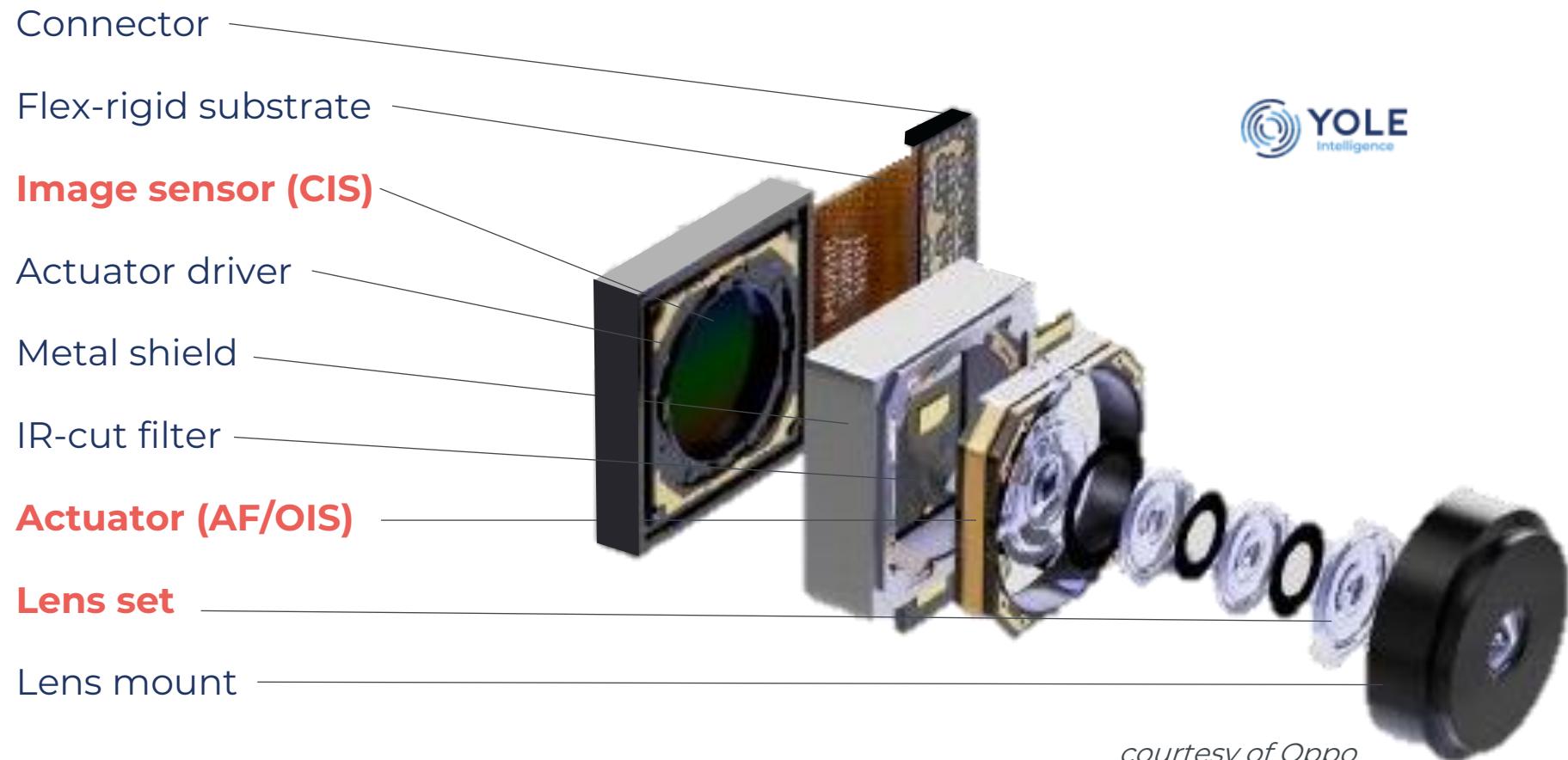
EXECUTIVE SUMMARY



CONTEXT

What does a mobile camera module consist of?

Once a relatively basic module, CCM has evolved into a complex microelectro-mechanical device.



Module assembly brings all these components together into a module

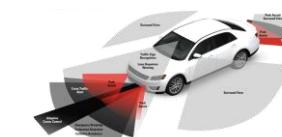


CONTEXT

Camera module market segmentation and applications



Market	MOBILE & CONSUMER			AUTOMOTIVE & MOBILITY	MEDICAL	INDUSTRIAL
Segment	Mobile	Computing	Other consumer	Automotive	Medical	Industrial
End system Applications	Smartphone	Computer mice	Action camera	Light vehicle	Endoscopy	Matrix code reader
	➤ Rear photography	Tablet	Consumer drone	➤ In-cabin		
	➤ Front selfie	➤ Rear photography	Personal robotic	➤ Viewing		
	➤ Authentication	➤ Front selfie	AR/VR headset	➤ ADAS		
	➤ Rear 3D sensing	➤ Authentication	➤ Tracking cameras	➤ Exterior access		
	Feature phone	➤ Rear 3D sensing	➤ See through			
	➤ Rear photography	Laptop	➤ 3D sensing			
	➤ Front selfie	➤ Webcam	Game station			
		➤ Authentication	Smart speaker / assistant			
			Smartwatch			
			Security camera			



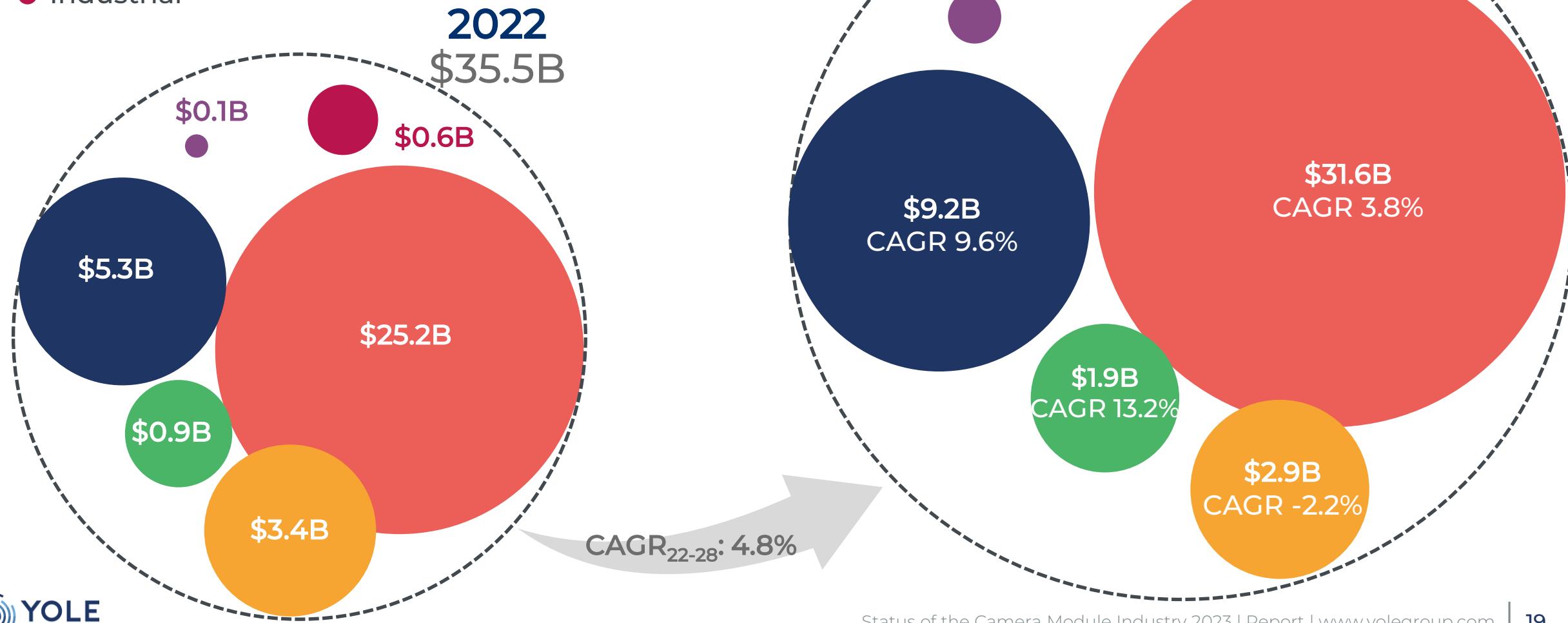
2022-2028 COMPACT CAMERA MODULE MARKET FORECAST – BY MARKET



Mobile & Consumer



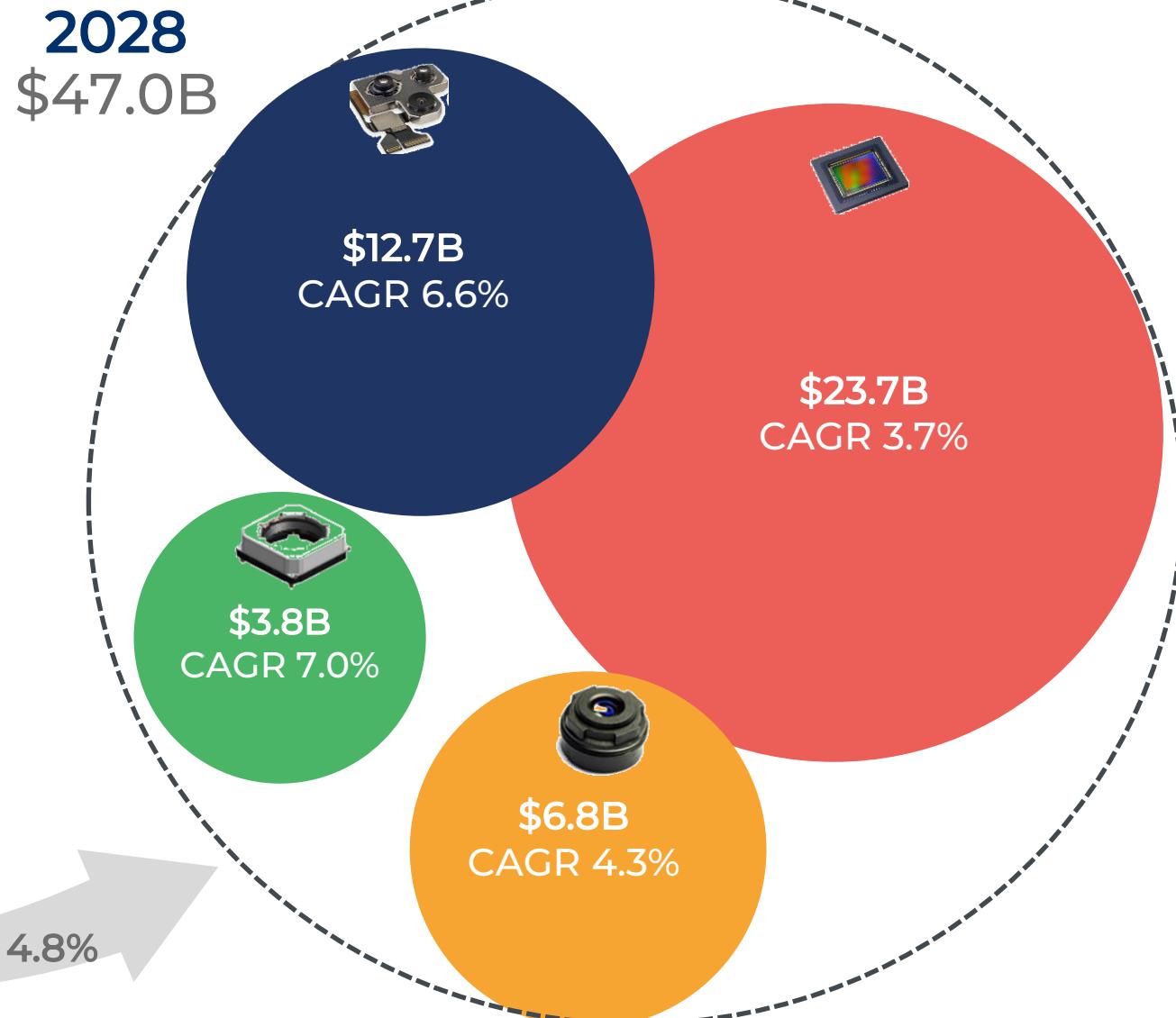
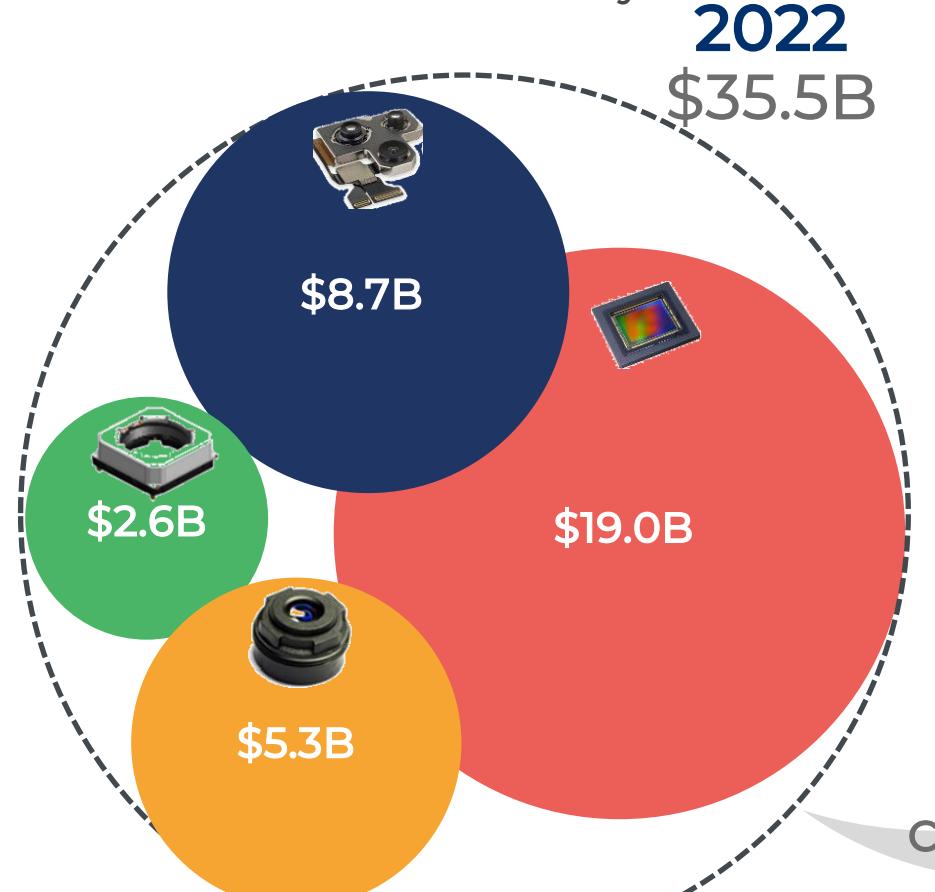
- Mobile
- Computing
- Other Consumer
- Automotive
- Medical
- Industrial



2022-2028 COMPACT CAMERA MODULE MARKET FORECAST – BY ELEMENT



- Image sensor
- Lens set
- Actuator (AF and OIS)
- Camera module assembly



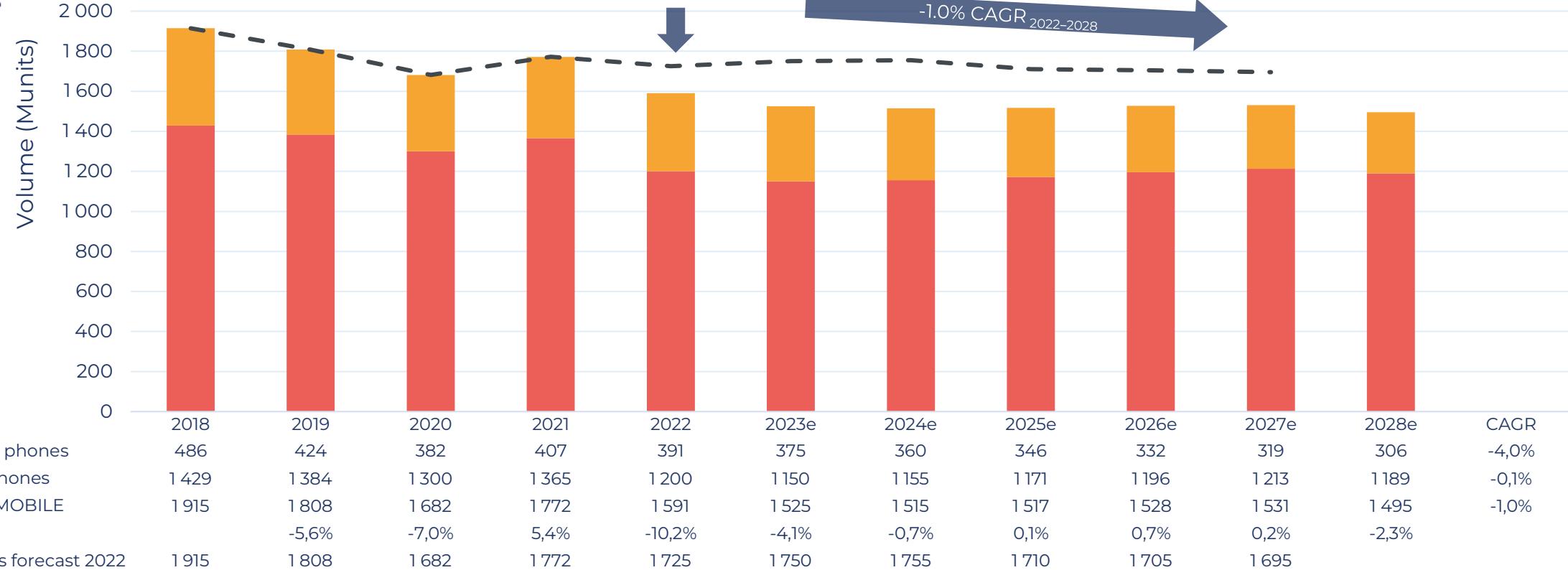
MOBILE MARKET TRENDS

Market dynamics



2018-2028 Smartphone and feature phone total production (in Munits)

YOLE
Intelligence



- In 2022, there was a significant drop in the total mobile market, -10.2% YoY. The new trend results in a slightly negative CAGR, -1.2%, for the entire mobile market. The replacement rate is expected to slow down in the coming years, also impacted by the current precarious economic and inflationary climate. In the long term, we expect the smartphone market to be below 1.2Bunits by 2028.



Courtesy
of Nokia

> 2020

More 3D sensing cameras

Front camera:

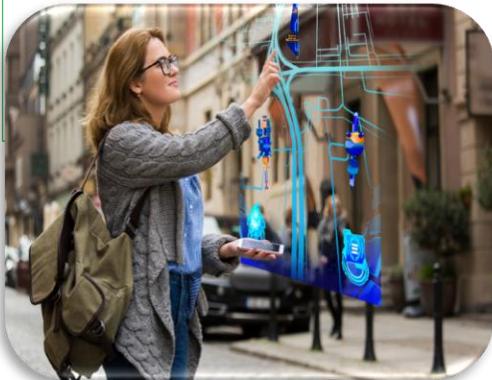
Face identification

Rear camera:

Photography, bokeh effect

Augmented reality

Gaming...



> 2024

+ Event-based camera

Rear camera:

Live deblurring

Slow motion

SLAM...



> 2026

+ Multispectral camera

Front camera:

Face identification

Rear camera:

Skin care, cosmetics

Accurate color photography...

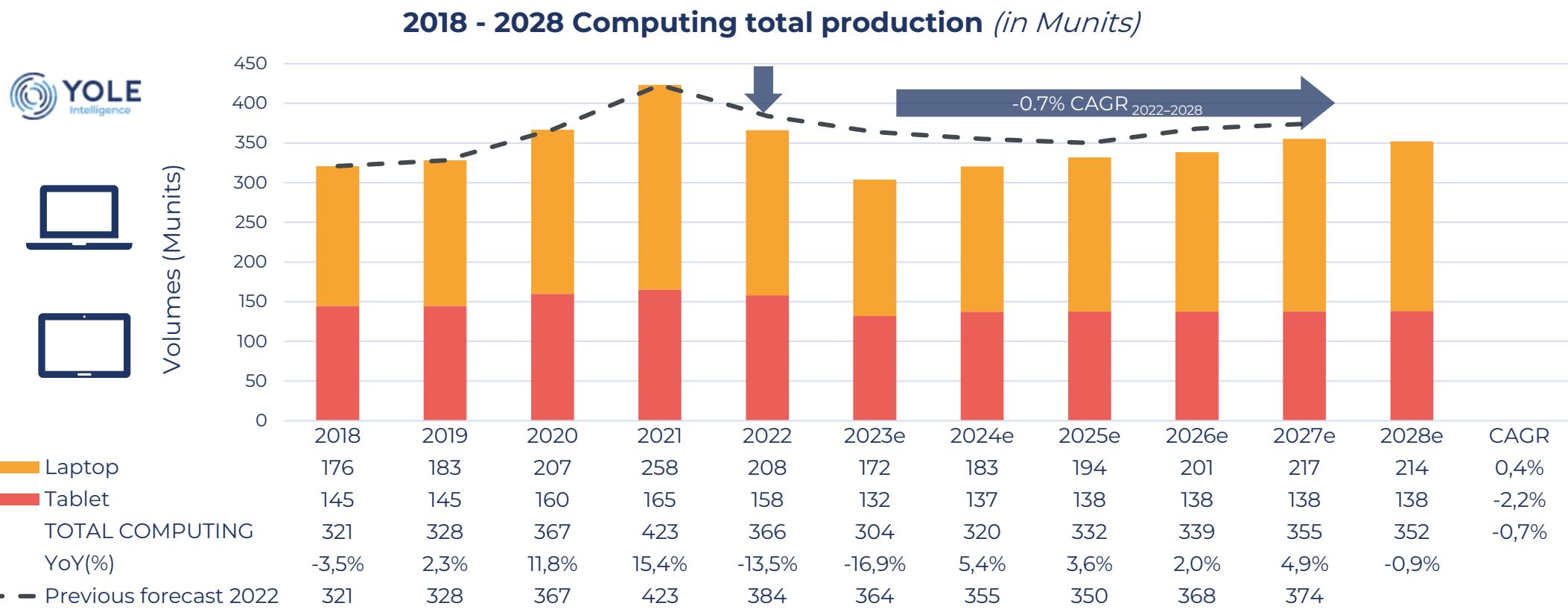


New imaging
and sensing
opportunities?



COMPUTING MARKET TRENDS

Market dynamics

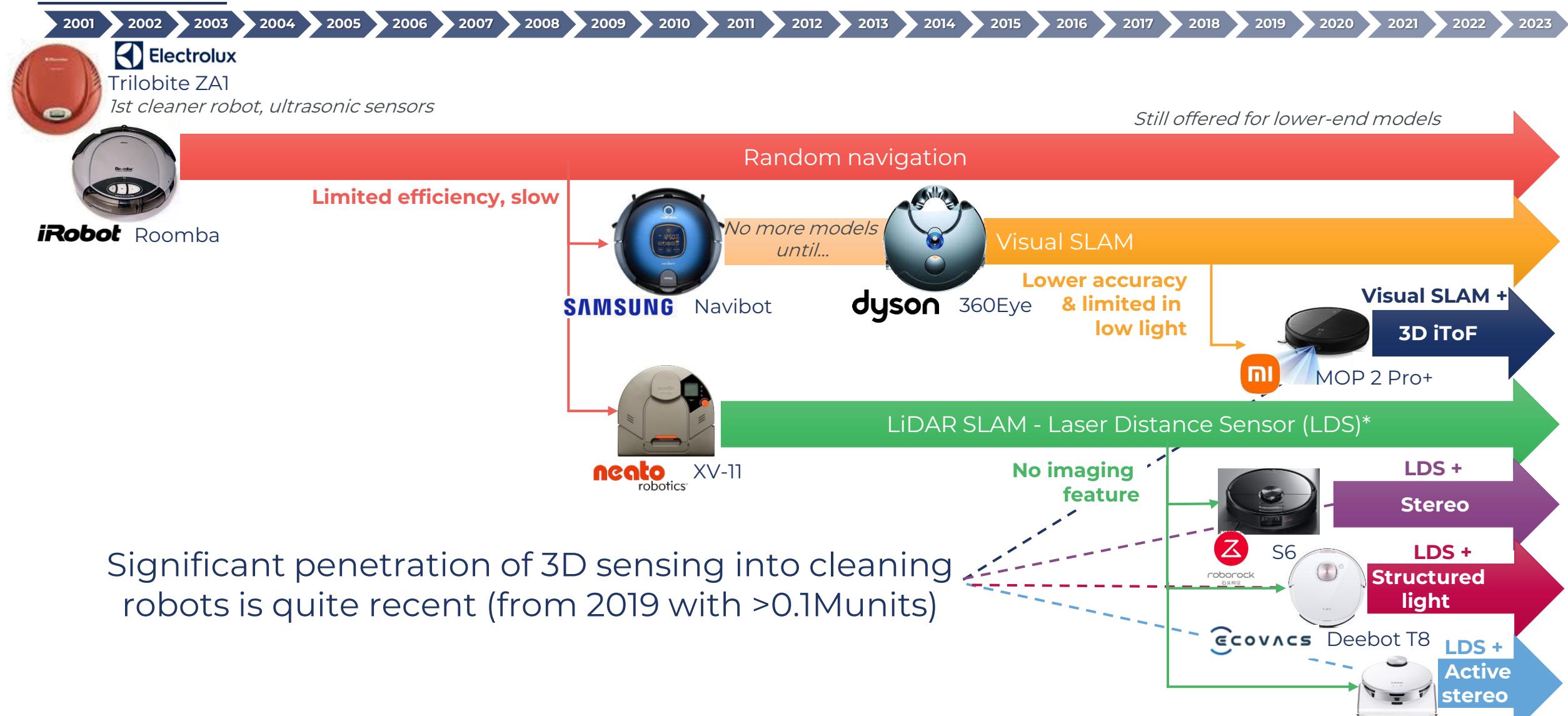


- The computing market suffered from competition with smartphones and was declining until the COVID-19 crisis, which boosted sales in 2020 and 2021 due to lockdowns and stay-at-home policies.
- In 2022, the market decreased, and it is expected to continue falling in 2023 as the COVID-linked bubble is bursting and global inflation is reducing sales of consumer devices. We expect demand to recover slightly in the coming years before reaching its pre-COVID trend around 2028 and then slowly decrease.



CONSUMER MARKET TRENDS

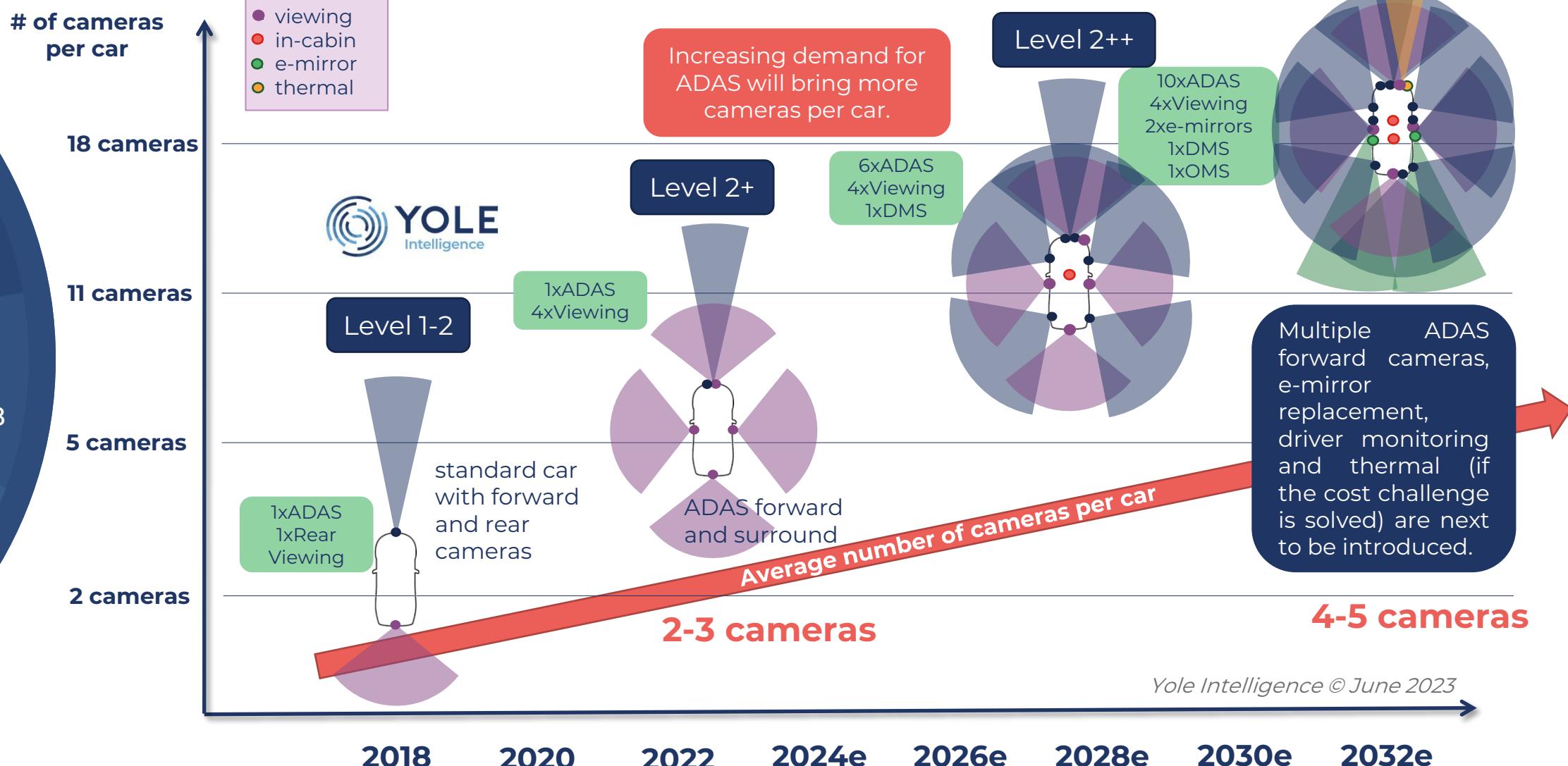
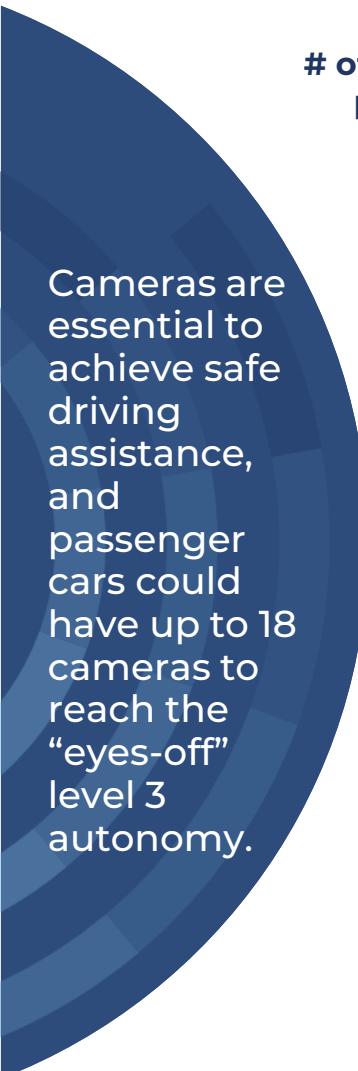
Vacuum cleaner robots: from random navigation to 3D sensing





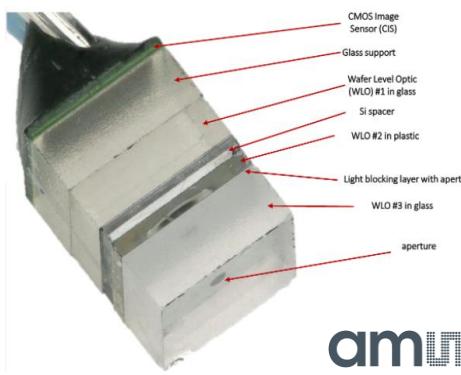
AUTOMOTIVE MARKET TRENDS

An increasing number of cameras per car

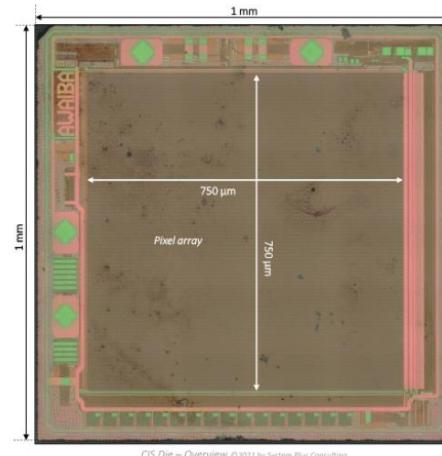




Ams NanEye camera

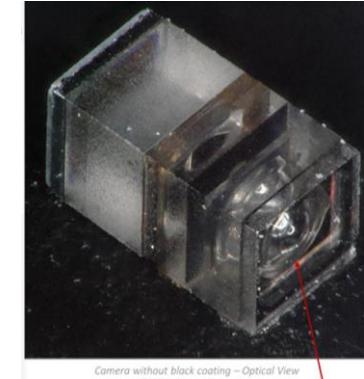


CIS top view



CIS Die – Overview ©2021 by System Plus Consulting

Omnivision OVM6948 camera



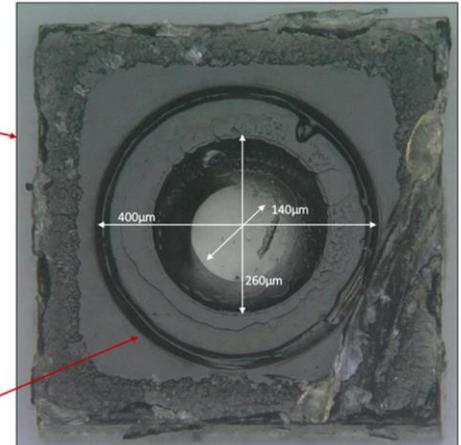
Camera without black coating – Optical View
©2020 by System Plus Consulting

OMNIVISION™



Camera – Cross-Section – SEM View
©2020 by System Plus Consulting

Wafer optics stacked lens



WLO #6 – Optical View ©2020 by System Plus Consulting

- The OVM6948 CameraCubeChip is a camera module measuring 0.66mm x 0.66mm. Thanks to backside illumination, it provides excellent image quality and better low-light performance to help reduce LED heat, along with improved sensitivity. The resolution is about 40k pixels. The NanEye is slightly bigger and includes an FSI image sensor operating at a higher resolution: about 62k pixels.
- These ultra-small 'chip-on-tip' camera modules, fully packaged with wafer-level optics, can be integrated into an endoscope with a diameter as small as 1 mm. **CIS's low light performance and reduced optical formats are critical for endoscopy applications.**

Model	Resolution	Package dimensions
Ams NanEye	200 x 200	0.66 x 0.66 x 1.16mm ³
Omnivision OVM6848	250 x 250	1 x 1 x 1.43mm ³
Omnivision OCH2B	1,500 x 1,500	2.5 x 2.5 x 3.6 mm ³



INDUSTRIAL MARKET TRENDS

Automatic Data Capture (ADC): code scanning is everywhere

The code connects money and personal information through the smartphone and has been widely used in daily life.



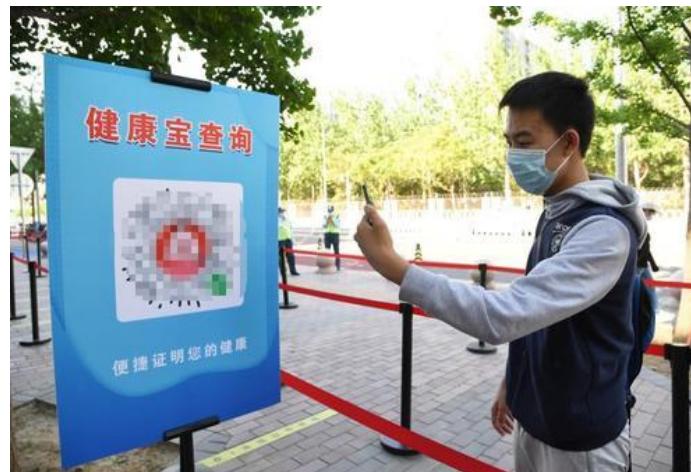
Scan to play



Scan to travel



Scan to access

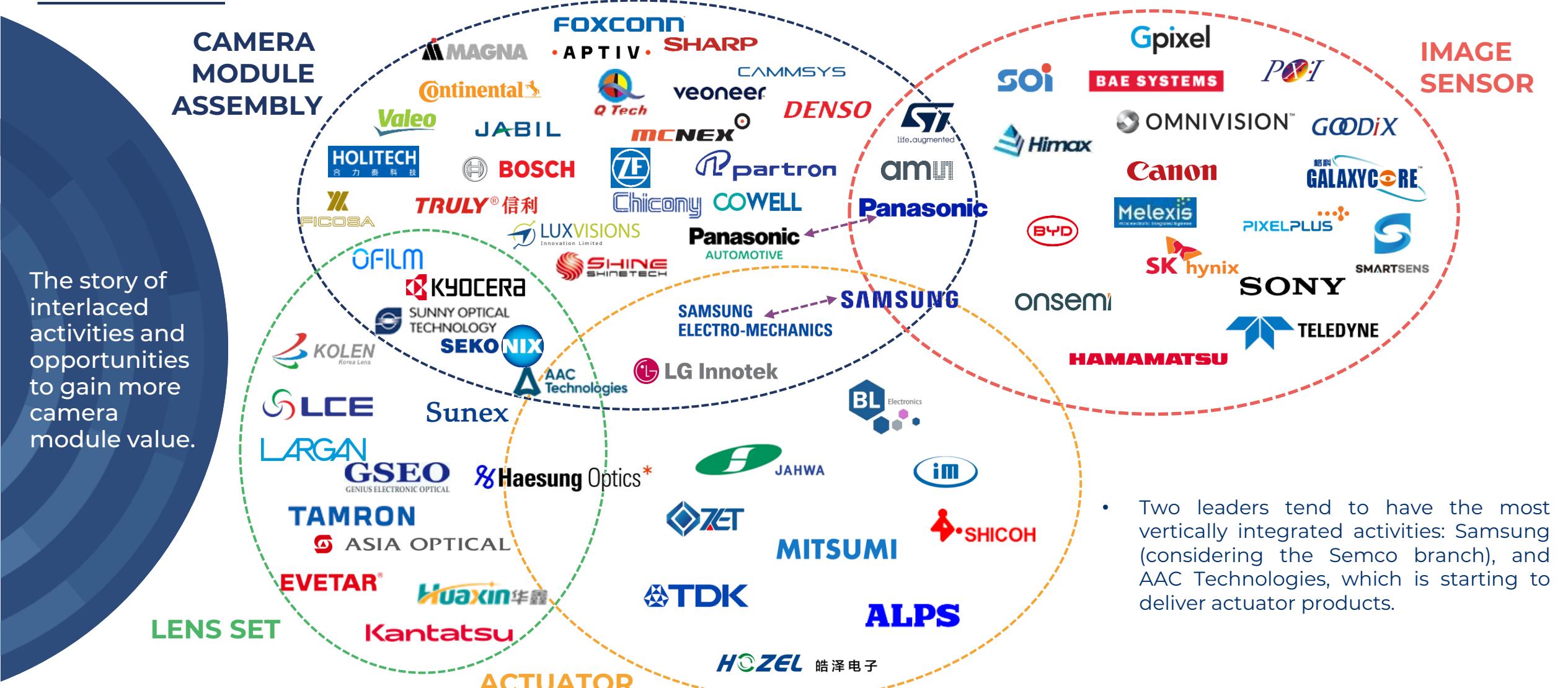


During the COVID-19 outbreaks, personal travel information could be accessed by scanning a health code. This facility remained after the pandemic and is boosting the opportunities for barcode reader applications.

CAMERA MODULE INDUSTRY SUPPLY CHAIN



Activity mapping

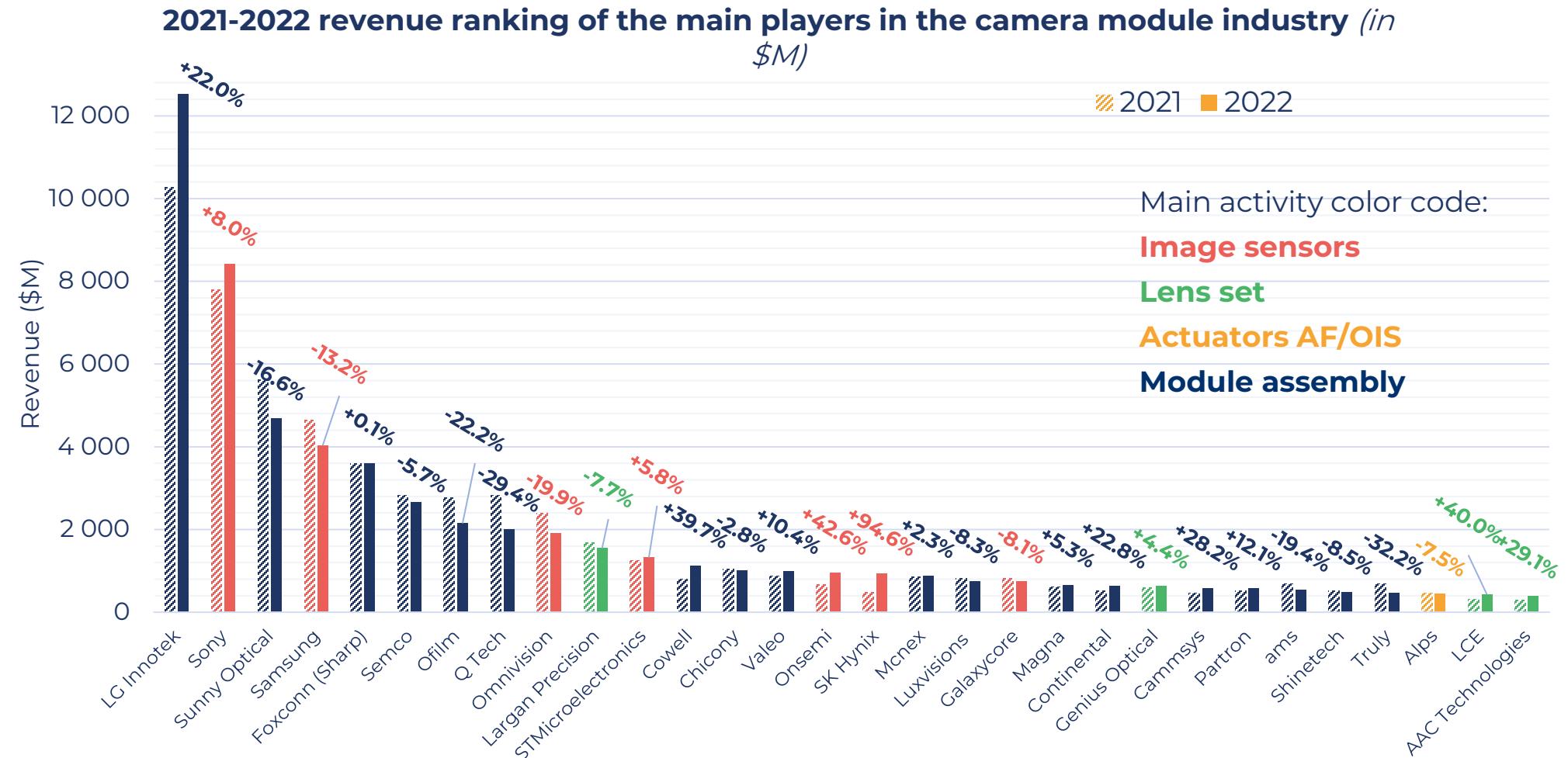


The story of interlaced activities and opportunities to gain more camera module value.

- Two leaders tend to have the most vertically integrated activities: Samsung (considering the Semco branch), and AAC Technologies, which is starting to deliver actuator products.

CAMERA MODULE INDUSTRY SUPPLY CHAIN

Camera module industry revenue ranking



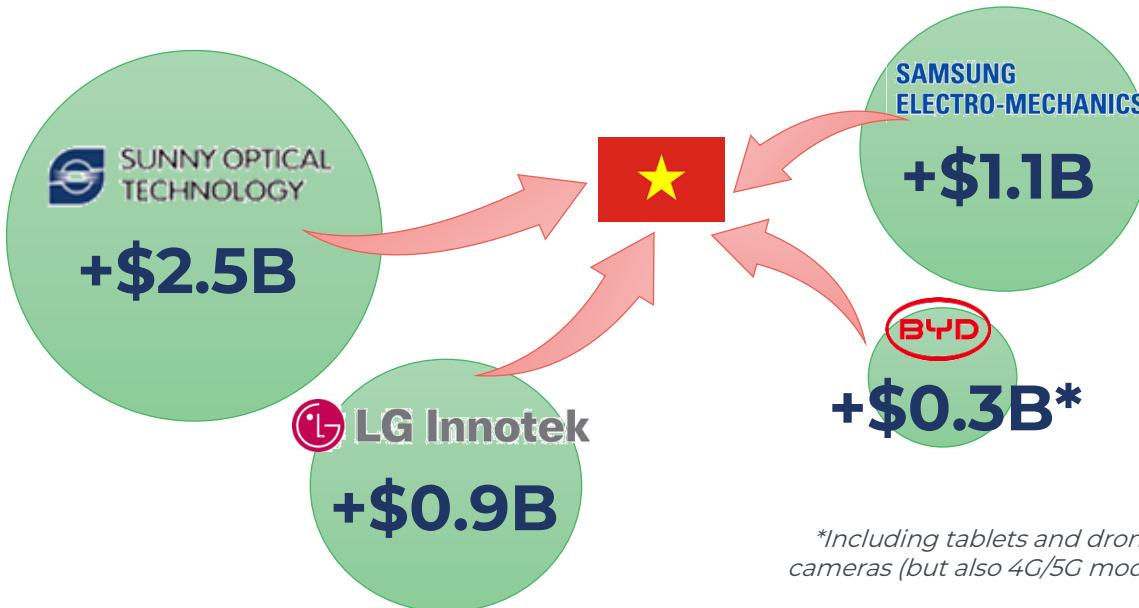
- Beyond their main activity generating most of the revenue, some leaders are involved in several activities: Suny Optical also for lens set, LG Innotek and Semco for actuator, Ofilm in lens set, AAC Technologies in module assembly and actuator, etc.
- If we add revenues from Samsung CIS and Semco activities, Samsung group could rank 3rd with revenues close to \$6.7B, being the most vertically integrated complete CCM solution provider.



CAMERA MODULE INDUSTRY SUPPLY CHAIN

Camera module industry focussing investments in Vietnam

Major investments announced in CCM production capacity in Vietnam factories since 2022:



\$6B investment in Vietnam CCM production capacity

Other CCM companies operating production and investing in Vietnam:



DRIVING FORCES

- Relative political stability
- Lower labor cost
- Alternative supply chain from China



POTENTIAL RISKS

- Infrastructure stability (power outage in 2023)
- Workforce shortage



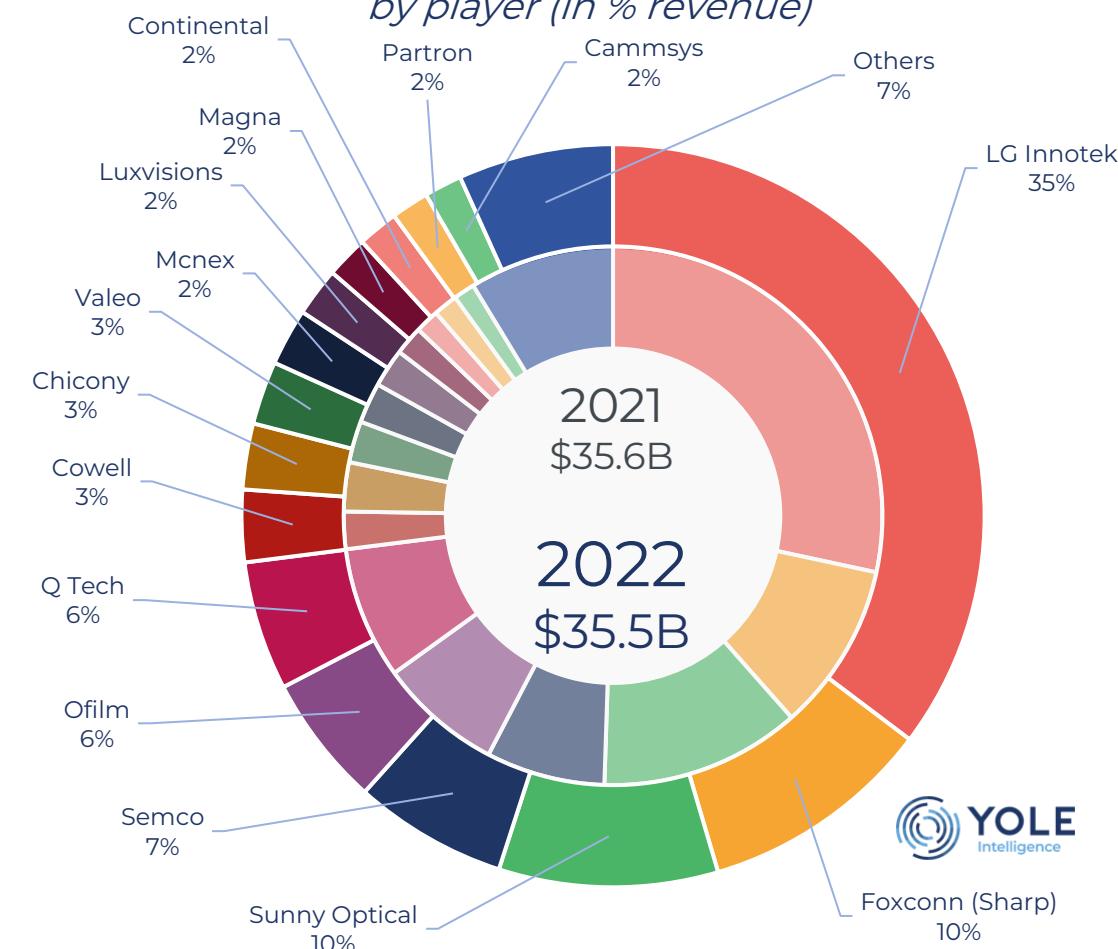
CAMERA MODULE MANUFACTURING MARKET SHARES

by player, in \$M (Yole data)



Revenue (\$M)	2021	2022	YoY (%)
LG Innotek	\$10,108	\$12,527	23.9%
Foxconn (Sharp)	\$3,600	\$3,605	0.1%
Sunny Optical	\$4,290	\$3,385	-21.1%
Semco	\$2,543	\$2,373	-6.7%
Ofilm	\$2,646	\$2,029	-23.3%
Q Tech	\$2,826	\$1,995	-29.4%
Cowell	\$799	\$1,116	39.7%
Chicony	\$1,048	\$1,018	-2.8%
Valeo	\$886	\$978	10.4%
Mcnex	\$862	\$882	2.3%
Luxvisions	\$821	\$753	-8.3%
Magna	\$619	\$652	5.3%
Continental	\$511	\$627	22.8%
Partron	\$520	\$583	12.1%
Cammsys	\$455	\$583	28.2%
Others	\$3,095	\$2,397	-22.6%
TOTAL	\$35,629	\$35,502	-0.4%

2022 Camera Module market share by player (in % revenue)

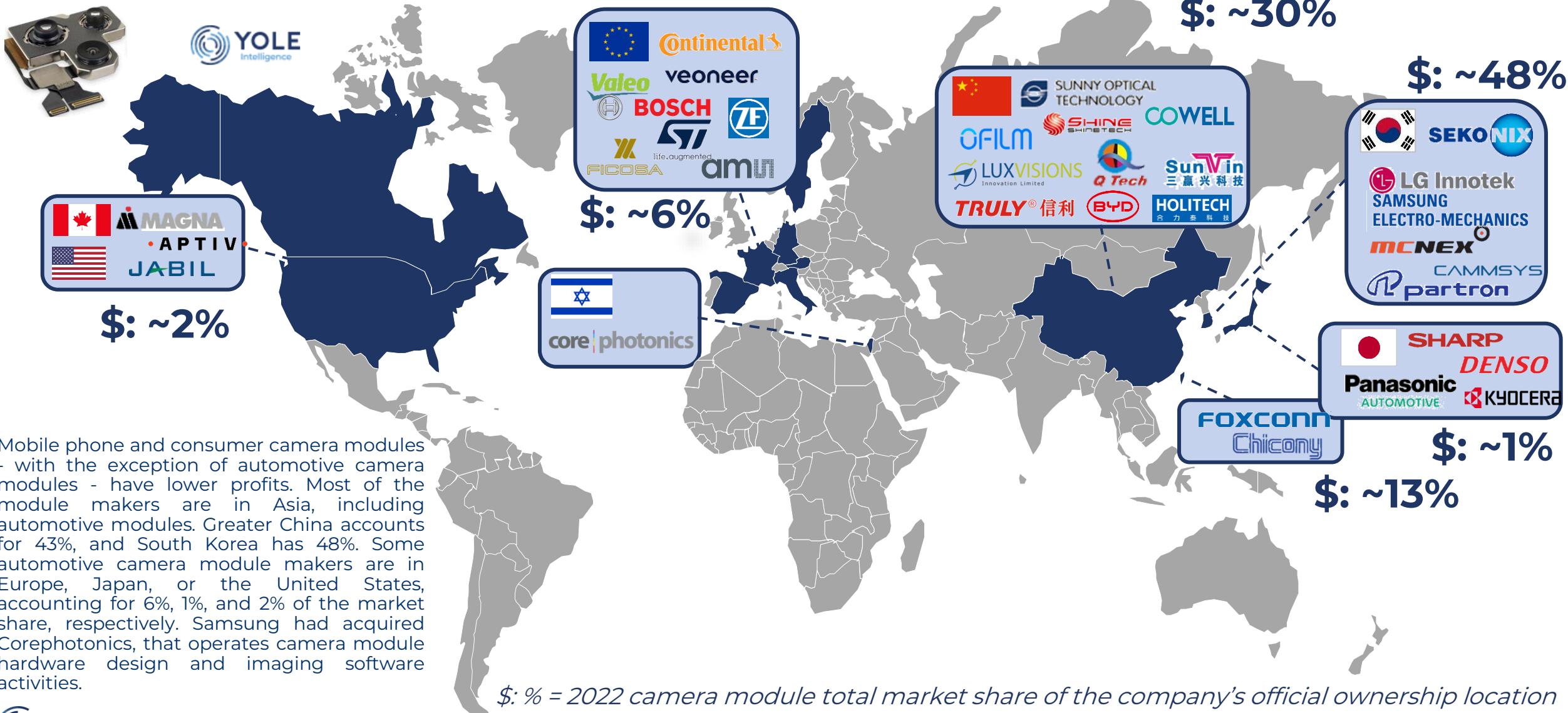


Luxvisions acquired 63% of Cowell E Holdings in 2022, the parent company of Cowell Electronics, so the actual share of Luxvisions group of companies, including Cowell activity, would represent a 5% market share. We kept them separated as Cowell seems to operate quite independently.



CAMERA MODULE MANUFACTURING MARKET SHARES

Competitive map of the TOP Camera Module players





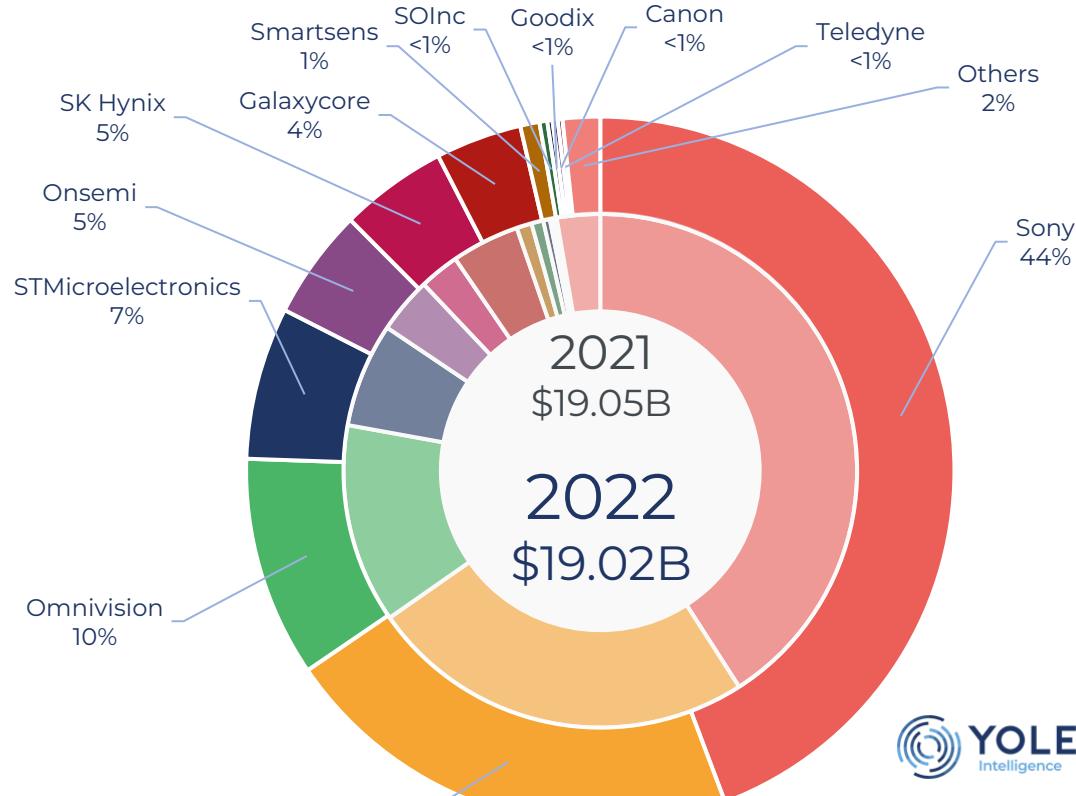
CMOS IMAGE SENSOR MARKET SHARES – FOR CAMERA MODULE ONLY

by player, in \$M (Yole data)



Revenue (\$M)	2021	2022	YoY (%)
Sony	\$7,795	\$8,421	8.0%
Samsung	\$4,649	\$4,035	-13.2%
Omnivision	\$2,391	\$1,915	-19.9%
STMicroelectronics	\$1,250	\$1,323	5.8%
Onsemi	\$672	\$958	42.6%
SK Hynix	\$479	\$932	94.6%
Galaxycore	\$815	\$749	-8.1%
Smartsens	\$181	\$167	-7.7%
SOInc	\$143	\$68	-52.4%
Goodix	\$79	\$45	-43.0%
Canon	\$44	\$45	2.3%
Teledyne	\$39	\$41	6.2%
Others	\$518	\$325	-37.4%
TOTAL	\$19,055	\$19,024	-0.2%

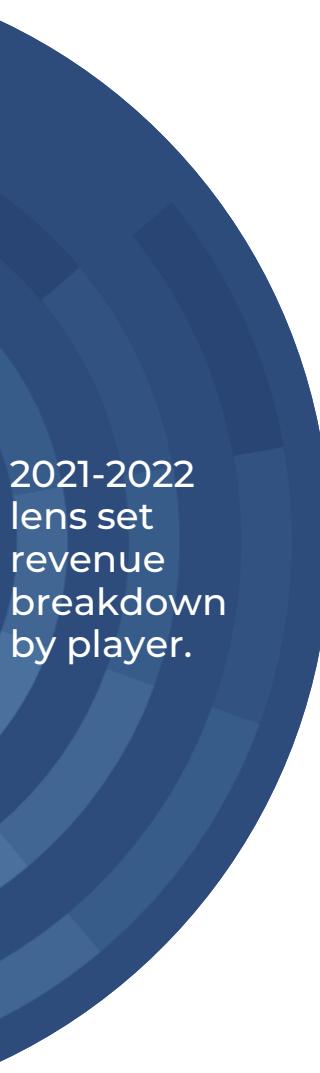
2022 CIS for camera module market share
by player (in % revenue)



Important note: considering the scope of the CCM report, we exclude CIS revenues related to non-compact camera modules (defense & aerospace, some industrial, medical, and consumer photography applications) and remove the related revenues generated by these applications for each CIS player.

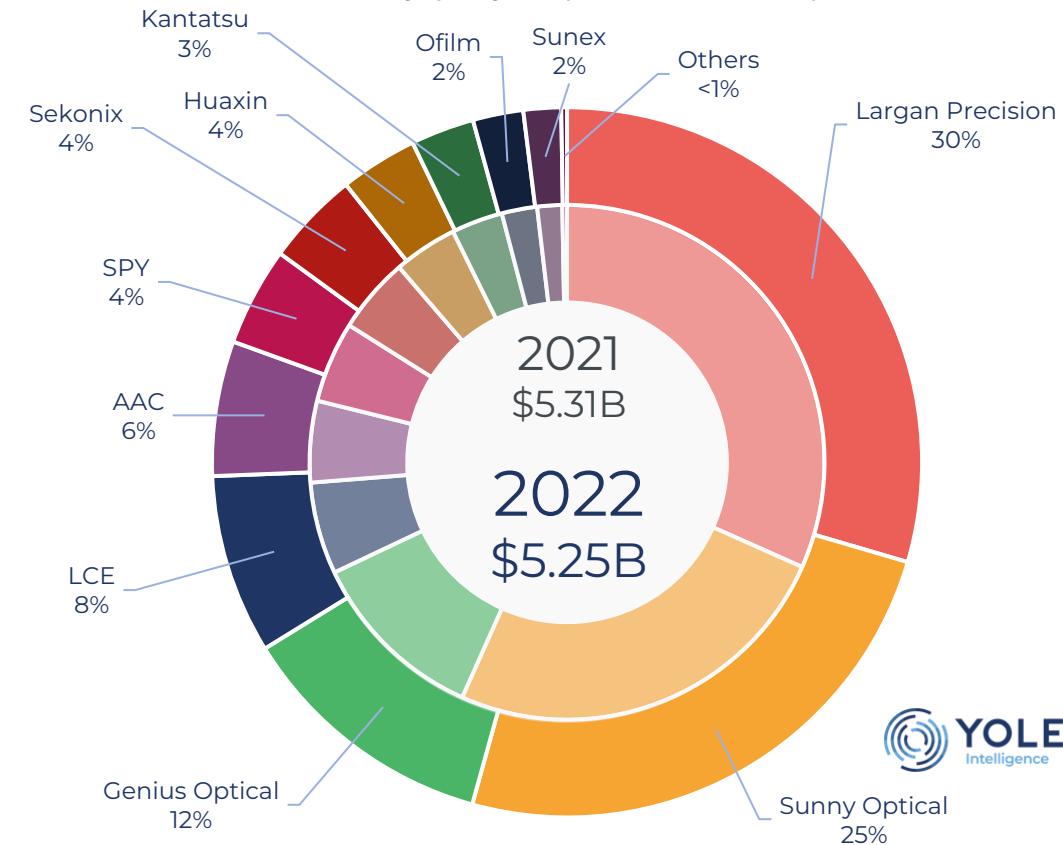


OPTICS LENS SET MARKET SHARES by player, in \$M (Yole data)



Revenue (\$M)	2021	2022	YoY (%)
Lagan Precision	\$1,681	\$1,552	-7.7%
Sunny Optical	\$1,328	\$1,301	-2.0%
Genius Optical	\$599	\$625	4.4%
LCE	\$307	\$429	40.0%
AAC Technologies	\$271	\$323	18.9%
SPY	\$270	\$236	-12.6%
Sekonix	\$252	\$225	-10.7%
Huaxin	\$213	\$186	-12.7%
Kantatsu	\$171	\$152	-11.1%
Ofilm	\$118	\$121	2.3%
Sunex	\$83	\$90	8.4%
Others	\$16	\$14	-12.4%
TOTAL	\$5,309	\$5,254	-1.0%

2022 Optics lens sets for camera module market
share by player (in % revenue)



The “Others” category is estimated to be less than \$20M. We possibly included some players activity that could not always be entered in this report’s scope, for example, non-camera module high-end optics, as it is difficult to differentiate. However, that shows that it is a far less fragmented market than the camera module manufacturing one.

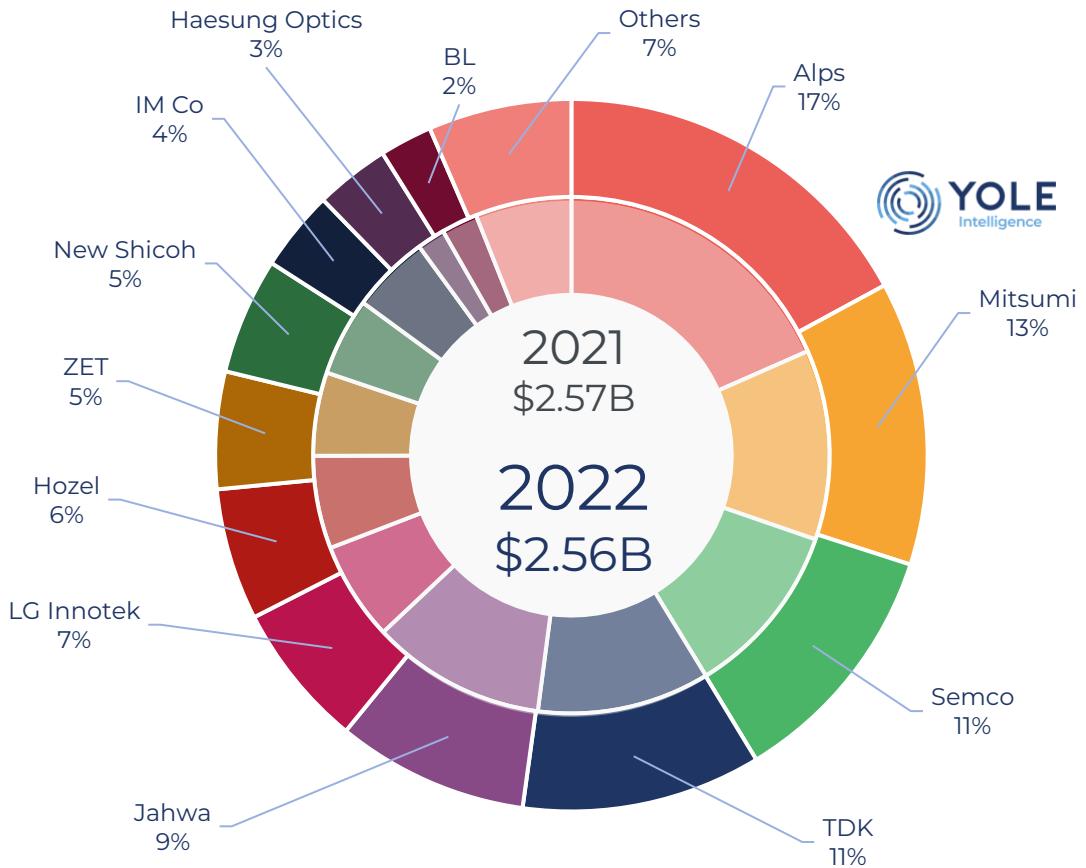


ACTUATOR MARKET SHARES by player, in \$M (Yole data)

2021-2022
actuator
revenue
breakdown
by player.

Revenue (\$M)	2021	2022	YoY (%)
Alps	\$472	\$437	-7.5%
Mitsumi	\$305	\$329	7.9%
Semco	\$282	\$290	2.8%
TDK	\$277	\$278	0.4%
Jahwa	\$280	\$223	-20.4%
LG Innotek	\$158	\$168	6.3%
Hazel	\$149	\$153	2.7%
ZET	\$134	\$136	1.5%
New Shicoh	\$125	\$135	8.0%
IM Co	\$126	\$93	-25.9%
Haesung Optics	\$45	\$86	92.6%
BL	\$58	\$61	5.2%
Others	\$154	\$166	7.8%
TOTAL	\$2,565	\$2,556	-0.4%

2022 Actuators for camera module market
share by player (in % revenue)



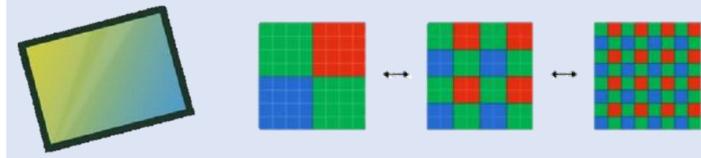
"Others" include Yova, Jot and AAC Technologies (China). Haesung Optics retired from the camera module manufacturing and lens set business and has started to deliver OIS actuators for two years.



TECHNOLOGY TRENDS

Innovation path for the CCM industry

Electronics



- High resolution
- Large optical format
- In-pixel hybrid stack
- PDAF
- Quantum dots
- Curved sensor

Camera diversity

- 3D sensing camera
- Under-display camera
- Multi-camera...

Electro-Mechanics



- Sensor/module-shift
- Liquid lens
- Shape memory alloy (SMA)
- Piezo motor/MEMS



Manufacturing

- Active alignment process
- COB
- Flip-chip

Optics



- High number of lens elements ✓ 7p, 8p and 9p
- Periscope
- Hybrid Lens (WLG glass+ Plastic)
- Free-form lens
- Metalens



TECHNOLOGY TRENDS

Overview of new CCM innovations comparison table

Sub-component	Innovation path	Performance			Module compactness		Cost	Active companies*
		Sensitivity	Optical perf.	Reliability	XY footprint	Z-height		
Image sensor	Triple stack sensor	Green	Orange	Orange	Green	Orange	Red	SONY ST OMNIVISION
Image sensor	Curved sensor	Orange	Green	Orange	Orange	Green	Yellow	cea leti SOLINA CURVE-ONE
Optics	Liquid lens/tunable polymer	Orange	Green	Green	Orange	Green	Red	polight CORNING NEXTLENS
Optics	Metalens (passive metasurface)	Green	Green	Orange	Orange	Green	Yellow	MOXTEK NLT TECHNOLOGY ST metalenz
Optics	Hybrid lenses (moving from plastic to glass) Mobile & Consumer	Orange	Green	Green	Orange	Orange	Red	SAMSUNG LG Innotek SUNNY OPTICAL AAC Technologies
Optics	Hybrid lenses (moving from glass to plastic) Automotive	Orange	Red	Red	Green	Green	Green	SUNNY OPTICAL LCE Sunex AAC Technologies
Actuators	SMA actuator	Orange	Green	Green	Orange	Green	Red	ALPS TDK CAMBRIDGE MECHATRONICS

Brings a significant progress

Neutral or compensated impact

Degradation

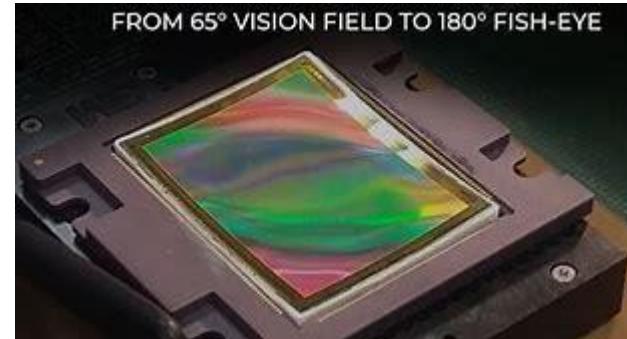
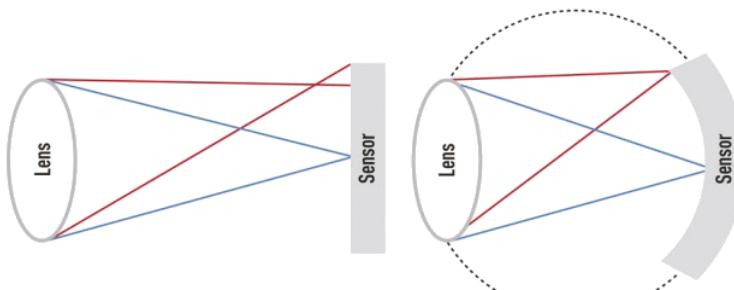
*non-exhaustive list



TECHNOLOGY TRENDS

Curved image sensor technology

- Curving the image sensor is an innovative approach to reducing lens system complexity.
- This approach was initially tested for large chips, mainly in high-end photography and astronomy.
- This could be later applied to consumer camera modules as the first start-ups, such as Curve-one and Silina, entered the space.

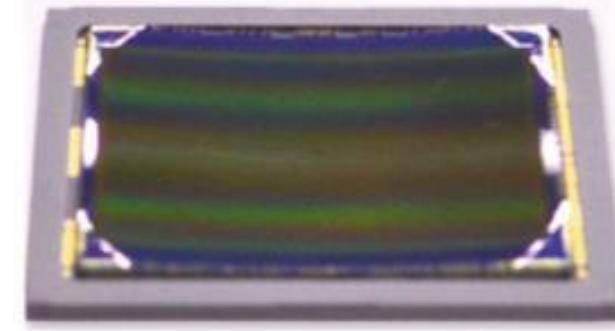


courtesy of Leti

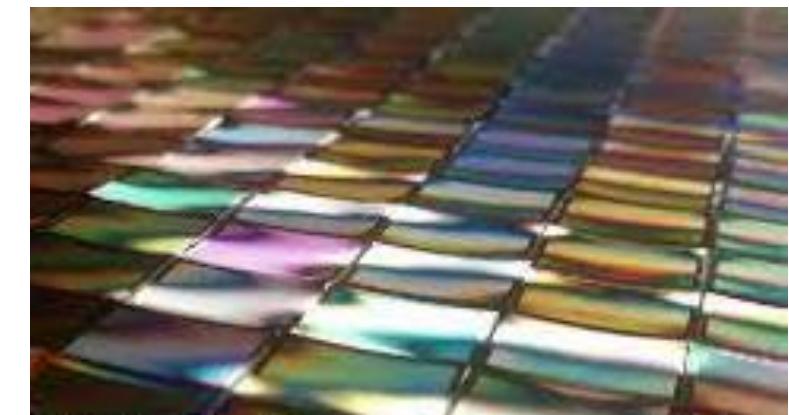
CURVE-ONE
REVOLUTION FOR IMAGING SYSTEMS



SONY



courtesy of Sony

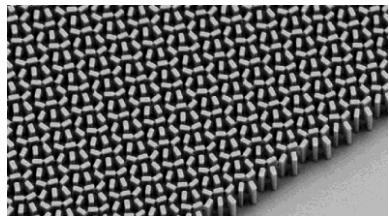


courtesy of Silina

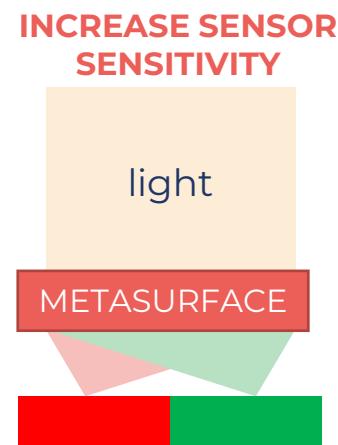


TECHNOLOGY TRENDS

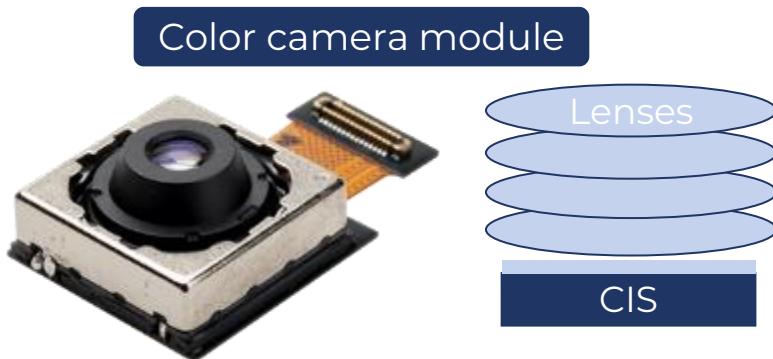
Metasurfaces: the ultimate evolution of flat optics (2/2)



Source: Capasso group,
Harvard university



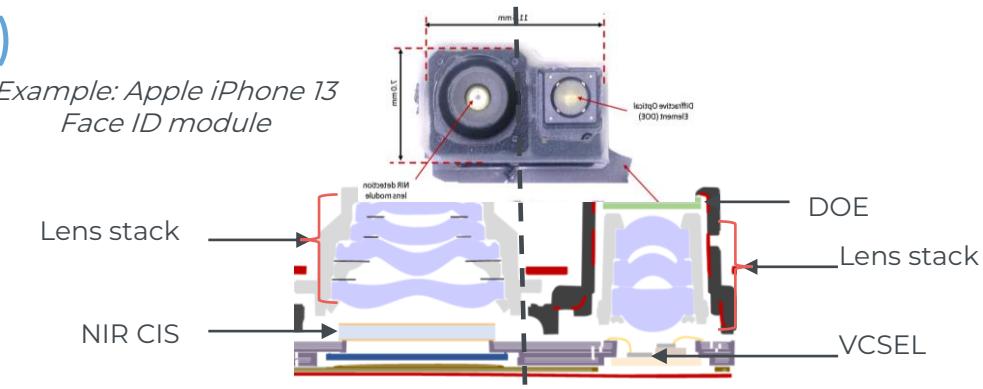
BEAM STEERING
Source: Lumotive



Source: LG Innotek



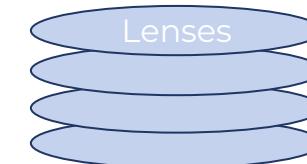
Example: Apple iPhone 13
Face ID module



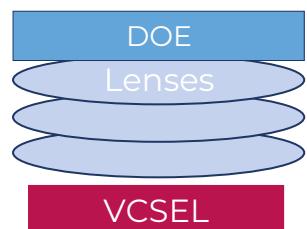
Camera module

Dot projector

2021



NIR CIS



>2024



METASURFACE



METASURFACE

>2027



METASURFACE



TECHNOLOGY TRENDS

From VCM to other emerging technologies

Actuator type	Voice Coil Motor VCM 	Shape Memory Alloy SMA 	Tunable polymer 	Liquid lens 	MEMS
Physical effect	Electromagnetic	Electromechanic	Piezoelectric	Electrostatic (electrowetting)	Electrostatic
Cost assumption	+	++	++	+++	+++
AF			Demonstrated in Xiaomi Mitu 4 Pro smartwatch (Polight)	Demonstrated in Xiaomi Mix Fold phone (Nextlens)	
OIS					
Wafer level					
Mass production					
Main players	 	 		 	
Challenging the leaders on VCM market shares	 				

Non-exhaustive list of technologies and companies

Other potential technologies not mentioned (piezo motors, liquid crystals...)

Techno. proven/mature

Potential/getting mature

Not available



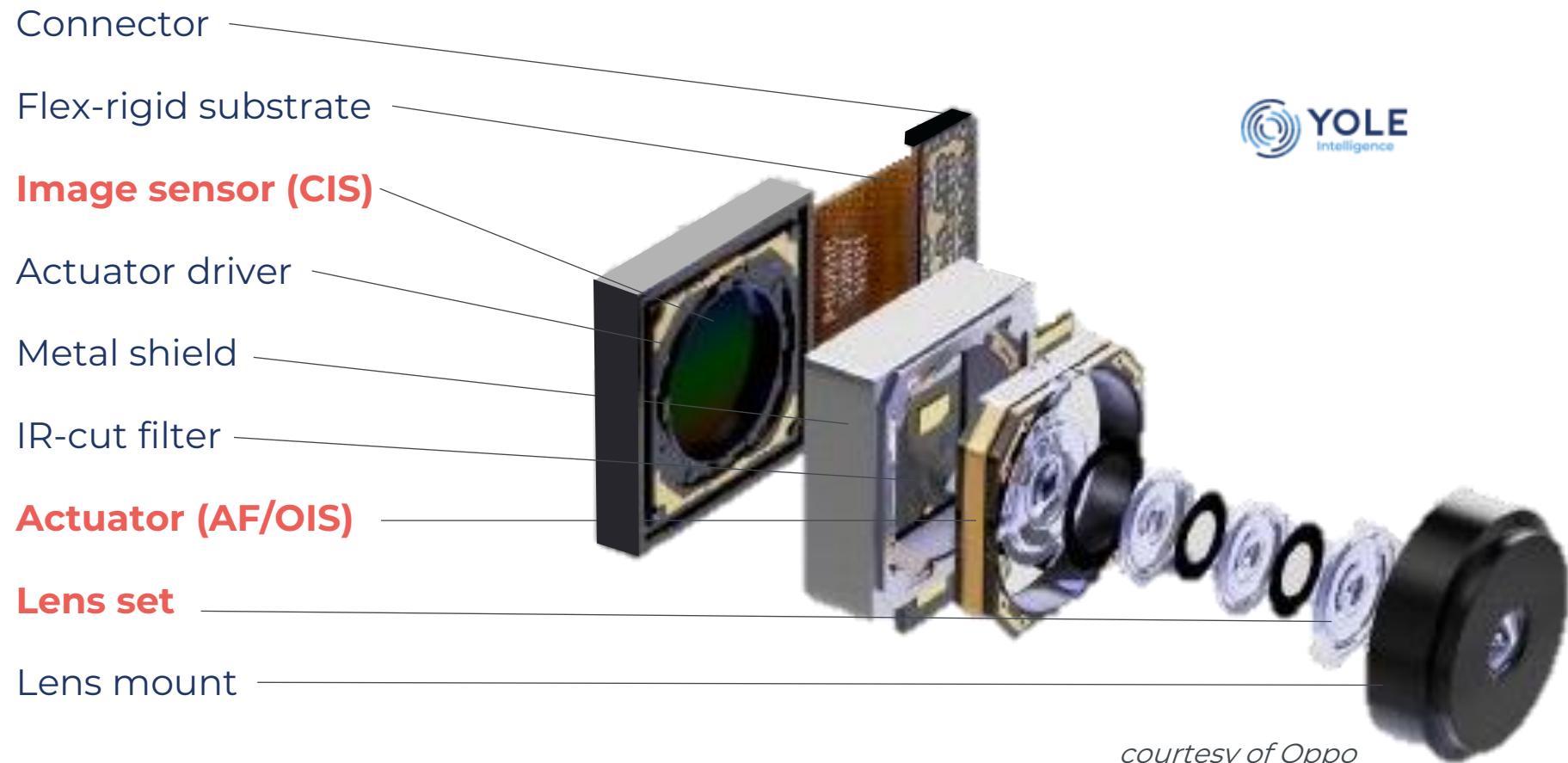
CONTEXT



CONTEXT

What does a mobile camera module consist of?

Once a relatively basic module, CCM has evolved into a complex microelectromechanical device.

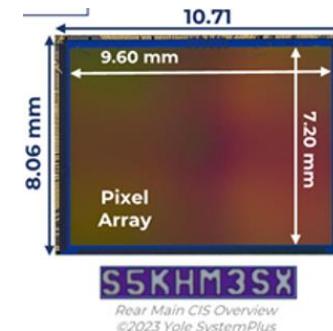


Module assembly brings all these components together into a module

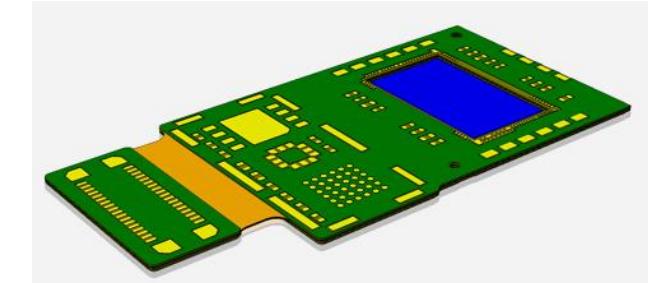
CONTEXT

Sub-module definition (1/2)

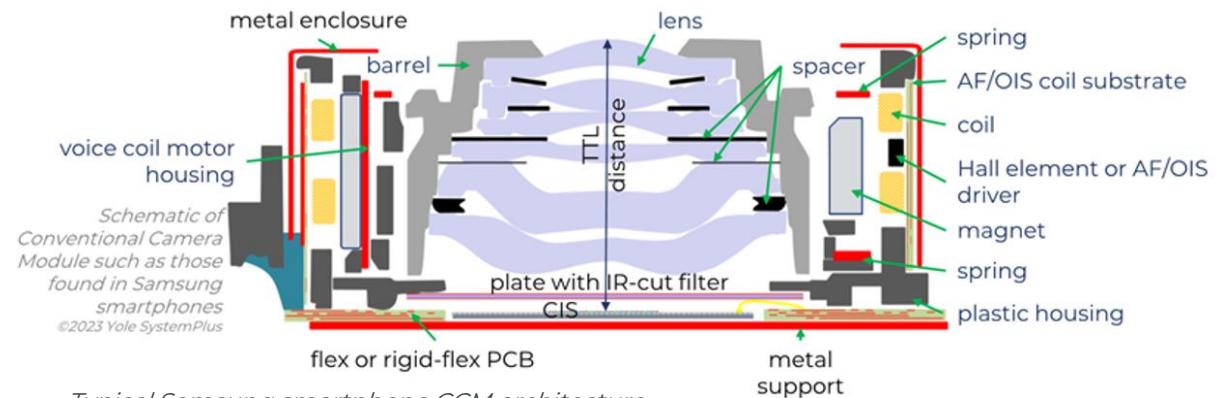
- Image Sensor:** From visible and near-infrared applications, it is mainly made with a Silicon photodiode pixels array that aims to convert the light into an electrical signal and produce an image. This layer can sometimes be stacked with a logic wafer underneath to bring further performance. It leverages the classical semiconductor manufacturing process and packaging and comes with different pixel sizes, resolutions, Silicon surfaces, and electro-optical performance.
- Optics lens set:** The lens aims to collect the light emitted from the scene to produce an image. Individual optical elements lenses are combined in a single lens set, with the help of a barrel and spacers, to compensate for the aberration that a single lens could bring. Lenses in the optical stack can be made in polymer, glass, or mixing both in and hybrid approach. Some computational approaches can also be used to help correct the aberration and aim to get rid of one or several lenses or simplify their design, miniaturizing the system in a highly constrained compact module being one of the most relevant challenges.
- Printed Circuit Board (PCB):** Usually a rigid-flexible substrate, on which different CCM elements such as image sensors, actuators, insulators, copper foil, and photo solder resist material (PSR) are linked together. The PCB acts as an interface to transfer CCM output to external circuitry, through dedicated **connectors**.
- Other elements, such as **plastic housing**, **metal shields**, and **IR filters**, can be found in typical CCM architectures.



Samsung CMOS image sensor
Top view, Galaxy S21 Ultra rear main camera
From: Yole SystemPlus



PCB design structure
From: Semco



Typical Samsung smartphone CCM architecture
From: Yole SystemPlus

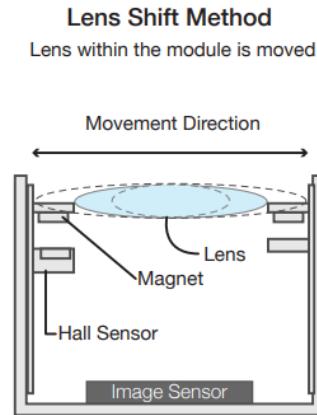


CONTEXT

Sub-module definition (2/2)

- Actuator:** The actuator is an electro-mechanical component that serves to achieve focus or image stabilization by rapidly moving the lens within the camera module at high speed. The key future of CCM actuators, include AF, OIS, and optical zoom that is critical for folded optics (also called periscope) CCM. Actuators are operated thanks to a dedicated driver component.
 - AF actuator (Auto Focus):** It consists of moving the lenses along the optical axis, while an algorithm that will calculate the resulting figure of merit to evaluate the image sharpness. The camera focus will be changed accordingly by moving the lens with a new figure of merit. The best focus for the scene can be obtained successfully. VCM are a widely adopted technology, but other exist, such as piezoelectric, electroactive polymer, MEMS-based devices, or different lens materials such as liquid lenses.
 - OIS actuator (Optical Image Stabilization):** In order to reduce photography and video blur, the camera lens set needs to be moved regarding the sensor position to compensate for camera shake and other erroneous movement. Lens shift OIS was used first, and then the sensor-shift technique was introduced; it allows the use of larger lenses that movement itself would require too much energy, and extend the compensation to 5-axis stabilization. Traditional technique uses VCM, with magnet and electromagnetic coils, and sensors such as Hall effect sensors or gyros to measure external forces. Actuators can adjust the lens set position to obtain a better image. Other technologies exist, such as SMA actuators.

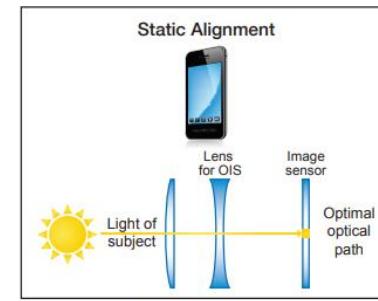
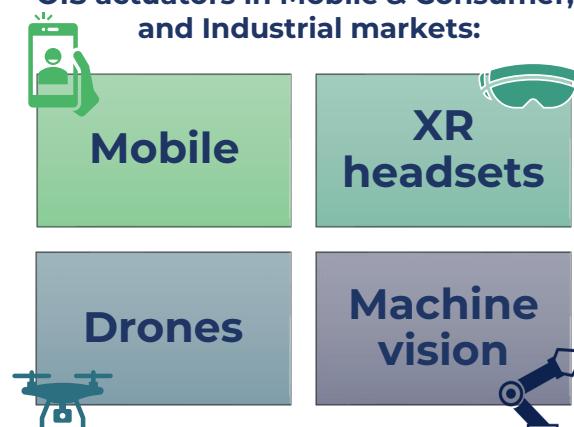
*OIS lens shift method
From: ROHM Semiconductor*



*Multi-camera arrangement
From: Semco*

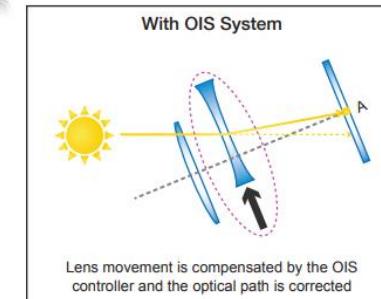
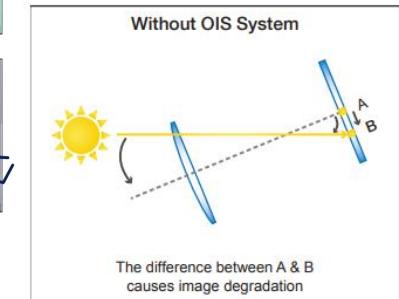


Different applications for AF and OIS actuators in Mobile & Consumer, and Industrial markets:



Phone Movement

*OIS principle for smartphone photography
From: ROHM Semiconductor*



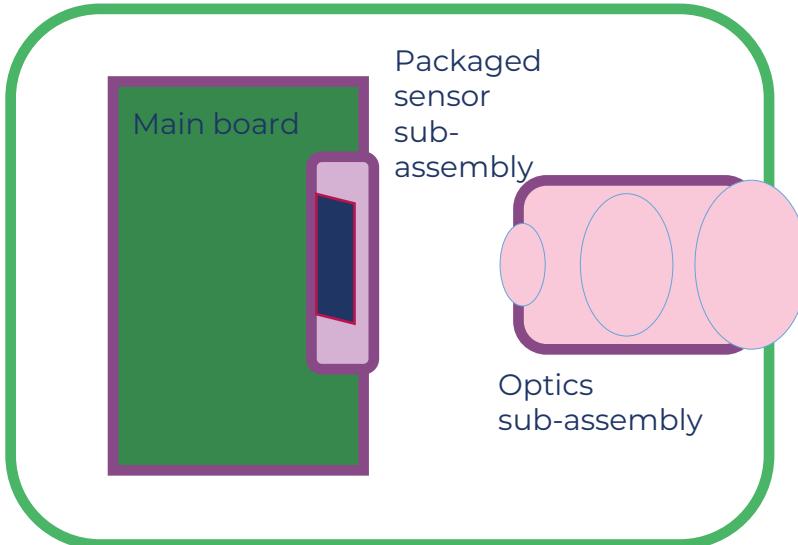


CONTEXT

CMOS image sensor integration in cameras

Image sensors can be found either in compact camera modules or in integrated cameras.

Integrated system approach



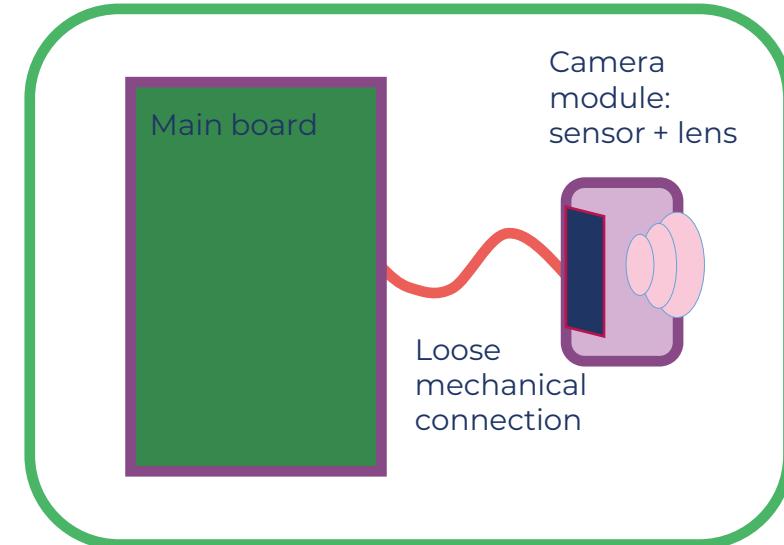
Typically found in:

- DSLR & DSC cameras
- High-end security cameras
- Industrial cameras
- Broadcast cameras



Scope of the report

Camera module approach



Typically found in:

- Mobile, laptop, and tablet cameras
- “Chip-to-the-tip” endoscopes
- Action cameras and drone cameras
- Consumer security cameras
- Automotive cameras



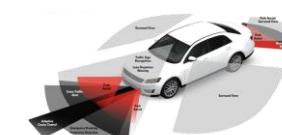
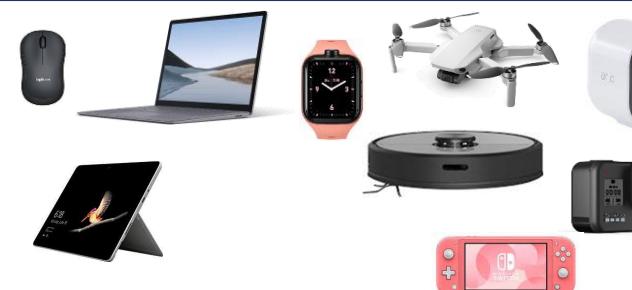


CONTEXT

Camera module market segmentation and applications



Market	MOBILE & CONSUMER			AUTOMOTIVE & MOBILITY	MEDICAL	INDUSTRIAL
Segment	Mobile	Computing	Other consumer	Automotive	Medical	Industrial
End system Applications	Smartphone	Computer mice	Action camera	Light vehicle	Endoscopy	Matrix code reader
	➤ Rear photography	Tablet	Consumer drone	➤ In-cabin		
	➤ Front selfie	➤ Rear photography	Personal robotic	➤ Viewing		
	➤ Authentication	➤ Front selfie	AR/VR headset	➤ ADAS		
	➤ Rear 3D sensing	➤ Authentication	➤ Tracking cameras	➤ Exterior access		
	Feature phone	➤ Rear 3D sensing	➤ See through			
	➤ Rear photography	Laptop	➤ 3D sensing			
	➤ Front selfie	➤ Webcam	Game station			
		➤ Authentication	Smart speaker / assistant			
			Smartwatch			
			Security camera			





CONTEXT

Human vision vs. computer vision

Sensing and processing an image can follow different outputs...



HUMAN VISION

- Usually accepts image artifacts, noise...
- Highly sensitive to color fidelity, image quality, sharpness...

Imaging



COMPUTER VISION

- Lower acceptance of noise and other image artefacts: parasitic light, frame rate...
- Less sensitive to traditional image quality parameters

Sensing

- First, cameras have been dedicated mainly to imaging applications and initially designed to fit with human vision, which is the base for the traditional imaging pipeline, from the scene sensing through the image sensor, the optics, and filters to the processing capabilities.
- Computer vision applications refer to situations where the image is often not dedicated to being seen by a human eye, so they do not request the same performance levels.



CONTEXT

Types of cameras for CCM applications (focus on consumer devices)



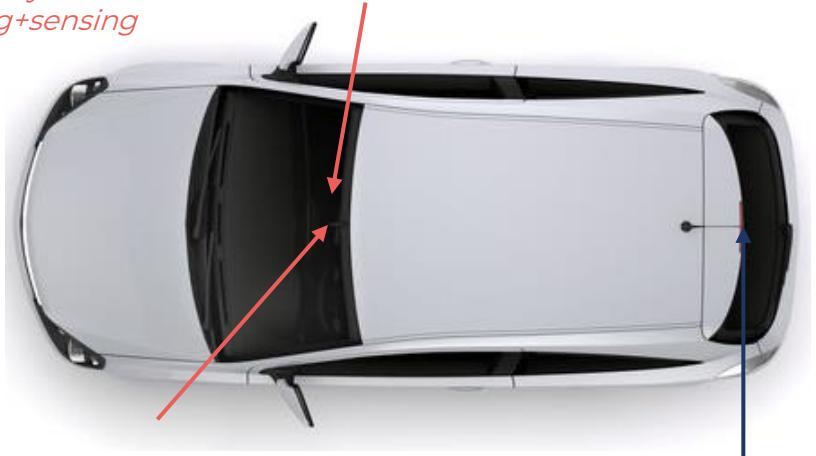
CONTEXT

Types of cameras for CCM applications (focus on other systems)

Automotive

Driver monitoring system*
Occupant monitoring system*

*Can be hybrid
imaging+sensing



Surveillance and security

Home security camera



Doorbell camera



Imaging cameras
Sensing cameras

Industry and commercial

Barcode reader



Medical



Endoscopy camera

Biometrics camera



CONTEXT

Transition from imaging to sensing

Imaging



Photography



Video record



Selfie

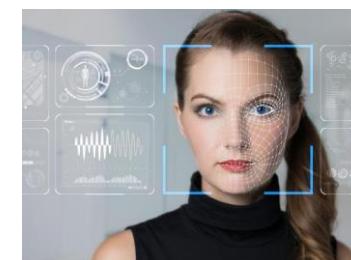


Video call

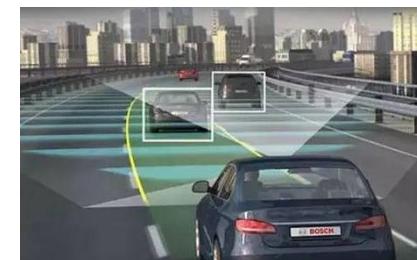
Sensing



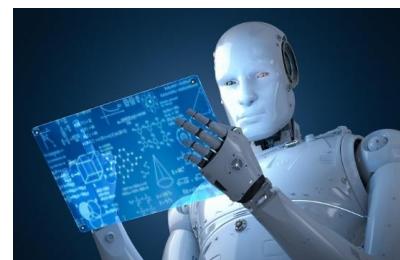
Barcode reader



3D sensing



Automotive ADAS



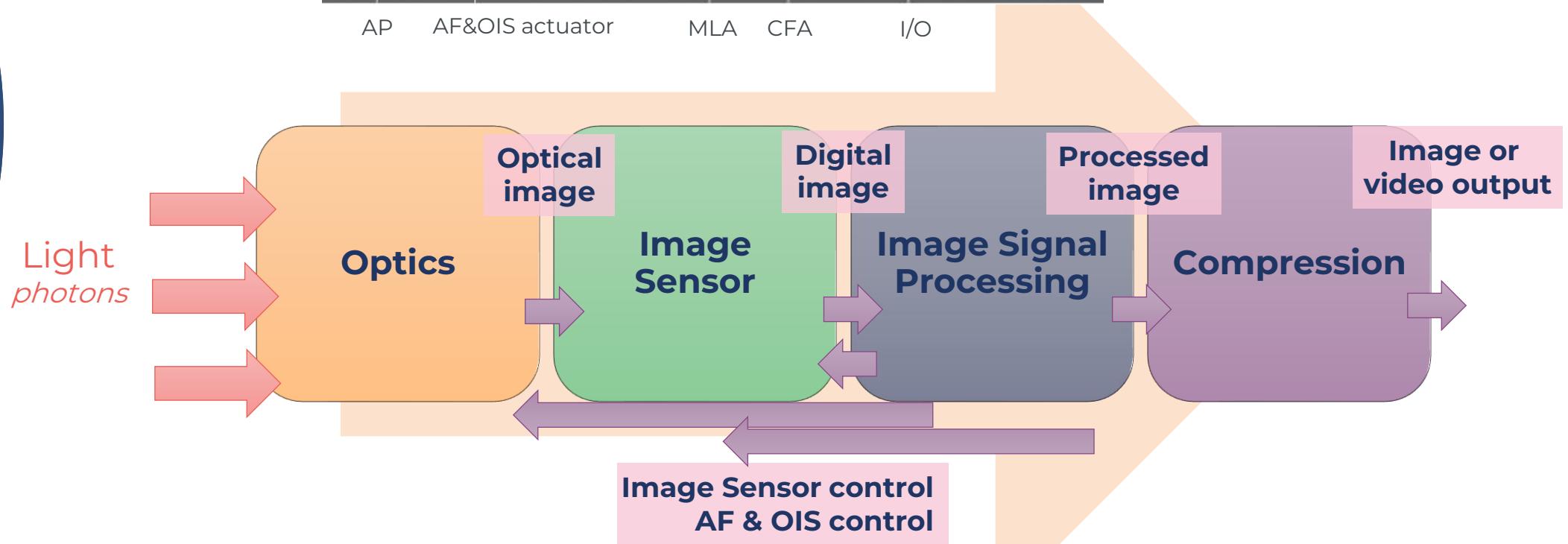
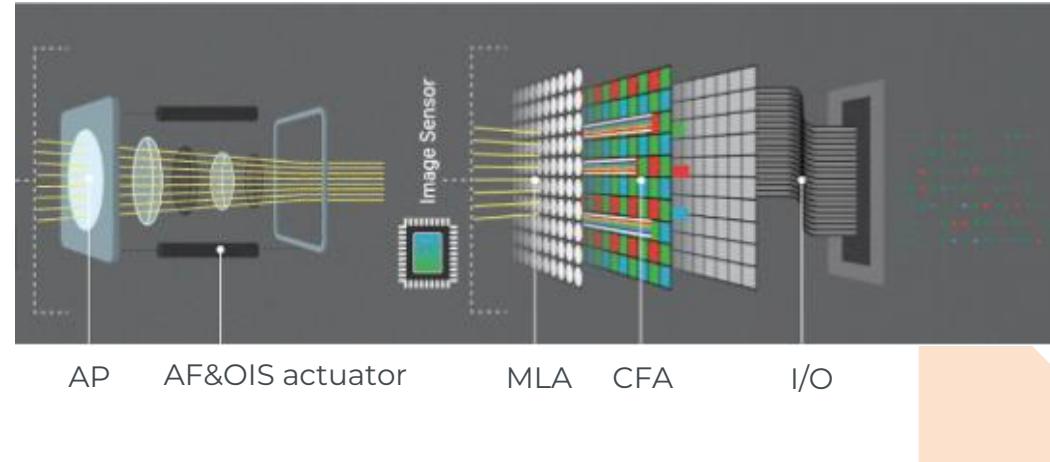
Robotics

Camera modules are primarily used for photography and video but are now expanding into machine sensing.



CONTEXT

Digital imaging block diagram

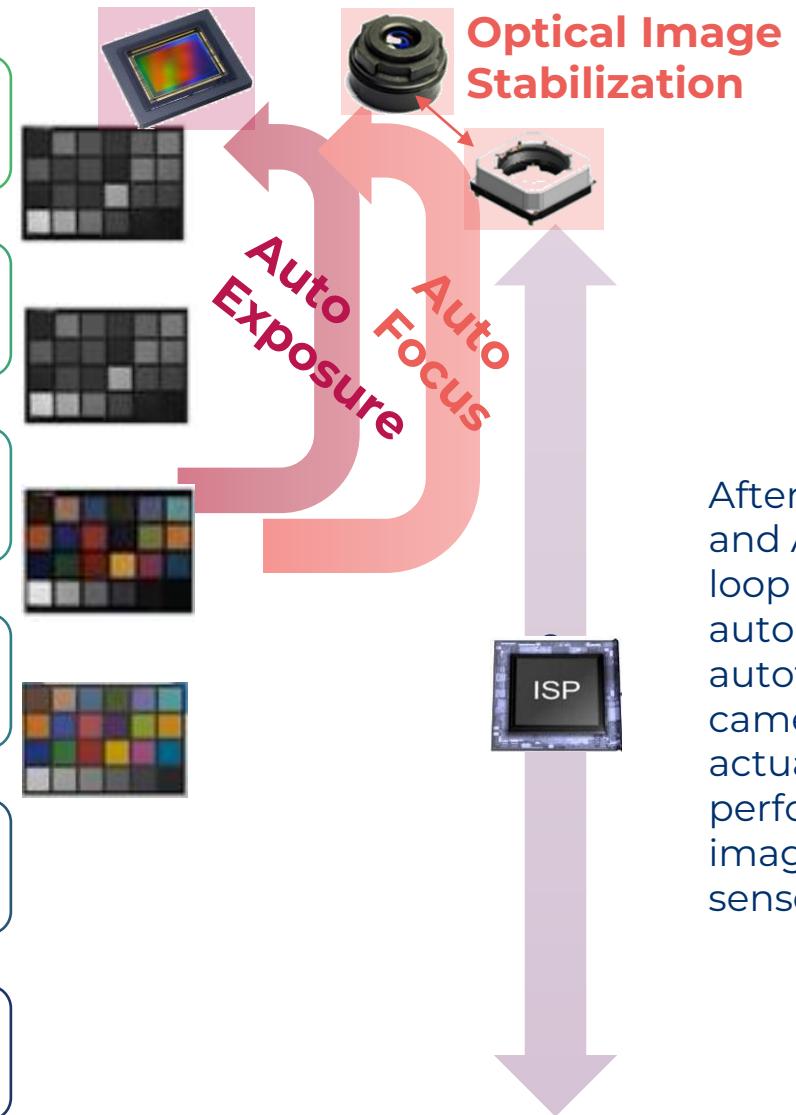
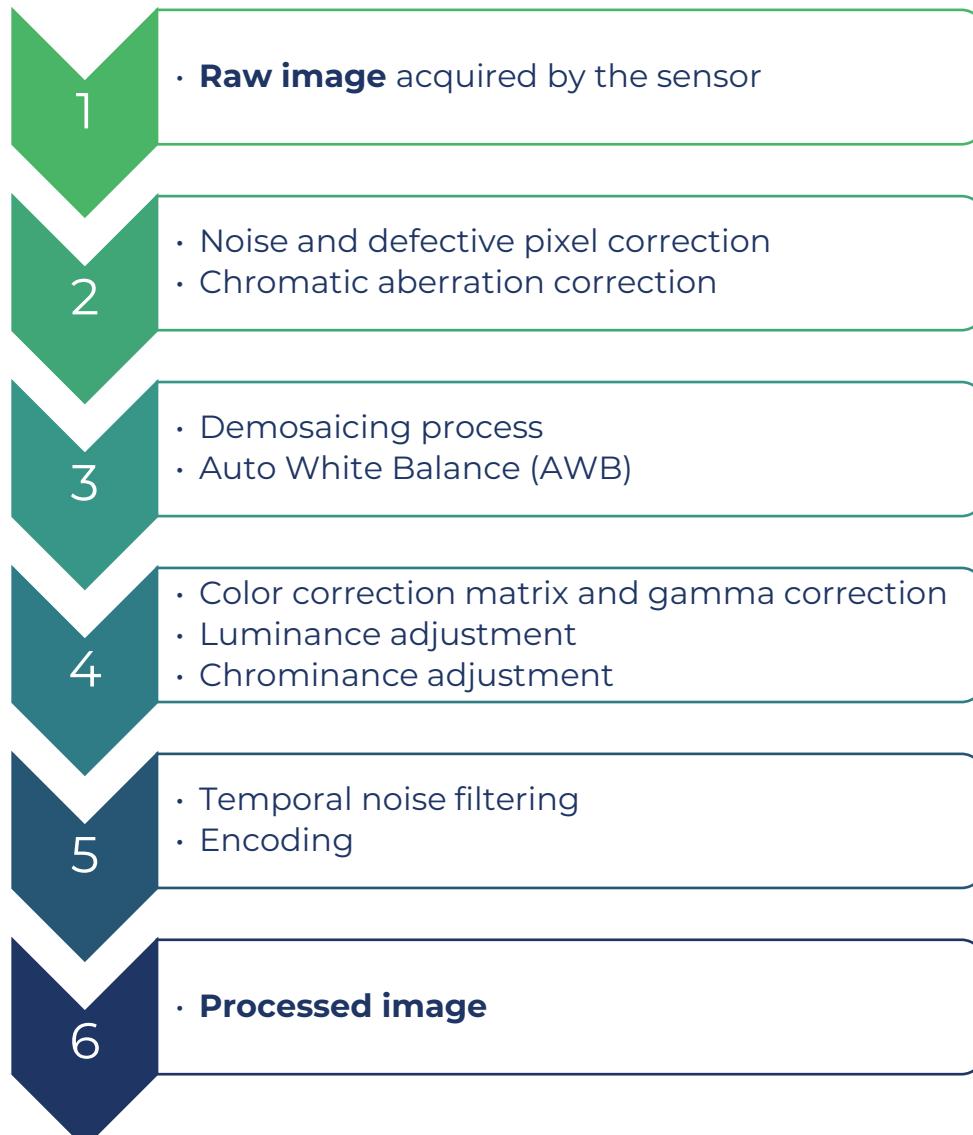




CONTEXT

From raw digital image to processed image

Typical imaging pipeline implies complex features...



After color demosaicing and AWB, a feedback loop can adjust sensor auto-exposure, and autofocus thanks to camera module actuators. OIS is performed during the image acquisition by the sensor if needed.



The flagship smartphones cameras competition



SAMSUNG



OPPO

vivo

HONOR

HUAWEI

Model <i>Release date</i>	Apple iPhone 15 Pro September 2023	Samsung S23 Ultra February 2023	Xiaomi 13S Ultra April 2023	OPPO Find X6 Pro March 2023	Vivo X90 Pro+ December 2022	Honor Magic 4 Pro February 2023	Huawei Mate 60 Pro August 2023
Rear cameras config.	Triple	Quad	Quad	Triple	Quad	Triple	Triple
Main	Resolution	48Mp	200Mp	50Mp	50Mp	50Mp	50Mp
	Format	1/1.28"	1/1.3"	1"	1"	1/1.12"	1/1.28"
	Supplier	SONY	SAMSUNG	SONY	SONY	SONY	SONY
Ultra-wide	Resolution	12Mp	12Mp	50Mp	50Mp	48Mp	50Mp
	Format	1/2.55"	1/2.55"	1/2.55"	1/1.56"	1/2"	1/2.5"
	Supplier	SONY	SONY	SONY	SONY	SONY	OMNIVISION™
Telephoto	Resolution	12Mp	10Mp	10Mp	50Mp	50Mp	64Mp
	Format	1/3"	1/3.52"	1/3.52" (peri.)	1/2.51"	1/2.51" (peri.)	1/2.51"
	Supplier	SONY	SONY	SONY	SONY	SONY	OMNIVISION™ SONY
Periscope	NEW - x5 On Pro Max series	x10	x5	x2.8	x3.5	x3.5	x3.5
Front Selfie	Resolution	12Mp	12Mp	32Mp	32Mp	32Mp	12Mp
	Format	1/2.55"	1/3.2"	1/3.2"	1/2.8"	1/2.8"	1/2.9"
	Supplier	SONY	SAMSUNG	OMNIVISION™	SONY	SAMSUNG	SONY
3D Front	3D Rear	SL (unlock) STMicroelectronics	dToF SONY				iToF (unlock) SONY
							iToF (unlock) SONY

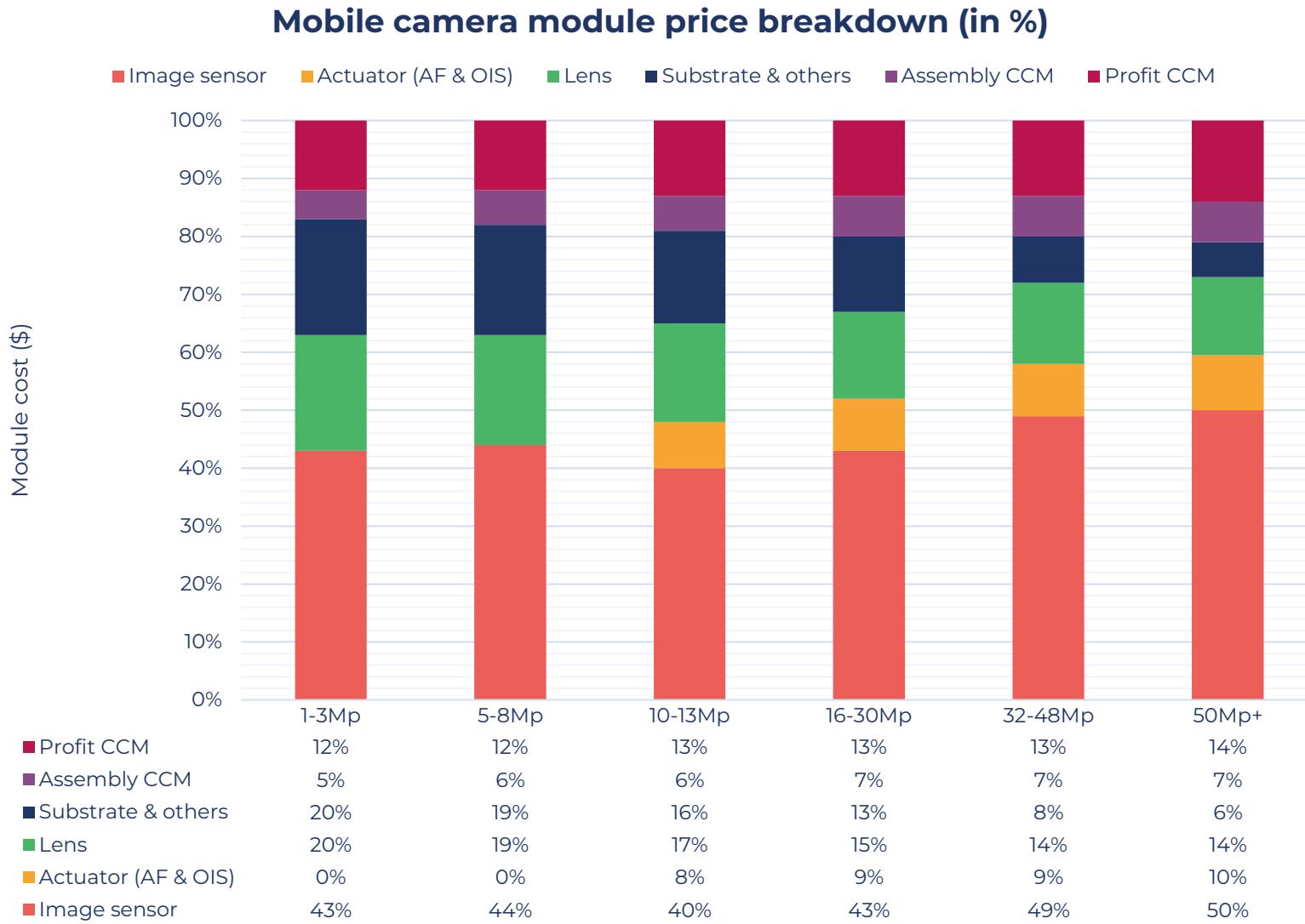
As CIS suppliers, Sony is everywhere for flagships cameras, Samsung and Omnivision come behind, and STMicroelectronics is the legacy supplier for Face ID

Status of the Camera Module Industry 2023 | Report | www.yolegroup.com

CONTEXT

Mobile camera module price breakdown, by resolution (in %)

- For high resolution modules with a large number of lenses and AF/OIS functionality, the relative cost of packaging and assembly increases due to its complexity.
- The relative cost of the optical part for 8Mp+ camera modules (actuator included) remains at 23 to 25% of the total CCM price.
- In general, going to higher resolution cameras:
 - Contribution of optics lenses, substrates and other materials (connectors, filters, housing...) is decreasing, since there is cost pressure for the introduction of higher resolution sensors and actuators
 - Module assembly cost is slightly increasing, and CCM manufacturer margin also tends to increase
 - In general CIS contribution is increasing with resolution, reaching about 50% for 50Mp+ cameras.



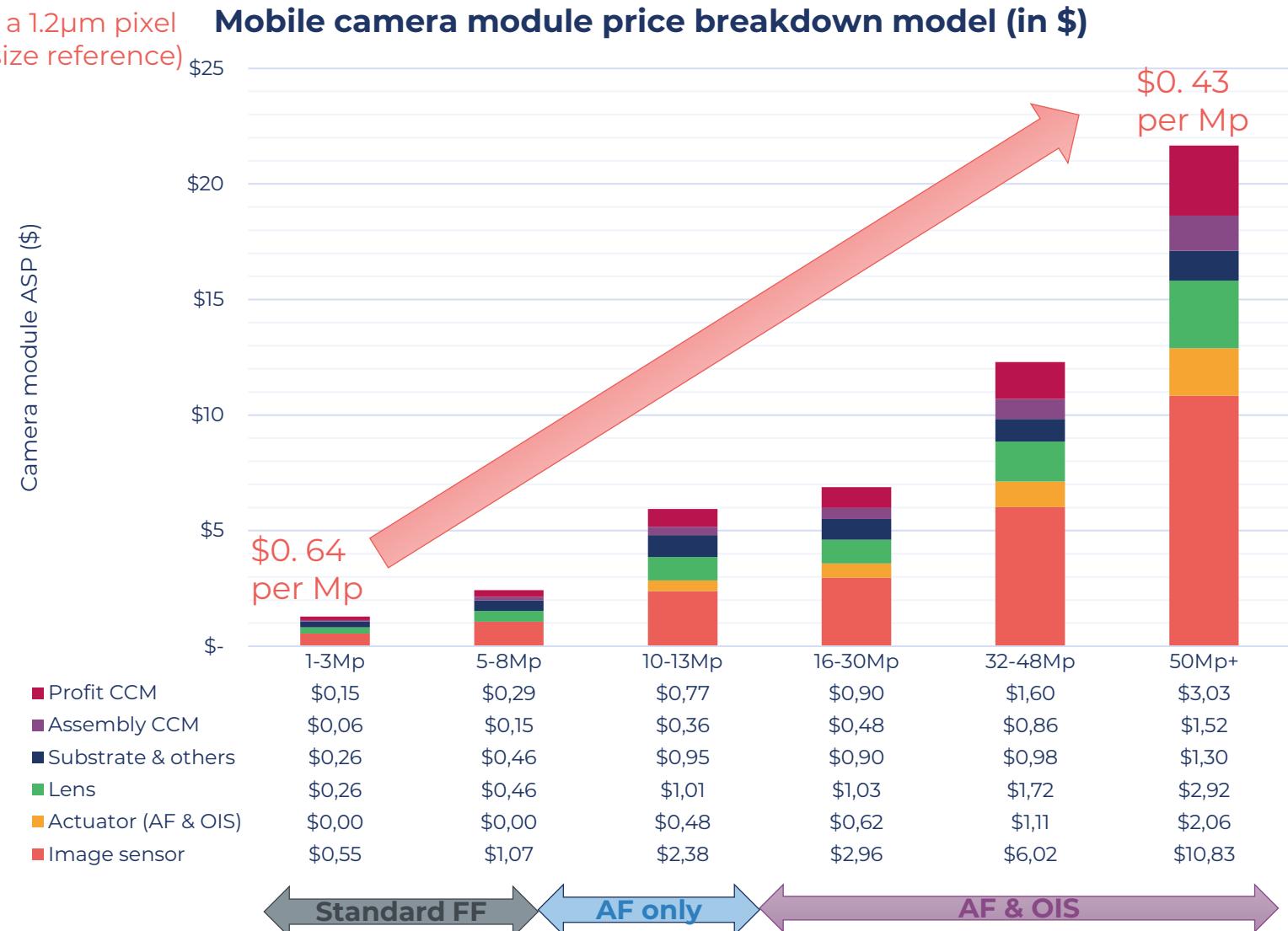


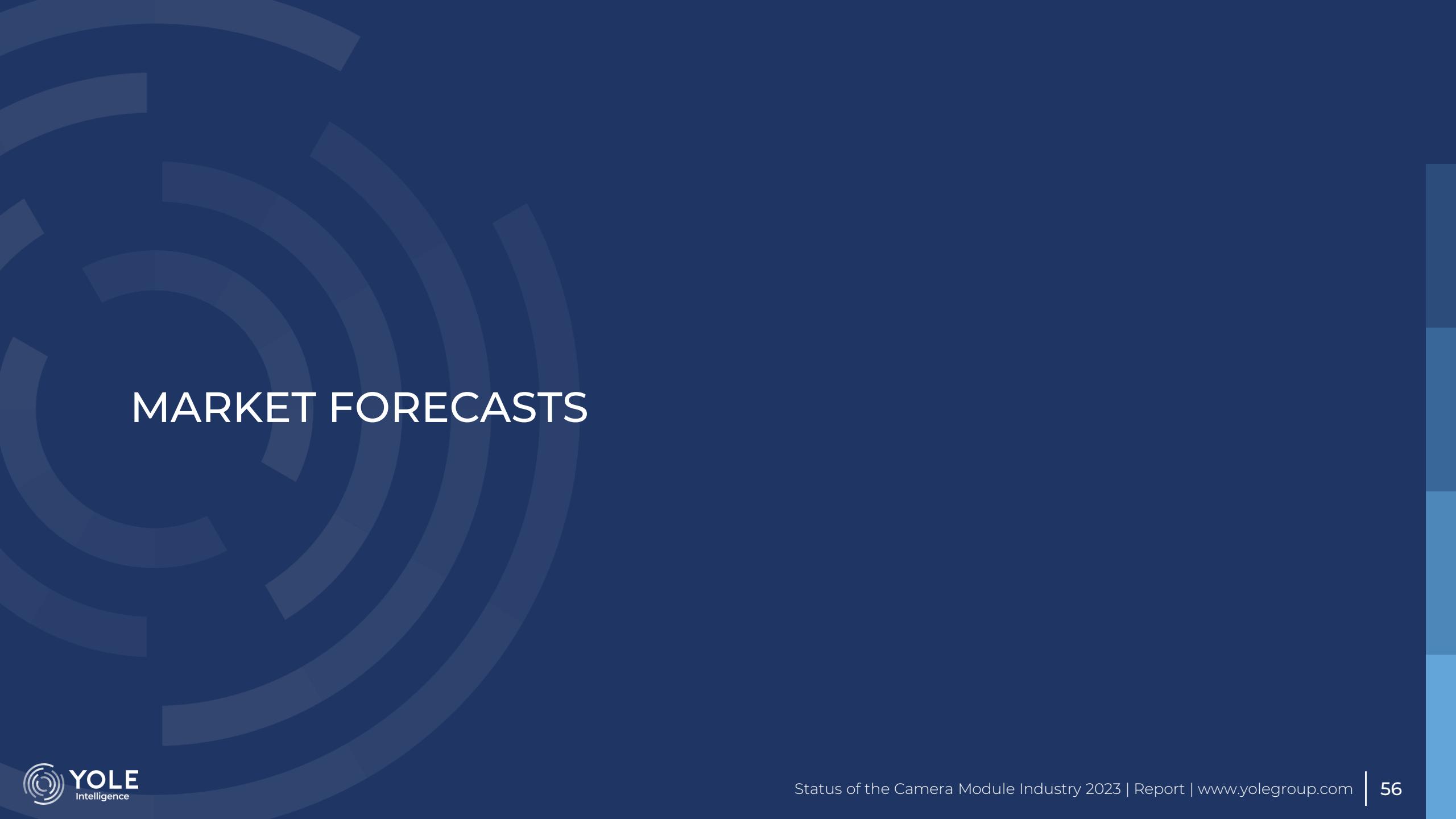
CONTEXT

Mobile camera module price breakdown, by resolution (in \$)

- Typical camera modules in the 1-3Mp range have an average cost of about 1.3\$.
- As the resolution goes up, so does the module cost. The main rear camera, which is integrated with high-resolution CIS, OIS, and AF actuator, maybe even with a periscope-type lens, costs over \$20.
- In general, the average price for 1Mp tends to decrease for higher resolution camera modules: the price of a module is around \$0.64 per Mp for the low-end and decreases to \$0.43 per Mp for the high-end.
- Our estimated average ASP for Mobile camera modules considering the whole set of applications shipped in the market (rear, front, fingerprint, 3D sensing cameras...) is \$4.9 in 2022.

(for a 1.2µm pixel size reference)



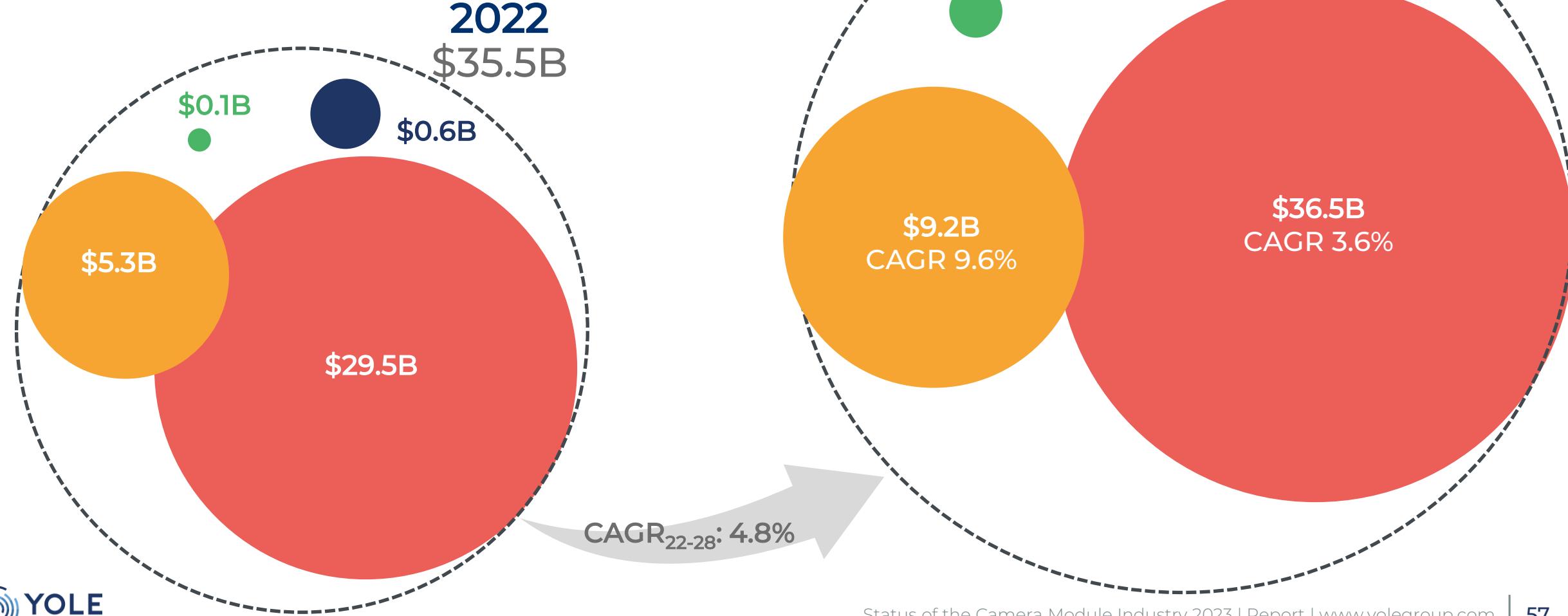


MARKET FORECASTS

2022-2028 COMPACT CAMERA MODULE MARKET FORECAST – BY MARKET



- Mobile & Consumer
- Automotive & Mobility
- Medical
- Industrial



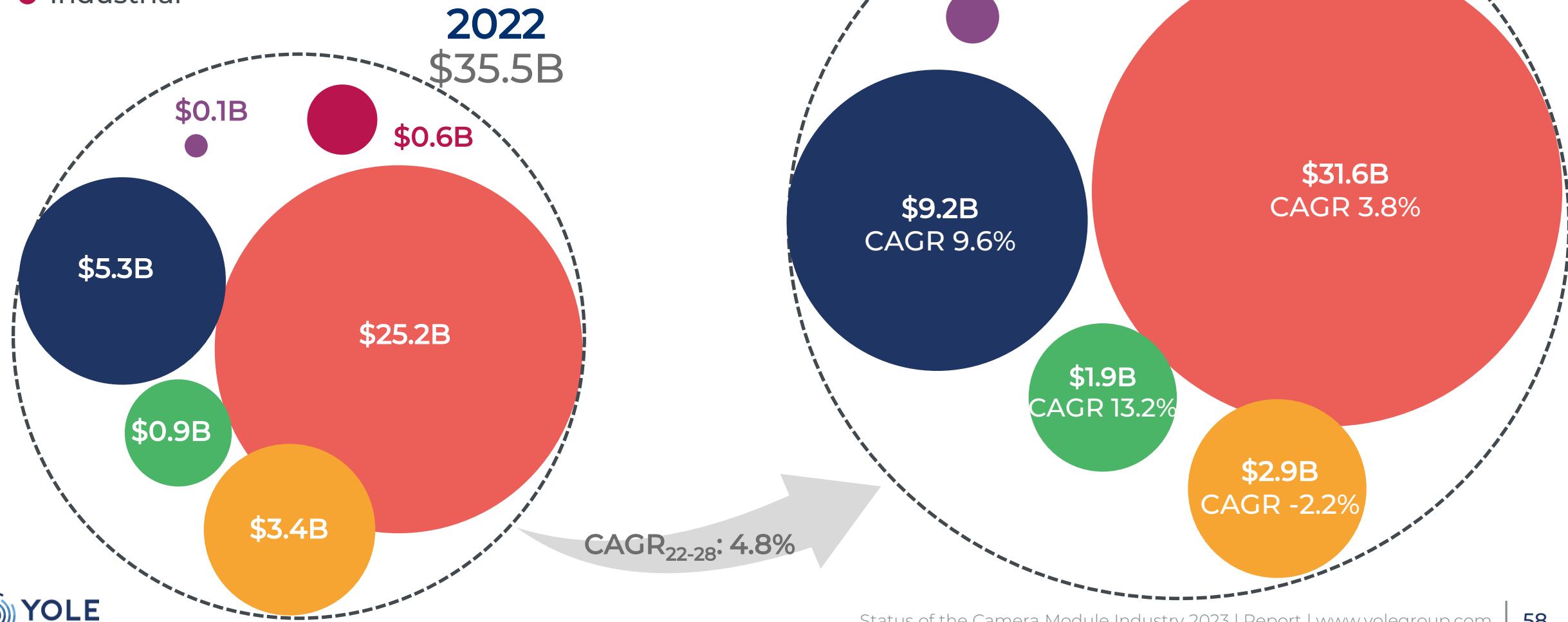
2022-2028 COMPACT CAMERA MODULE MARKET FORECAST – BY MARKET



Mobile & Consumer



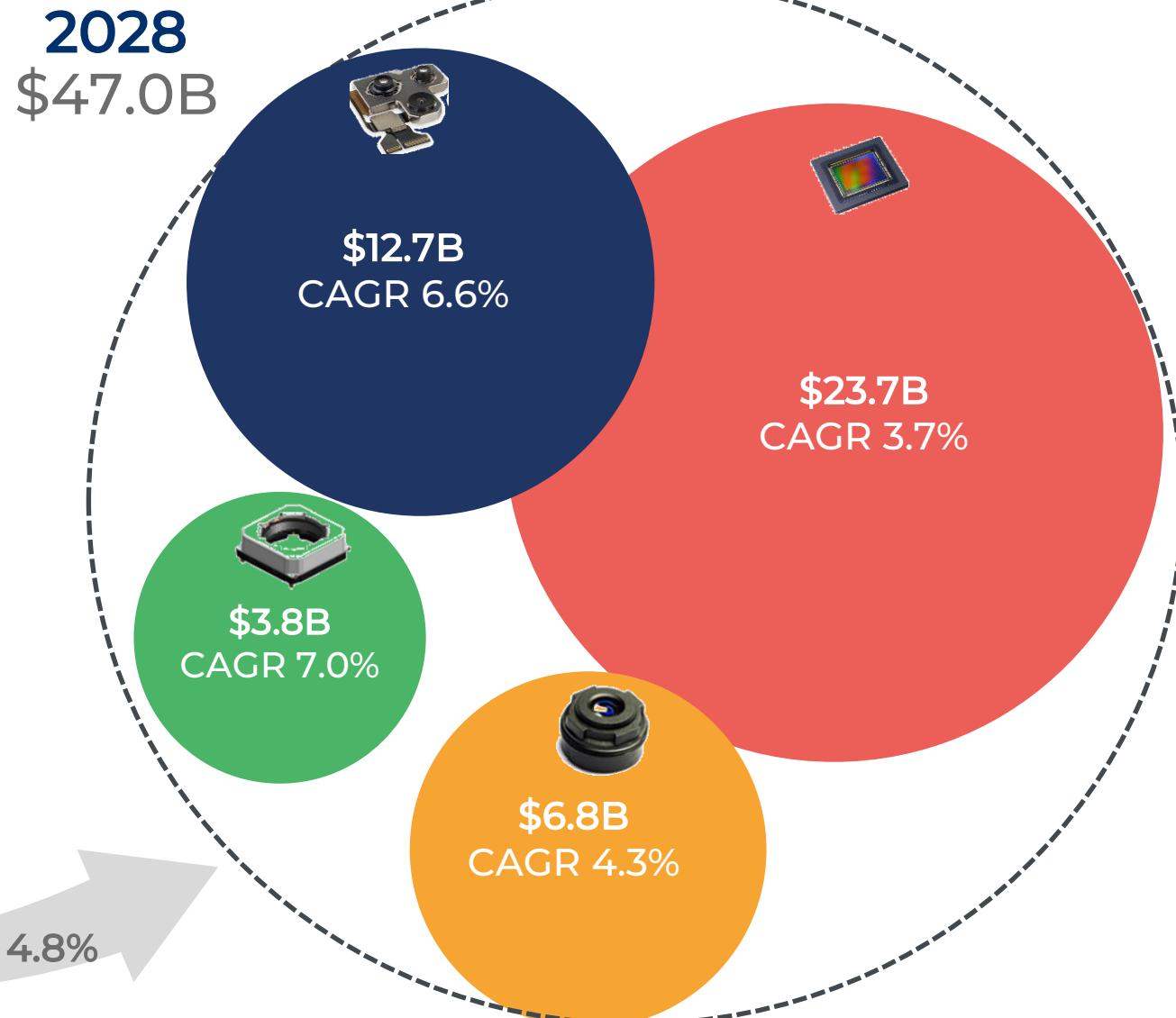
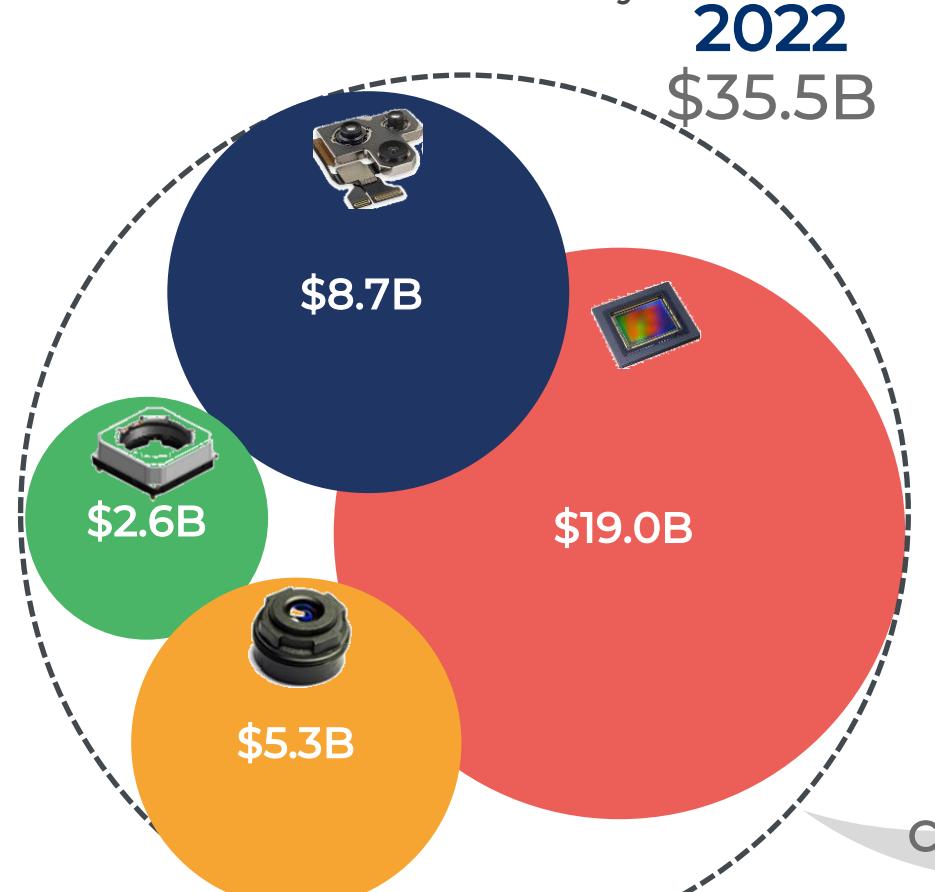
- Mobile
- Computing
- Other Consumer
- Automotive
- Medical
- Industrial



2022-2028 COMPACT CAMERA MODULE MARKET FORECAST – BY ELEMENT



- Image sensor
- Lens set
- Actuator (AF and OIS)
- Camera module assembly





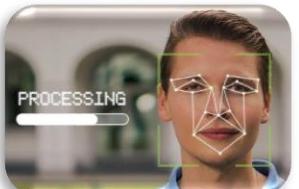
2022-2028 COMPACT CAMERA MODULE MARKET FORECAST

3D imaging and sensing growing contribution

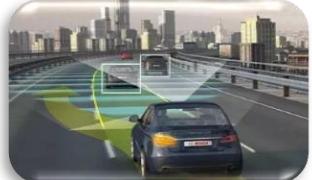
- We consider the whole revenue from 3D imaging and sensing camera module applications. We removed contributions not attributed to compact camera module products for 3D sensing: ADAS LiDARs, construction, defense and aerospace high-end LiDARs, medical and industrial CT systems, laser triangulation, access control and other industrial systems.
- 3D imaging and sensing camera module solutions account for 12% of the total CCM market in 2022, and are expected to increase to 14% by 2028.

Applications examples:

Face recognition in mobile applications



ADAS (stereo)



Interaction in AR/VR/MR



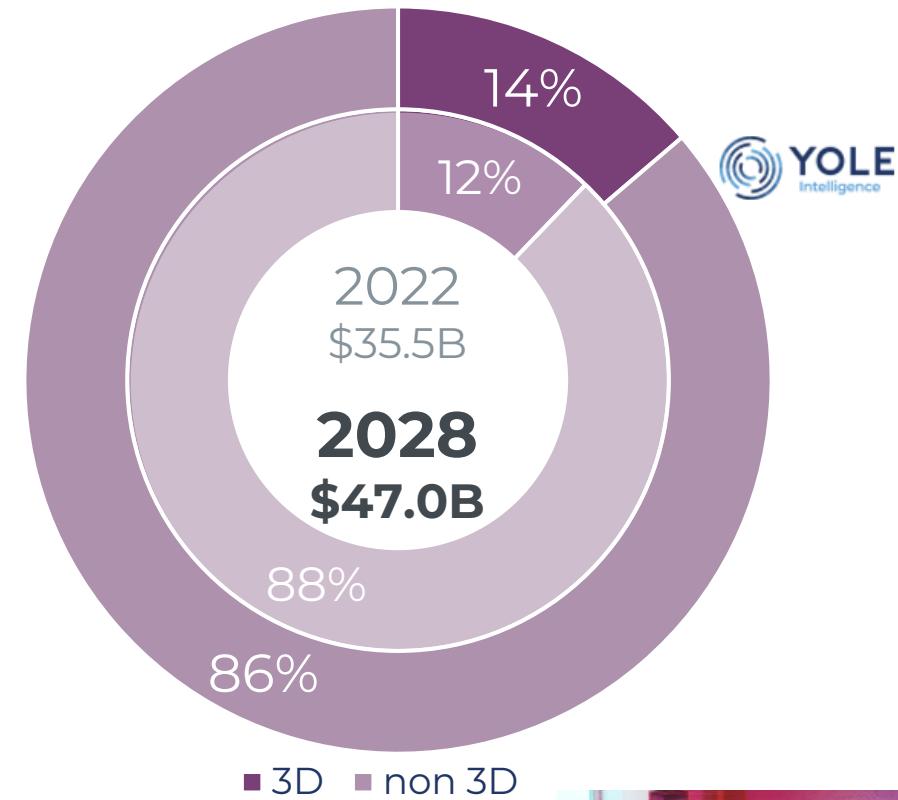
Driver and occupancy monitoring

Obstacle avoidance in drones



Detection in robots

2022-2028 evolution of 3D sensing camera module market share (in % revenue)



For more details: see our report
3D Imaging and Sensing 2023



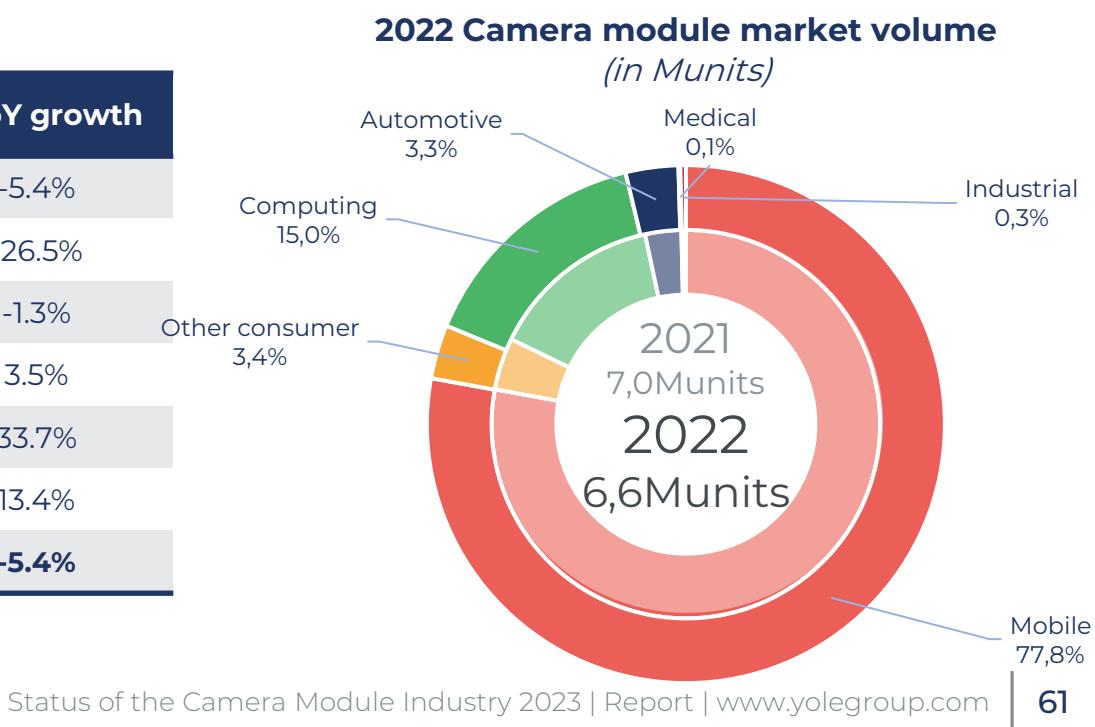


2022-2028 COMPACT CAMERA MODULE MARKET FORECAST

Looking back at 2022 volumes and revenues

- In 2022, the camera module market generated \$35.5B in revenue, Mobile and Consumer applications representing nearly 96% of the shipments with more than 6.3B units: Mobile only accounted for more than 5.1B units, Computing cameras (tablets, laptops, optical mice) for nearly 1B units and about 0.2B units camera modules have been shipped for other consumer applications (drones, consumer robotics, home security cameras, etc.).
- The strong decline in “other consumer” (non-mobile and non-computing) applications is mainly attributed to the shipment decrease of security camera modules products, following the excessive orders of the past years.
- Industrial camera modules include mainly barcode reader products, with a total of 23M units (0.3%). Automotive represents 3% of the total shipments, with 218M camera modules for viewing, ADAS and emerging in-cabin or exterior access applications. The Medical market accounts for a very small portion, with 8M units of endoscopic cameras shipped in 2022.
- This resulted in 6.6B units shipped, a -5.4% decline in 2022 vs. 2021.

MARKET	SEGMENT	2021	2022	% YoY growth
Mobile & Consumer	Mobile	5,449	5,153	-5.4%
Mobile & Consumer	Other consumer	303	223	-26.5%
Mobile & Consumer	Computing	1,009	996	-1.3%
Automotive & Mobility	Automotive	210	218	3.5%
Medical	Medical	6	8	33.7%
Industrial	Industrial	20	23	13.4%
TOTAL		6,997	6,620	-5.4%





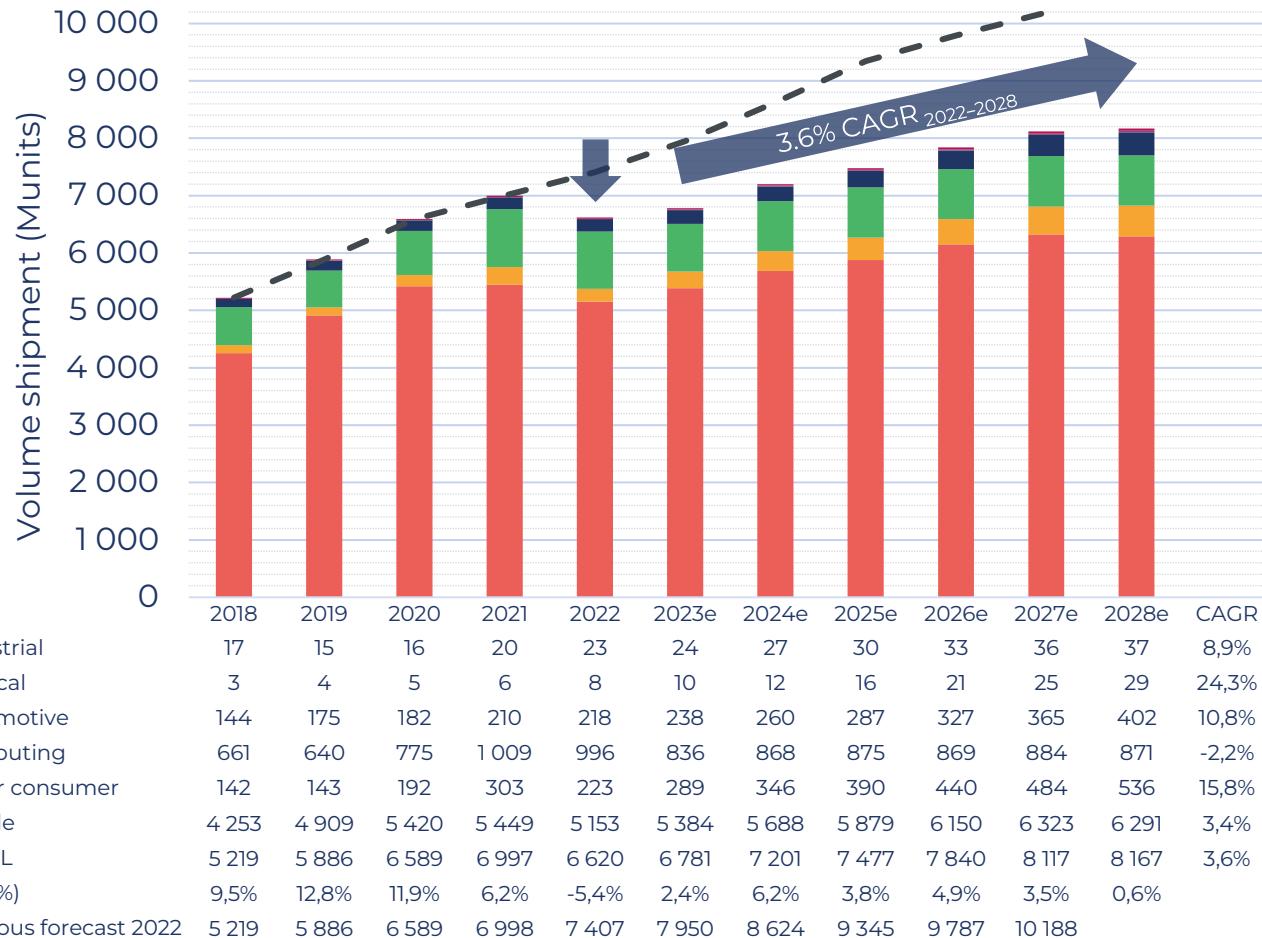
CAMERA MODULE VOLUME SHIPMENT FORECAST 2018-2028

by market segment (in Munits)



- Our long-term prediction has been reviewed downwards significantly: smartphone sales are expected to reach 1.2Bunits by 2028 instead of 1.4Bunits as last year forecast, and we confirm the deceleration in the increase of the average number of cameras per smartphone, that will limit the primary source of growth for CCM volumes (by about -1.5B units).
- The CCM market should resume growth in 2023, with a progressively slowing growth year-over-year rate from 2024. The natural decline expected for computing product shipments (tablets, laptops..) is confirmed. All the other market segments are promised to grow at different rates.
- Over the 2022-2028 period, CCM shipments should increase from 6.6Bunits to 8.2Bunits, with the corresponding CAGR adjusted from 6.5% to 3.6% versus our last year forecast. Beyond mobile, which will still drive CIS volumes, computing, automotive, and other consumer products camera modules are also sustaining the growing trend.

**2018 - 2028 Camera module volume shipment forecast
by market segment (in Munits)**





CAMERA MODULE VOLUME SHIPMENT FORECAST 2018-2028

by application (in Munits)



Market	Segment	Application/System	Location/Function	2018	2019	2020	2021	2022	2023e	2024e	2025e	2026e	2027e	2028e	CAGR
1Mobile and Consumer	Mobile	Smartphone	Rear	2107	2599	3263	3184	3080	3252	3475	3618	3785	3895	3892	4.0%
2Mobile and Consumer	Mobile	Smartphone	Front	1515	1593	1465	1393	1303	1347	1404	1452	1549	1606	1587	3.3%
3Mobile and Consumer	Mobile	Smartphone	Fingerprint	23	139	234	439	320	334	357	372	392	407	412	4.3%
4Mobile and Consumer	Mobile	Feature Phone	Rear	516	493	382	364	364	364	360	346	332	319	306	-2.8%
5Mobile and Consumer	Mobile	Feature Phone	Front	92	85	76	68	86	87	92	91	93	96	95	1.6%
6Mobile and Consumer	Computing	Computer Mice	Main	160	155	144	144	188	159	154	149	145	140	136	-5.3%
7Mobile and Consumer	Computing	Tablet	Rear/Front	325	312	424	480	471	395	412	413	413	414	415	-2.1%
8Mobile and Consumer	Computing	Laptop	Front	176	173	207	385	337	282	302	313	311	330	320	-0.8%
9Mobile and Consumer	Other consumer	Action Cam	Main	2.2	3.8	5.9	7.0	8.9	8.7	8.7	8.8	9.0	9.0	8.9	-0.1%
10Mobile and Consumer	Other consumer	Consumer Drone	Main	18	23	24	29	32	32	31	30	28	28	28	-2.3%
11Mobile and Consumer	Other consumer	Game Station	Main	10	11	12	18	15	23	33	39	41	40	39	17.0%
12Mobile and Consumer	Other consumer	Personal Robotic	Main	4	5	7	12	16	19	22	25	29	33	37	14.8%
13Mobile and Consumer	Other consumer	Smart Speaker / Assistant	Main	27	14	14	22	24	25	30	36	43	49	54	14.1%
14Mobile and Consumer	Other consumer	Security Camera	Main	73	75	113	189	90	133	153	162	174	182	190	13.3%
15Mobile and Consumer	Other consumer	AR-VR Headset	Front/Rear	7	8	12	21	30	41	60	79	103	128	162	32.5%
16Mobile and Consumer	Other consumer	Smartwatch	Main	0	2	4	5	7	7	8	10	12	15	17	17.7%
17Automotive and Mobility	Automotive	Passenger Car and LCV	In-cabin monitoring	20	22	21	26	19	24	31	44	66	86	107	34.0%
18Automotive and Mobility	Automotive	Passenger Car and LCV	ADAS	94	114	120	134	136	144	152	160	171	181	189	5.7%
19Automotive and Mobility	Automotive	Passenger Car and LCV	Viewing	29	39	41	51	63	70	77	83	90	98	105	8.7%
20Automotive and Mobility	Automotive	Passenger Car and LCV	Exterior access	0.00	0.00	0.00	0.01	0.02	0.04	0.07	0.13	0.33	0.77	1.11	102.7%
21Medical	Medical	Endoscopy	Main	3	4	5	6	8	10	12	16	21	25	29	24.3%
22Industrial	Industrial	Matrix Code Reader / ADC	Main	17	15	16	20	23	24	27	30	33	36	37	8.9%
TOTAL				5,219	5,886	6,589	6,997	6,620	6,781	7,201	7,477	7,840	8,117	8,167	3.6%
YoY GROWTH				9.5%	12.8%	11.9%	6.2%	-5.4%	2.4%	6.2%	3.8%	4.9%	3.5%	0.6%	

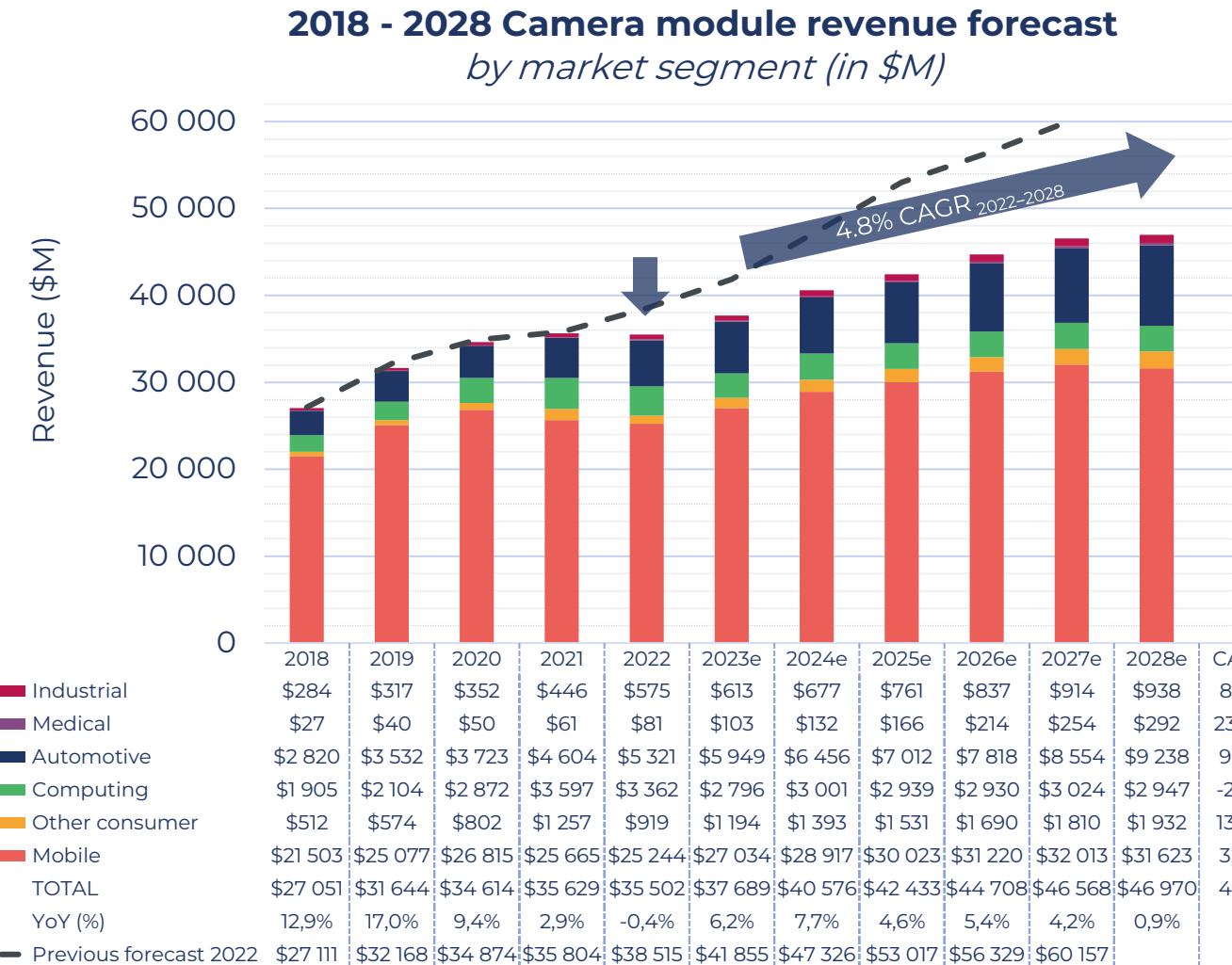


CAMERA MODULE REVENUE FORECAST 2018-2028

by market segment (in \$M)

Revenue decreased slightly to \$35.5B in 2022, and we expect a 4.8% CAGR over the 2022-2028 period.

- Over the 2022-2028 period, CCM revenue should increase from \$35.5B to \$47.0B, with a corresponding 4.8% CAGR.
- Long-term revenue in 2028 has been revised downwards significantly, mainly due to the lowering of the main source of CCM growth, the Mobile market, associated to a revision of the long-term smartphone shipments.
- Double-digit CAGR is announced for the medical segment due to the expected flourishing of disposable endoscopic products, and “other consumer” products mainly due to the important CAGR expected for consumer security cameras, following the important decrease that occurred in 2022 for this market after the excessive previous camera modules stockpiling.
- Meanwhile the Computing CCM market will experience a smooth decline, due to the lowering of the laptop and tablet shipments, while the Mobile CCM market will continue on a reasonable but solid growth, with increasing sensing cameras opportunities, and a shift toward higher formats image sensors.
- Higher-end Automotive and Industrial camera products will sustain growth due to imaging solutions penetration rate increase and move to higher resolution for features such as ADAS.





CAMERA MODULE REVENUE FORECAST 2018-2028

by application (in \$M)



Market	Segment	Application/System	Location/Function	2018	2019	2020	2021	2022	2023e	2024e	2025e	2026e	2027e	2028e	CAGR
1Mobile and Consumer	Mobile	Smartphone	Rear	\$13,988	\$16,961	\$19,529	\$17,948	\$18,235	\$19,640	\$21,233	\$22,070	\$22,788	\$23,332	\$23,156	4.1%
2Mobile and Consumer	Mobile	Smartphone	Front	\$5,903	\$6,292	\$5,567	\$5,573	\$5,211	\$5,616	\$5,910	\$6,171	\$6,612	\$6,890	\$6,730	4.4%
3Mobile and Consumer	Mobile	Smartphone	Fingerprint	\$66	\$375	\$613	\$1,116	\$789	\$799	\$827	\$837	\$854	\$862	\$856	1.4%
4Mobile and Consumer	Mobile	Feature Phone	Rear	\$1,472	\$1,381	\$1,047	\$976	\$946	\$917	\$879	\$878	\$896	\$854	\$807	-2.6%
5Mobile and Consumer	Mobile	Feature Phone	Front	\$74	\$67	\$59	\$52	\$63	\$62	\$67	\$67	\$69	\$76	\$74	2.6%
6Mobile and Consumer	Computing	Computer Mice	Main	\$50	\$48	\$44	\$49	\$64	\$55	\$54	\$52	\$49	\$47	\$45	-5.8%
7Mobile and Consumer	Computing	Tablet	Rear/Front	\$1,572	\$1,787	\$2,473	\$2,860	\$2,713	\$2,235	\$2,396	\$2,308	\$2,298	\$2,366	\$2,317	-2.6%
8Mobile and Consumer	Computing	Laptop	Front	\$283	\$269	\$355	\$688	\$585	\$506	\$550	\$579	\$582	\$610	\$586	0.0%
9Mobile and Consumer	Other consumer	Action Cam	Main	\$23	\$38	\$64	\$76	\$97	\$97	\$97	\$99	\$102	\$101	\$99	0.5%
10Mobile and Consumer	Other consumer	Consumer Drone	Main	\$82	\$103	\$122	\$144	\$156	\$156	\$150	\$141	\$133	\$131	\$127	-3.4%
11Mobile and Consumer	Other consumer	Game Station	Main	\$45	\$48	\$53	\$79	\$64	\$99	\$139	\$164	\$171	\$162	\$153	15.5%
12Mobile and Consumer	Other consumer	Personal Robotic	Main	\$17	\$21	\$30	\$52	\$68	\$79	\$92	\$106	\$123	\$143	\$162	15.5%
13Mobile and Consumer	Other consumer	Smart Speaker / Assistant	Main	\$58	\$29	\$28	\$42	\$47	\$49	\$57	\$66	\$79	\$88	\$94	12.4%
14Mobile and Consumer	Other consumer	Security Camera	Main	\$264	\$301	\$467	\$809	\$399	\$615	\$730	\$795	\$891	\$966	\$1,036	17.2%
15Mobile and Consumer	Other consumer	AR-VR Headset	Front/Rear	\$24	\$22	\$18	\$26	\$52	\$61	\$85	\$103	\$124	\$141	\$170	22.0%
16Mobile and Consumer	Other consumer	Smartwatch	Main	\$0	\$11	\$20	\$29	\$35	\$38	\$43	\$56	\$67	\$78	\$90	16.9%
17Automotive and Mobility	Automotive	Passenger Car and LCV	In-cabin monitoring	\$501	\$565	\$489	\$580	\$382	\$506	\$681	\$954	\$1,433	\$1,860	\$2,280	34.7%
18Automotive and Mobility	Automotive	Passenger Car and LCV	ADAS	\$1,731	\$2,141	\$2,295	\$2,607	\$2,717	\$2,878	\$3,041	\$3,142	\$3,278	\$3,401	\$3,488	4.3%
19Automotive and Mobility	Automotive	Passenger Car and LCV	Viewing	\$588	\$826	\$938	\$1,418	\$2,221	\$2,564	\$2,733	\$2,913	\$3,099	\$3,278	\$3,449	7.6%
20Automotive and Mobility	Automotive	Passenger Car and LCV	Exterior access	\$0	\$0	\$0	\$0	\$0	\$1	\$1	\$3	\$7	\$15	\$21	94.3%
21Medical	Medical	Endoscopy	Main	\$27	\$40	\$50	\$61	\$81	\$103	\$132	\$166	\$214	\$254	\$292	23.8%
22Industrial	Industrial	Matrix Code Reader / ADC	Main	\$284	\$317	\$352	\$446	\$575	\$613	\$677	\$761	\$837	\$914	\$938	8.5%
TOTAL				\$27,051	\$31,644	\$34,614	\$35,629	\$35,502	\$37,689	\$40,576	\$42,433	\$44,708	\$46,568	\$46,970	4.8%
YoY GROWTH				12.9%	17.0%	9.4%	2.9%	-0.4%	6.2%	7.7%	4.6%	5.4%	4.2%	0.9%	

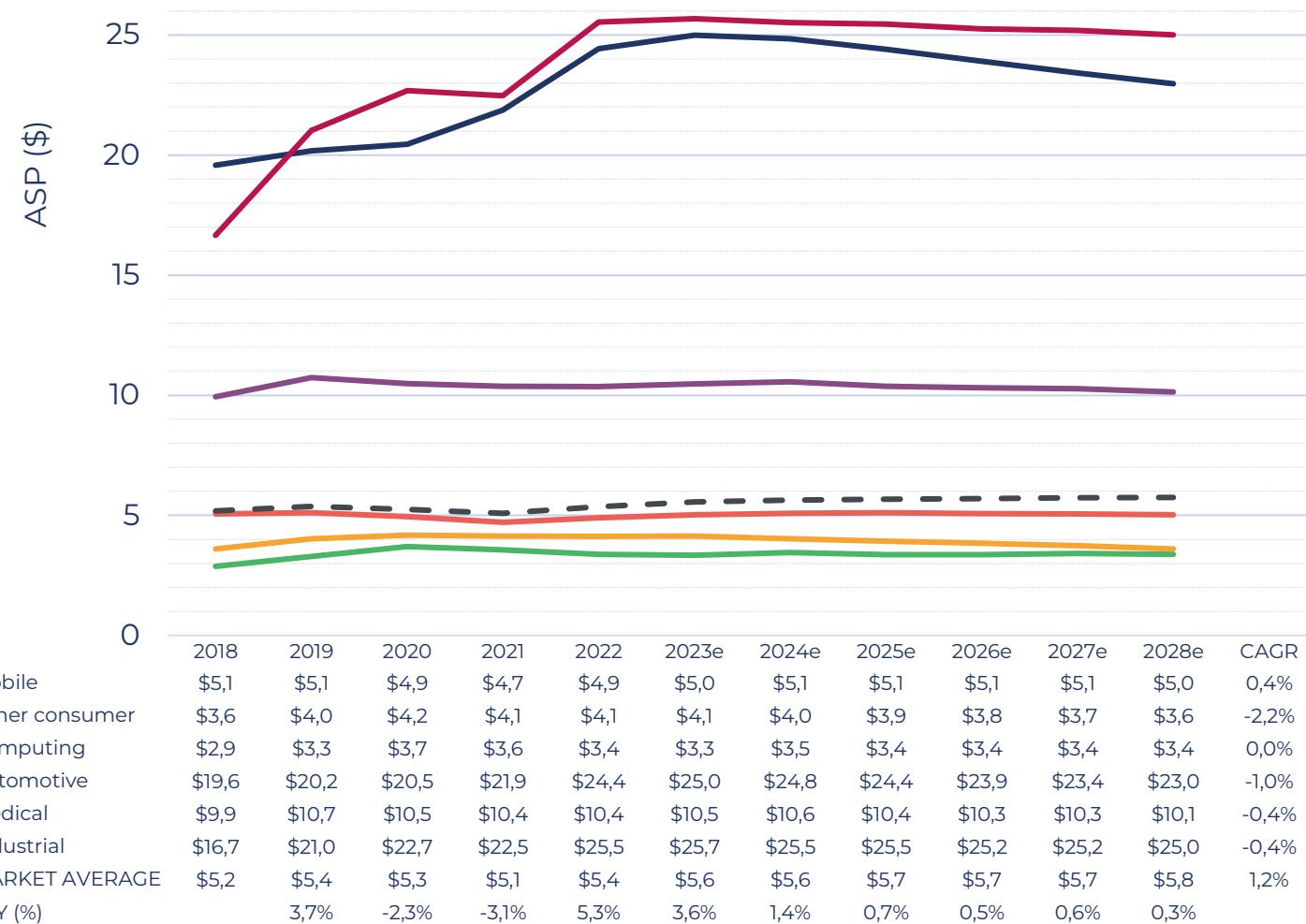


CAMERA MODULE ASP FORECAST 2018-2028

by market segment (in \$)

- In the mobile market, high-end photography is transitioning to larger resolution and size image sensors with higher ASP. Computing CCM ASP is maintained above 3.4\$, tracked by higher price for tablets camera modules.
- The Automotive CCM price surged further in 2022, as a soft-landing situation from the previous shortage and supply chain issues, and also due to the growing adoption of higher resolution including the 8Mp ADAS solutions. We expect it will saturate close to 25\$ until 2024 before entering a smoother price erosion for the next years.
- The price of compact cameras for Industrial has increased these past few years following supply chain issues and the anticipation of a recession that might occur, while medical endoscopic cameras ASP has been relatively stable.
- This results for the whole CCM market in a slight average ASP increase at 1.2% CAGR from 2022 to 2028, as the consequence of a slightly increasing ASP for Mobile applications that represent most of the volume shipped.**

2018 - 2028 Camera module ASP forecast
by market segment (in \$)





CAMERA MODULE ASP FORECAST 2018-2028

by application (in \$)



Market	Segment	Application/System	Location/Function	2018	2019	2020	2021	2022	2023e	2024e	2025e	2026e	2027e	2028e	CAGR
1Mobile and Consumer	Mobile	Smartphone	Rear	\$6.64	\$6.53	\$5.99	\$5.64	\$5.92	\$6.04	\$6.11	\$6.10	\$6.02	\$5.99	\$5.95	0.1%
2Mobile and Consumer	Mobile	Smartphone	Front	\$3.90	\$3.95	\$3.80	\$4.00	\$4.00	\$4.17	\$4.21	\$4.25	\$4.27	\$4.29	\$4.24	1.0%
3Mobile and Consumer	Mobile	Smartphone	Fingerprint	\$2.92	\$2.70	\$2.62	\$2.54	\$2.46	\$2.39	\$2.32	\$2.25	\$2.18	\$2.12	\$2.08	-2.8%
4Mobile and Consumer	Mobile	Feature Phone	Rear	\$2.85	\$2.80	\$2.74	\$2.68	\$2.60	\$2.52	\$2.44	\$2.54	\$2.70	\$2.68	\$2.64	0.3%
5Mobile and Consumer	Mobile	Feature Phone	Front	\$0.81	\$0.79	\$0.77	\$0.76	\$0.73	\$0.71	\$0.72	\$0.73	\$0.75	\$0.79	\$0.78	1.0%
6Mobile and Consumer	Computing	Computer Mice	Main	\$0.31	\$0.31	\$0.30	\$0.34	\$0.34	\$0.34	\$0.35	\$0.35	\$0.34	\$0.34	\$0.33	-0.6%
7Mobile and Consumer	Computing	Tablet	Rear/Front	\$4.84	\$5.73	\$5.84	\$5.96	\$5.76	\$5.66	\$5.82	\$5.59	\$5.56	\$5.71	\$5.58	-0.5%
8Mobile and Consumer	Computing	Laptop	Front	\$1.61	\$1.56	\$1.72	\$1.79	\$1.74	\$1.80	\$1.82	\$1.85	\$1.87	\$1.85	\$1.83	0.9%
9Mobile and Consumer	Other consumer	Action Cam	Main	\$10.25	\$10.04	\$10.91	\$10.87	\$10.81	\$11.07	\$11.21	\$11.29	\$11.37	\$11.18	\$11.20	0.6%
10Mobile and Consumer	Other consumer	Consumer Drone	Main	\$4.61	\$4.57	\$5.02	\$5.00	\$4.92	\$4.87	\$4.82	\$4.76	\$4.70	\$4.63	\$4.60	-1.1%
11Mobile and Consumer	Other consumer	Game Station	Main	\$4.35	\$4.18	\$4.45	\$4.35	\$4.23	\$4.24	\$4.21	\$4.18	\$4.15	\$4.02	\$3.91	-1.3%
12Mobile and Consumer	Other consumer	Personal Robotic	Main	\$4.35	\$4.18	\$4.45	\$4.35	\$4.23	\$4.24	\$4.26	\$4.28	\$4.33	\$4.37	\$4.39	0.6%
13Mobile and Consumer	Other consumer	Smart Speaker / Assistant	Main	\$2.11	\$2.02	\$1.97	\$1.93	\$1.91	\$1.94	\$1.91	\$1.87	\$1.82	\$1.78	\$1.75	-1.5%
14Mobile and Consumer	Other consumer	Security Camera	Main	\$3.60	\$4.00	\$4.12	\$4.28	\$4.44	\$4.62	\$4.77	\$4.91	\$5.12	\$5.31	\$5.45	3.5%
15Mobile and Consumer	Other consumer	AR-VR Headset	Front/Rear	\$3.4	\$2.9	\$1.5	\$1.2	\$1.7	\$1.5	\$1.4	\$1.3	\$1.2	\$1.1	\$1.05	-8.0%
16Mobile and Consumer	Other consumer	Smartwatch	Main	\$5.33	\$5.17	\$5.56	\$5.45	\$5.42	\$5.44	\$5.44	\$5.42	\$5.40	\$5.31	\$5.20	-0.7%
17Automotive and Mobility	Automotive	Passenger Car and LCV	In-cabin monitoring	\$24.58	\$25.75	\$23.61	\$22.19	\$20.65	\$21.43	\$21.85	\$21.91	\$21.86	\$21.61	\$21.29	0.5%
18Automotive and Mobility	Automotive	Passenger Car and LCV	ADAS	\$18.35	\$18.73	\$19.11	\$19.50	\$20.00	\$20.00	\$20.00	\$19.60	\$19.21	\$18.82	\$18.45	-1.3%
19Automotive and Mobility	Automotive	Passenger Car and LCV	Viewing	\$20.02	\$21.32	\$22.79	\$28.00	\$35.00	\$36.40	\$35.67	\$34.96	\$34.26	\$33.57	\$32.90	-1.0%
20Automotive and Mobility	Automotive	Passenger Car and LCV	Exterior access	\$31.24	\$29.42	\$27.72	\$26.11	\$24.60	\$23.17	\$21.85	\$20.85	\$19.98	\$19.16	\$19.07	-4.1%
21Medical	Medical	Endoscopy	Main	\$9.94	\$10.74	\$10.49	\$10.37	\$10.36	\$10.48	\$10.56	\$10.38	\$10.31	\$10.27	\$10.14	-0.4%
22Industrial	Industrial	Matrix Code Reader / ADC	Main	\$16.66	\$21.02	\$22.69	\$22.47	\$25.54	\$25.68	\$25.52	\$25.45	\$25.25	\$25.19	\$25.00	-0.4%
MARKET AVERAGE				\$5.2	\$5.4	\$5.3	\$5.1	\$5.4	\$5.6	\$5.6	\$5.7	\$5.7	\$5.7	\$5.8	1.2%
YoY GROWTH				3.7%	-2.3%	-3.1%	5.3%	3.6%	1.4%	0.7%	0.5%	0.6%	0.3%		

CAMERA MODULE REVENUE FORECAST 2018-2028

by element (in %)



	2018	2019	2020	2021	2022	2023e	2024e	2025e	2026e	2027e	2028e
Image sensor	46.8%	51.5%	50.9%	53.5%	53.6%	51.3%	51.4%	51.0%	50.7%	50.6%	50.4%
Lens set	15.4%	15.3%	15.1%	14.9%	14.8%	14.7%	14.6%	14.6%	14.5%	14.4%	14.4%
Actuator	6.9%	6.9%	7.0%	7.2%	7.2%	7.4%	7.6%	7.8%	8.0%	8.1%	8.2%
Module assembly (incl. substrates, others...)	30.9%	26.3%	27.0%	24.4%	24.4%	26.6%	26.4%	26.7%	26.8%	26.9%	27.0%
TOTAL	100.0%										

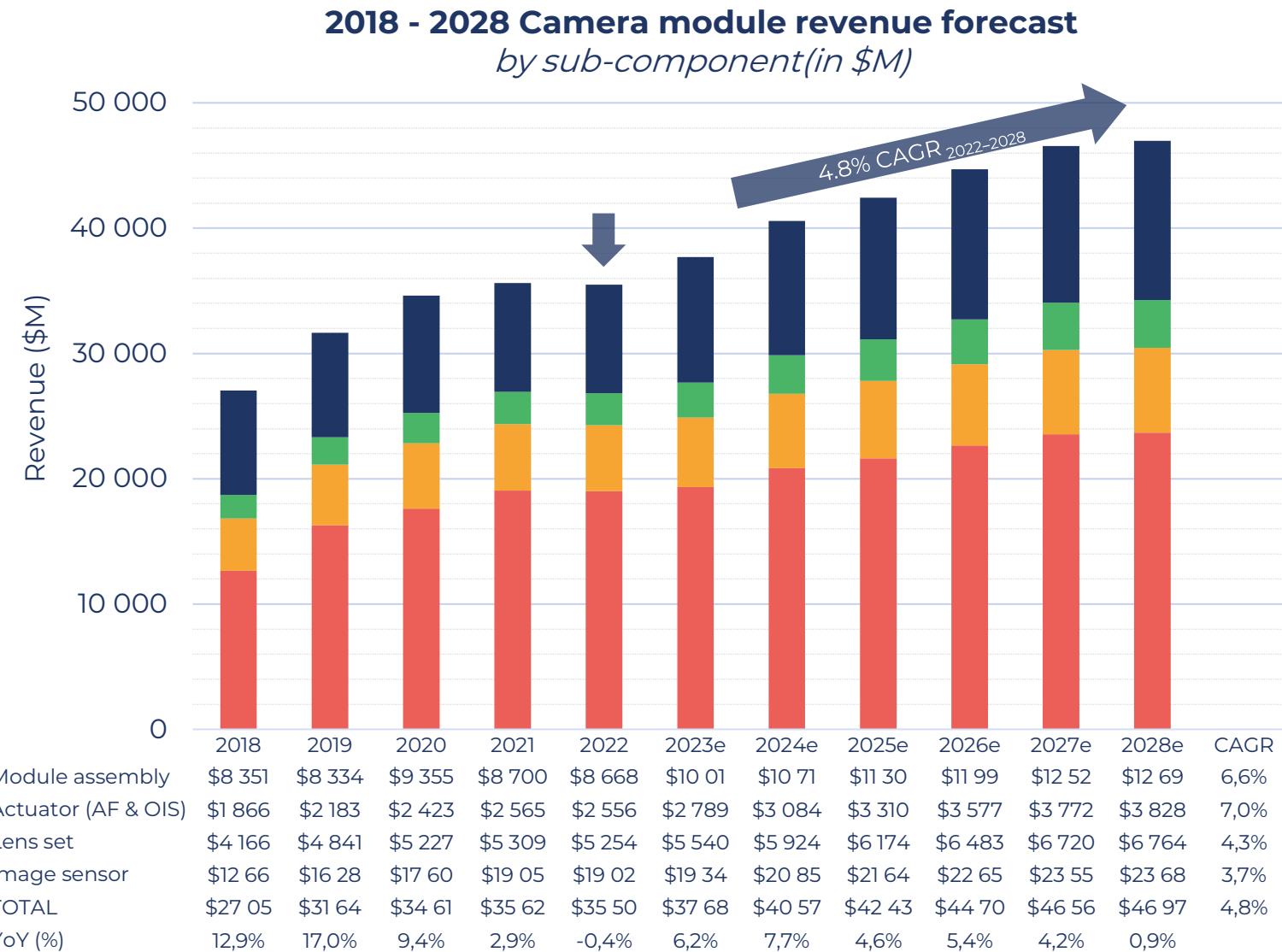
- After being on a decreasing trend, the module assembly contribution part should start to retake more percentage value from 2023 as modules are becoming more complex, diversification and, new sensing cameras are rising, and larger formats are coming to Mobile.
- At the same time, the contribution of both CIS and optics will slightly decrease. Indeed, the CIS Silicon-related share has increased these past few years with resolution and average imaging sensor size rising.
- As new technologies are adopted, AF & OIS penetration will also demonstrate an increased value share, spreading into more Camera Modules in the Mobile & Consumer market.



CAMERA MODULE REVENUE FORECAST 2018-2028

by sub-component (in \$M)

- Overall image sensors and optics will grow at a slightly slower pace than actuating and module assembly contributions. The trend to replace some plastic lenses with glass ones in Mobile should remain limited, and some efforts are being conducted to simplify the optics module.
- With larger format image sensors in Mobile, AF/OIS actuator feature is developing at different levels, whether it is material - such as VCM or SMA - or the implementation method - such as lens shift, sensor-shift, module shift, or other more advanced technology. Both can enable AF/OIS to increase its penetration in the market further and increase CCM revenue.
- Module assembly could still benefit from the diversity of cameras, from imaging to sensing applications, and from the growing share of higher-value Automotive applications in the camera module assembly.





CAMERA MODULE MARKET FORECAST

Key takeaways

- The CMOS compact camera module industry continued to grow until 2021 thanks to the massive volume of mobile phones, booming new energy vehicle adoption, and the temporary high demand for PC & tablet devices. Then, revenue decreased slightly to \$35.5B in 2022. The CCM market should resume growth in 2023, with a progressively slowing growth year-over-year rate from 2024, and we expect a 4.8% CAGR over the 2022-2028 period. The natural decline expected for computing product shipments (tablets, laptops..) is confirmed. All the other market segments are promised to grow at different rates.
- In 2022, the camera module market generated \$35.5B in revenue, Mobile and Consumer applications representing nearly 96% of the shipments with more than 6.3B units: Mobile only accounted for more than 5.1B units, Computing cameras (tablets, laptops, optical mice) for nearly 1B units and about 0.2B units camera modules have been shipped for “other consumer” applications (drones, consumer robotics, home security cameras, etc.). Automotive represented 3% of the total shipments, with 218M camera modules for viewing, ADAS and emerging in-cabin or exterior access applications. This resulted in 6.6B units shipped, a -5.4% decline in 2022 vs. 2021.
- 3D imaging and sensing camera module solutions accounted for 12% of the total CCM market in 2022, and are expected to increase to 14% by 2028.
- Over the 2022-2028 period, CCM shipments should increase from 6.6B units to 8.2B units, with the corresponding CAGR adjusted from 6.5% to 3.6% versus our last-year forecast. Beyond mobile, which will still drive CIS volumes, computing, automotive, and other consumer products camera modules are also sustaining the growing trend. Indeed, our long-term prediction has been reviewed downwards significantly: smartphone sales are expected to reach 1.2B units instead of 1.4B units, and the deceleration in the increase of the average number of cameras per smartphone will limit the primary source of growth for CCM volumes (by about -1.5B units).
- In the mobile market high-end photography is transitioning to larger resolution and size image sensors with higher ASP. The Automotive CCM price surged further in 2022, as a soft-landing situation from the previous shortage and supply chain issues, and also due to the growing adoption of higher resolution including the 8Mp ADAS solutions. This results for the whole CCM market in a slight average ASP increase at 1.2% CAGR from 2022 to 2028, as the consequence of a slightly increased ASP for Mobile applications that represent most of the volume shipped.
- After being on a decreasing trend, the module assembly contribution part should start to retake more percentage value from 2023 as modules are becoming more complex, diversification and new sensing cameras are rising, and larger formats are coming to Mobile. As new technologies are adopted, AF & OIS penetration will also demonstrate an increased share of the value, being spread into more camera modules in Mobile & Consumer market. Overall image sensors and optics will grow at a slightly slower pace than actuating and module assembly contributions. The trend to replace some plastic lenses by glass ones in Mobile should remain limited, and some efforts are conducted to simplify the optics module. Module assembly could still benefit from the diversity of cameras, from imaging to sensing applications, and from the growing share of higher-value Automotive applications in the camera module assembly.



MARKET TRENDS



Mobile and Consumer



Mobile

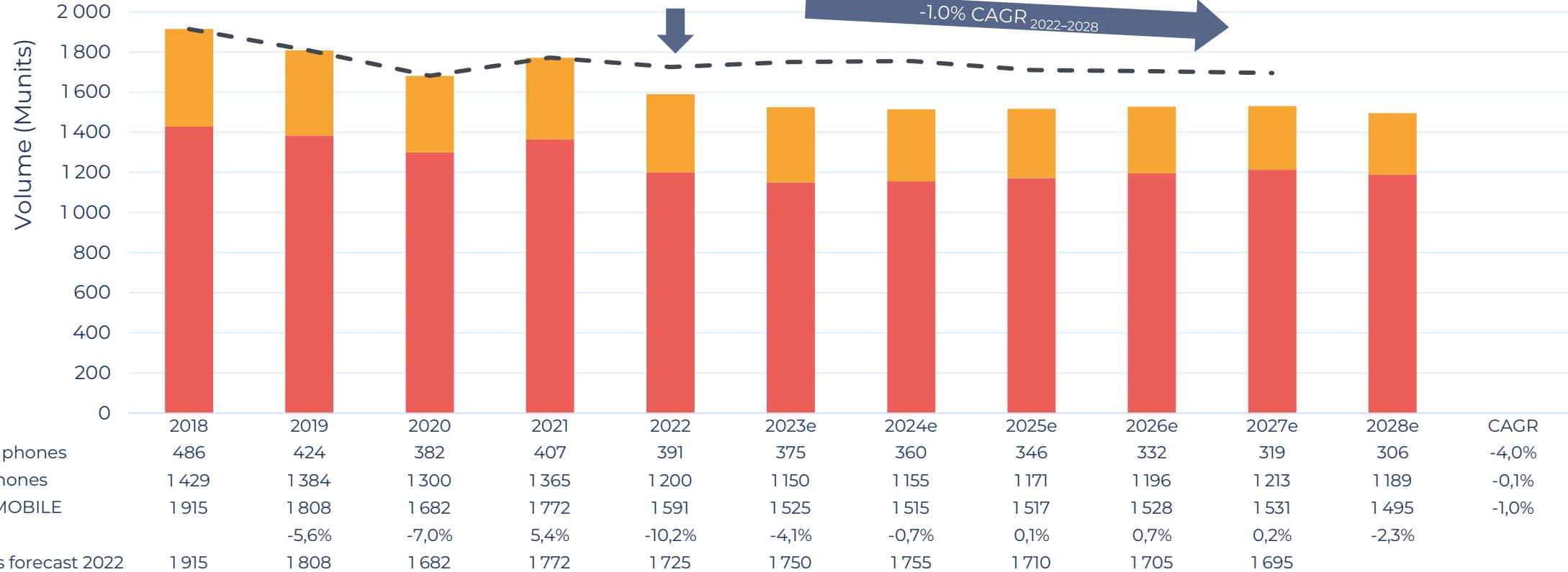
MOBILE MARKET TRENDS

Market dynamics



2018-2028 Smartphone and feature phone total production (in Munits)

YOLE
Intelligence



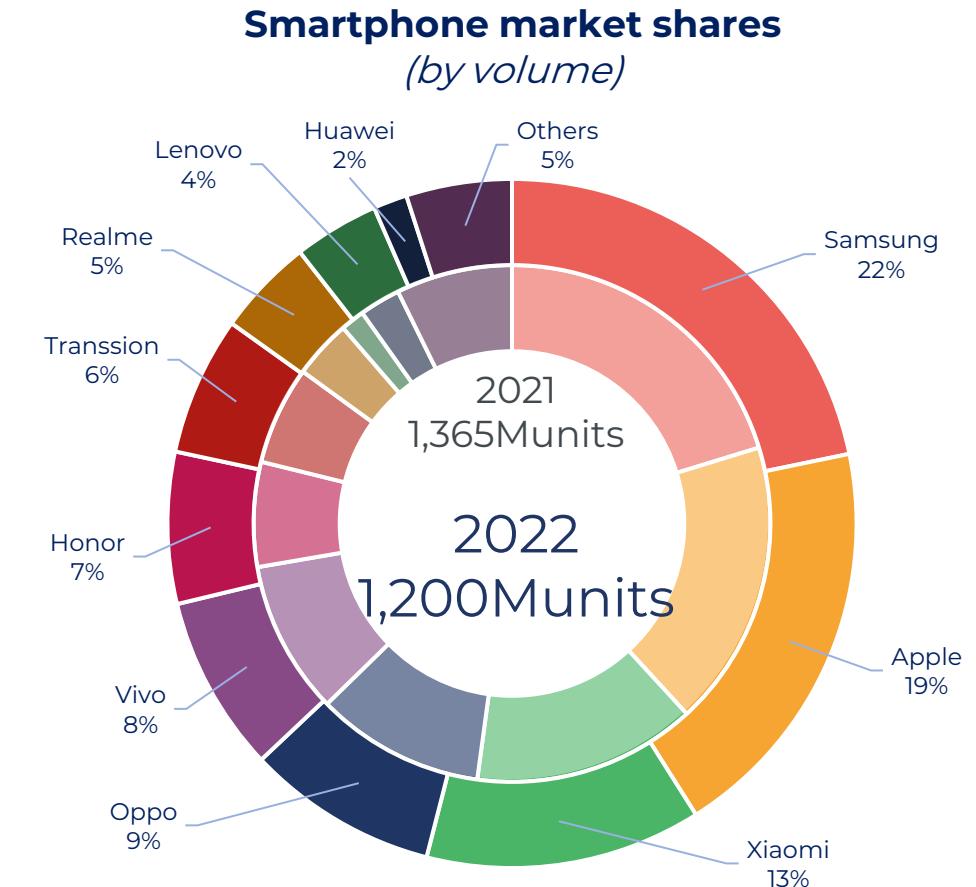
- In 2022, there was a significant drop in the total mobile market, -10.2% YoY. The new trend results in a slightly negative CAGR, -1.2%, for the entire mobile market. The replacement rate is expected to slow down in the coming years, also impacted by the current precarious economic and inflationary climate. In the long term, we expect the smartphone market to be below 1.2Bunits by 2028.



MOBILE MARKET TRENDS

Smartphone market breakdown, by player

- Following the 10% volume decrease in 2022, the TOP 6 smartphone vendor rankings remained unchanged: Samsung, Apple, Xiaomi, Oppo, Vivo, and Honor. Combined, they have more than 78% of the market.
- Despite sanctions, Huawei still sells a significant number of smartphones (about 19 million in 2022).
- Apple and Samsung appear to be consolidating their leading positions.
- As a strong leader, Apple has sustained the mobile 3D sensing market for structured light and dToF array camera modules, while Samsung, Xiaomi, Oppo, Vivo, and Honor are supporting the opportunities for dToF multizone solutions, which could even result in increased penetration of iToF products in the future.

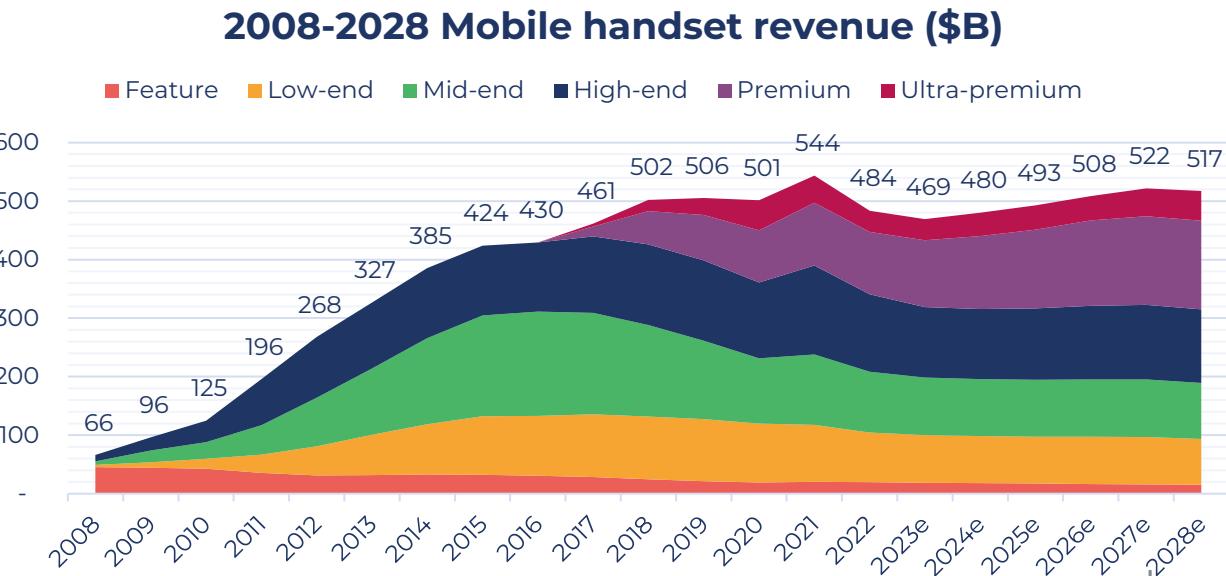
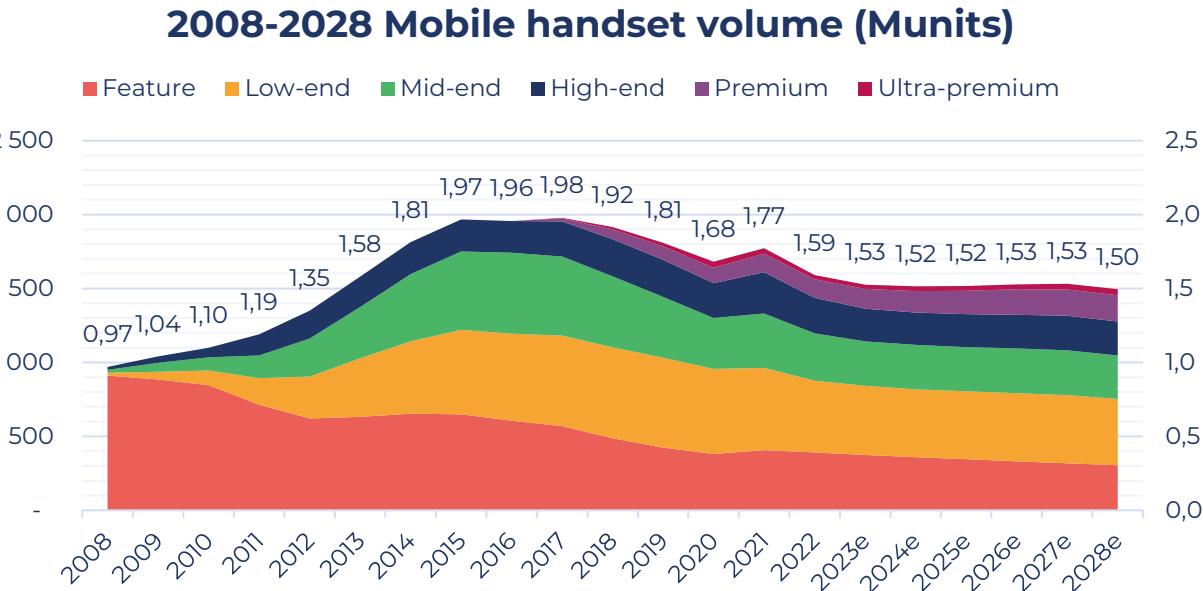




MOBILE MARKET TRENDS

15 years of history in mobile handset volumes and revenues

- The smartphone era started in 2007 with Apple's release of the first iPhone. The volume of mobile handsets doubled from 2007 to 2017, peaking in 2017 after reaching close to 2 billion units shipped that year. It then retreated 20% to ~1.6 billion before the COVID-related rebound of 2021. **This is expected to fall slightly to about 1.5 billion by 2028.**
- The revenue generated grew drastically until 2021. **The expected mobile revenue CAGR over the 2022-2028 period should reach about 1.1%, lower than the expected GDP growth (~3%), with about \$512B in revenues.**
- Global volume and revenues for mobile handsets have been revised downwards from last year. Indeed, the mobile market has matured, and with the current cautious economic context, we expect a slower average replacement rate.





MOBILE MARKET TRENDS

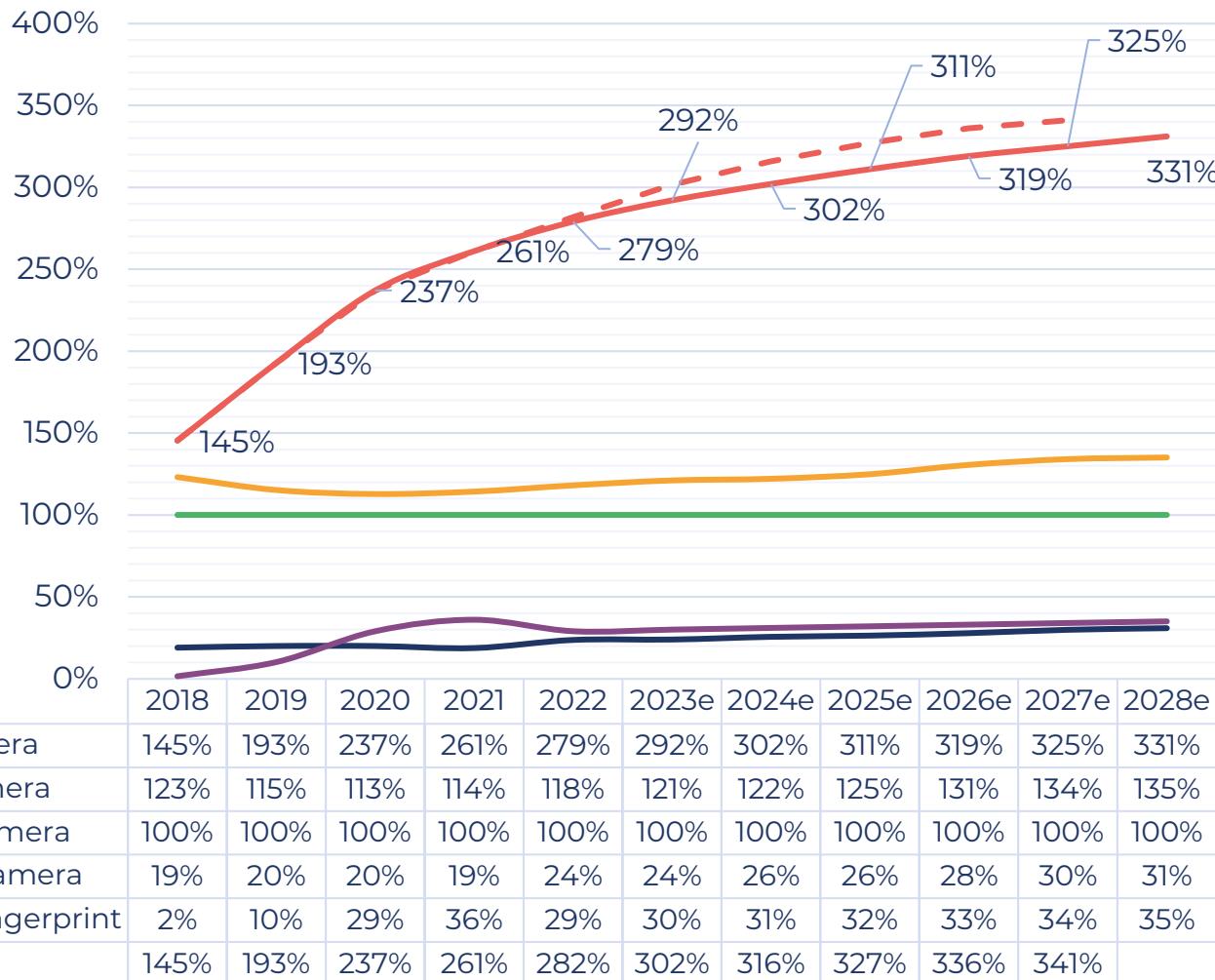
Average number of cameras per mobile handset

- The number of cameras per mobile handset is still increasing, mainly on the rear of smartphones.
- However, we have decreased slightly our previous estimate: the average number of cameras per smartphone was around 3.9 in 2022 and is expected to rise to 4.6 in 2028. Indeed, this increasing trend has also been counterbalanced by further spending efforts of OEMs to develop the quality of the existing main imaging cameras.
- Finally, the trend will be supported by new sensing camera modalities that should rise in the coming years: 3D sensing, event-based imaging, multispectral opportunities...



Nine-camera smartphone proposal, 2018
From: Light

2018 - 2028 average number of cameras per smartphone handset





MOBILE MARKET TRENDS

Camera arrangement type, in %

- Rear multiple-camera approaches have quickly increased to include up to five cameras for some higher-end models, including 3D cameras.
- Dual-camera implementation peaked in 2019. Triple- and quad-camera implementation will dominate the market in the coming years, and the triple configuration might remain the most significant.
- We significantly revised the penetration of the rear penta downwards since last year and slightly the penetration of the quad while increasing that of the rear triple camera configuration to account for the current trend.
- We have observed a deceleration in the expected adoption of quad- or penta-camera smartphone models. For example, the Honor Magic 5 Pro has been released with a rear quad-camera configuration, while the Magic Pro 4 was a penta-camera model. These models include a 3D sensing multizone dToF camera for the autofocus feature.

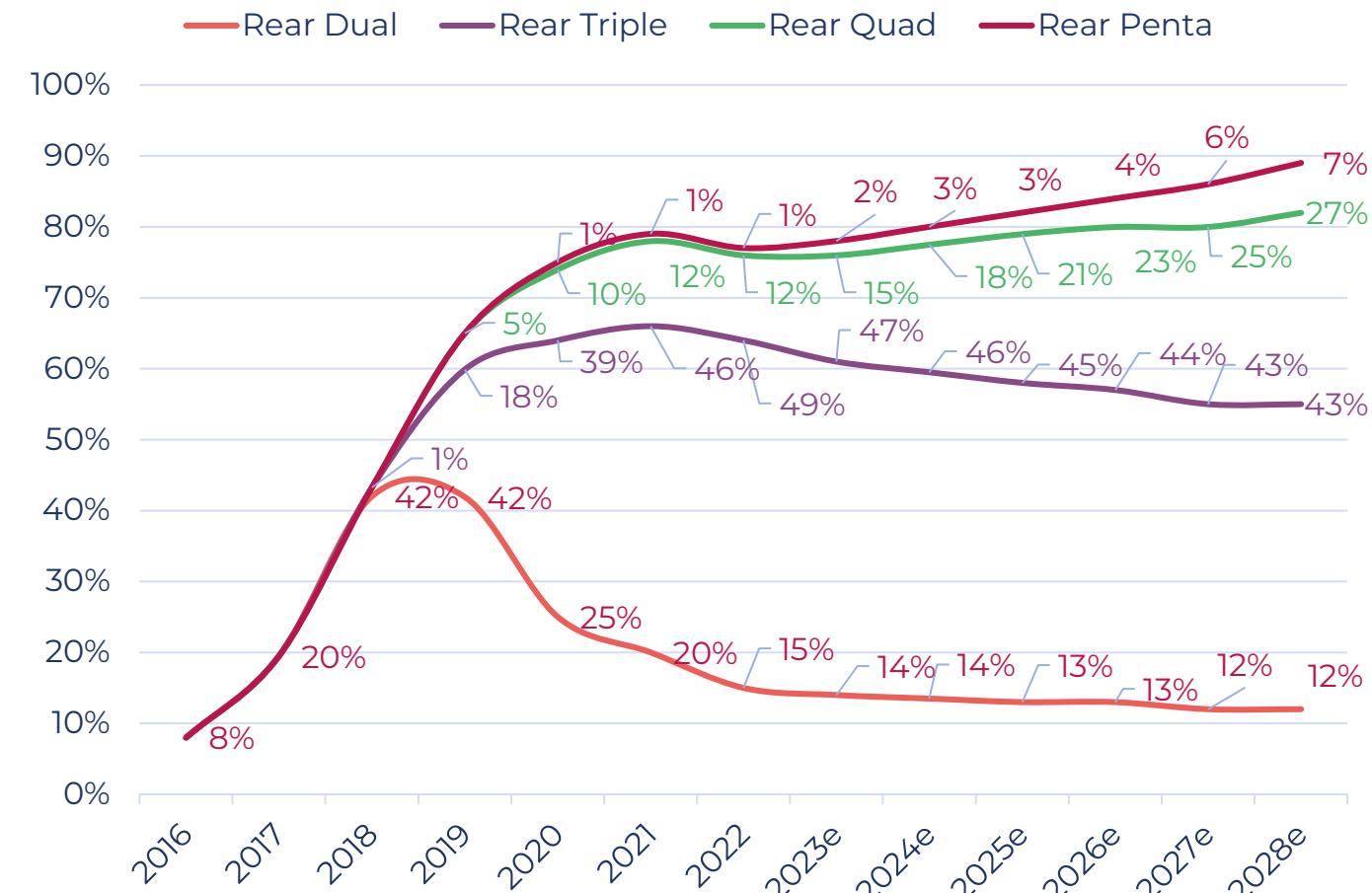


Honor Magic 4 Pro
(Rear penta-camera)

Honor Magic 5 Pro
(Rear quad-camera)

2018 - 2028 Mobile volume breakdown

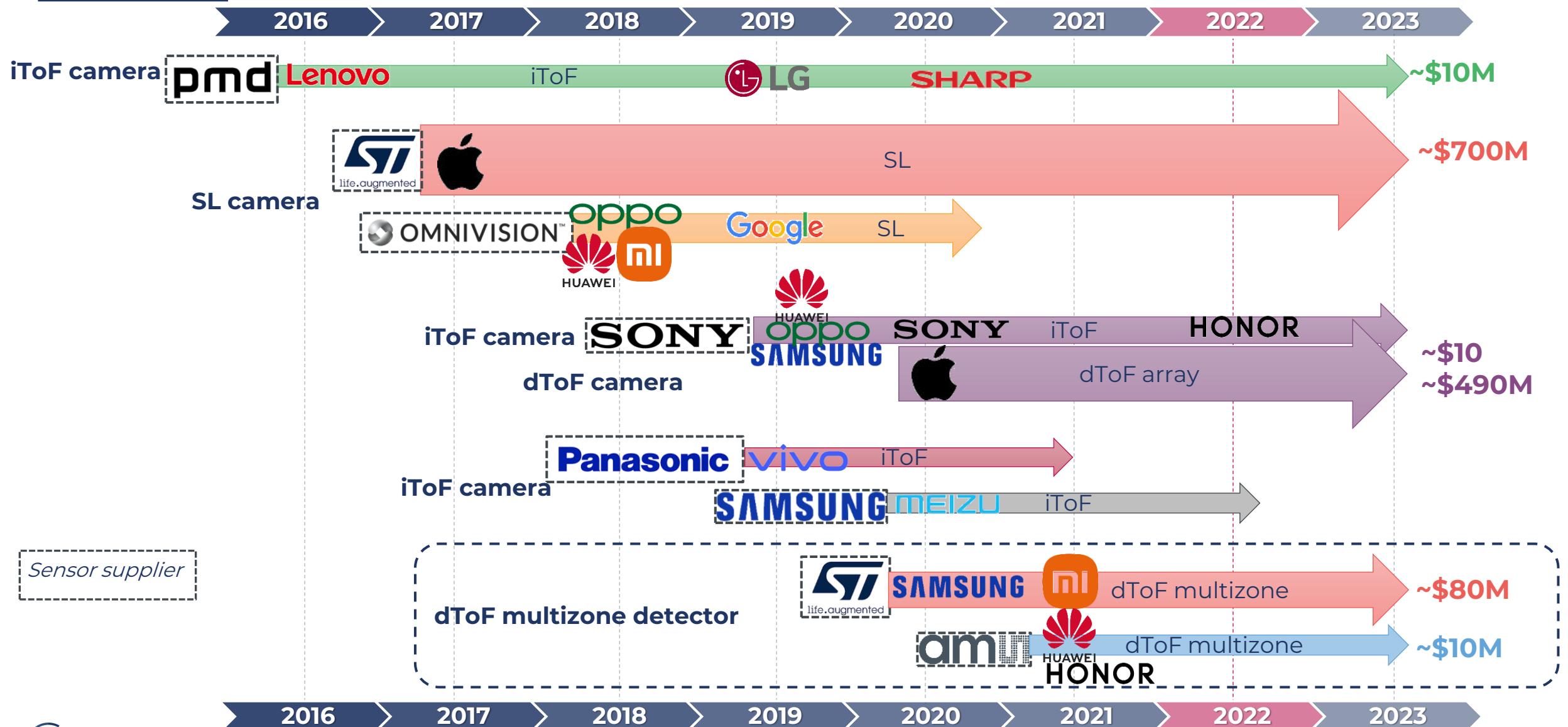
by camera arrangement type (in %)



- Note: the remaining percentage is for the single rear camera configuration, including the feature phone mobile market.

MOBILE MARKET TRENDS

A brief history of 3D sensing design wins at Mobile OEMs – sensor level

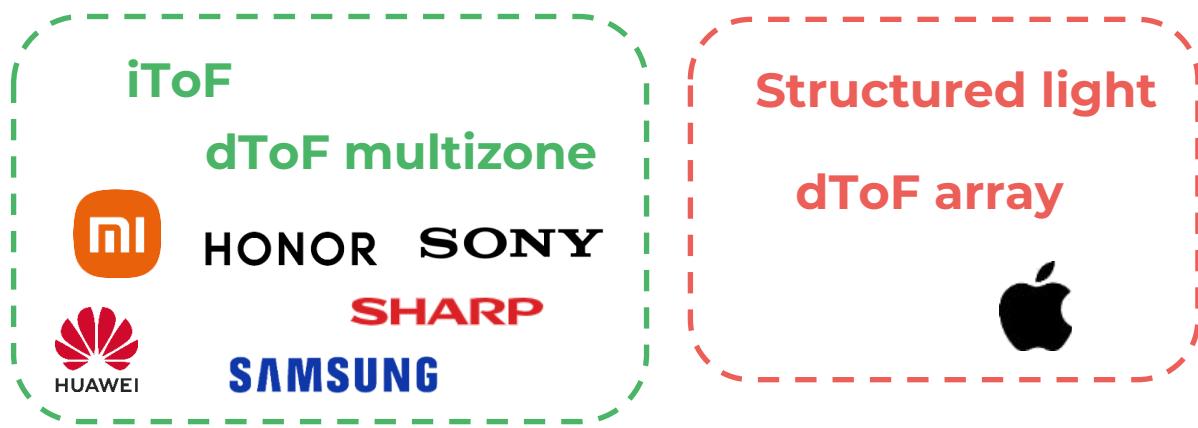




MOBILE MARKET TRENDS

Apple vs. Android 3D sensing adoption history

- In 2019, Android smartphone 3D cameras peaked at 103 million, representing 41% of all 3D sensing devices used in mobile phones, while Apple had the remaining 59%. In 2020, Android adoption started decreasing slightly to more than 43 million in 2022 (despite growing adoption of dToF multizone), about 12% of total 3D sensing devices. **Android players are looking for the right time to come back and are evaluating solutions and technologies.**
- Since 2020, Apple has continued to expand its use of 3D cameras since all of Apple's smartphones, apart from the SE, use the Face ID module. In addition, having previously implemented a rear dToF LiDAR in its iPad Pro, Apple implemented the same module in the iPhone 12 Pro and Max in 2020. In 2021, this module continued to be used in the Pro and Max series, but it could be used by other models in the near future. **Apple actively drives its strategy for 3D sensing.**



2017-2022 3D camera adoption in Apple vs. Android smartphones (in Munits)





MOBILE MARKET TRENDS

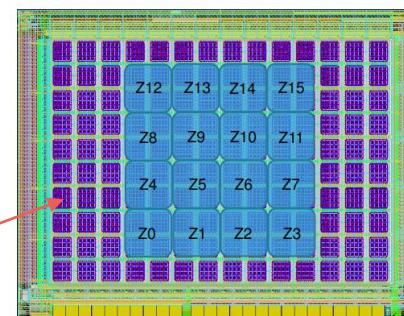
dToF multizone is becoming popular for mobile and consumer applications

- The dToF multizone sensor module, offering typically 4x4 to 8x8 depth zones, is a key device for low-cost 3D sensing in consumer products.
- So far, the main players that have demonstrated commercial products are STMicroelectronics and ams. They supply their own module and sensing component (and also the emitting VCSEL on the part of ams).
- This low-resolution 3D sensing device has the right price point (< \$1 estimated) to penetrate further into Mobile & Computing and Smart IoT applications. More than 102 million have already been shipped for rear 3D sensing for smartphones, considering cumulated volumes since 2020.

STMicroelectronics' VL53L5 Depth Ranger
- Module Tilted View - Optical View
(Source: STMicroelectronics' VL53L5 dToF Laser Autofocus, Yole SystemPlus, 2022)



YOLE
SystemPlus



Example of 4x4 zone configuration
Each zone is an aggregation of macro-pixels with dozens of SPAD pixels
Source: STMicroelectronics



am**pl**



Mobile
photography



Consumer
robotics
navigation

am**pl**

ST



Computing
user detection



Automotive
in-cabin



XR headset
tracking



Drone
navigation

dToF
multizone



Courtesy
of Nokia

> 2020

More 3D sensing cameras

Front camera:

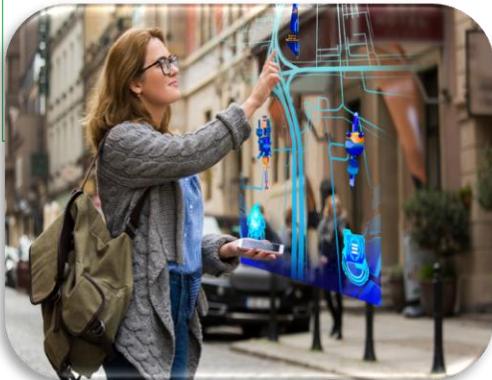
Face identification

Rear camera:

Photography, bokeh effect

Augmented reality

Gaming...



> 2024

+ Event-based camera

Rear camera:

Live deblurring

Slow motion

SLAM...



> 2026

+ Multispectral camera

Front camera:

Face identification

Rear camera:

Skin care, cosmetics

Accurate color photography...



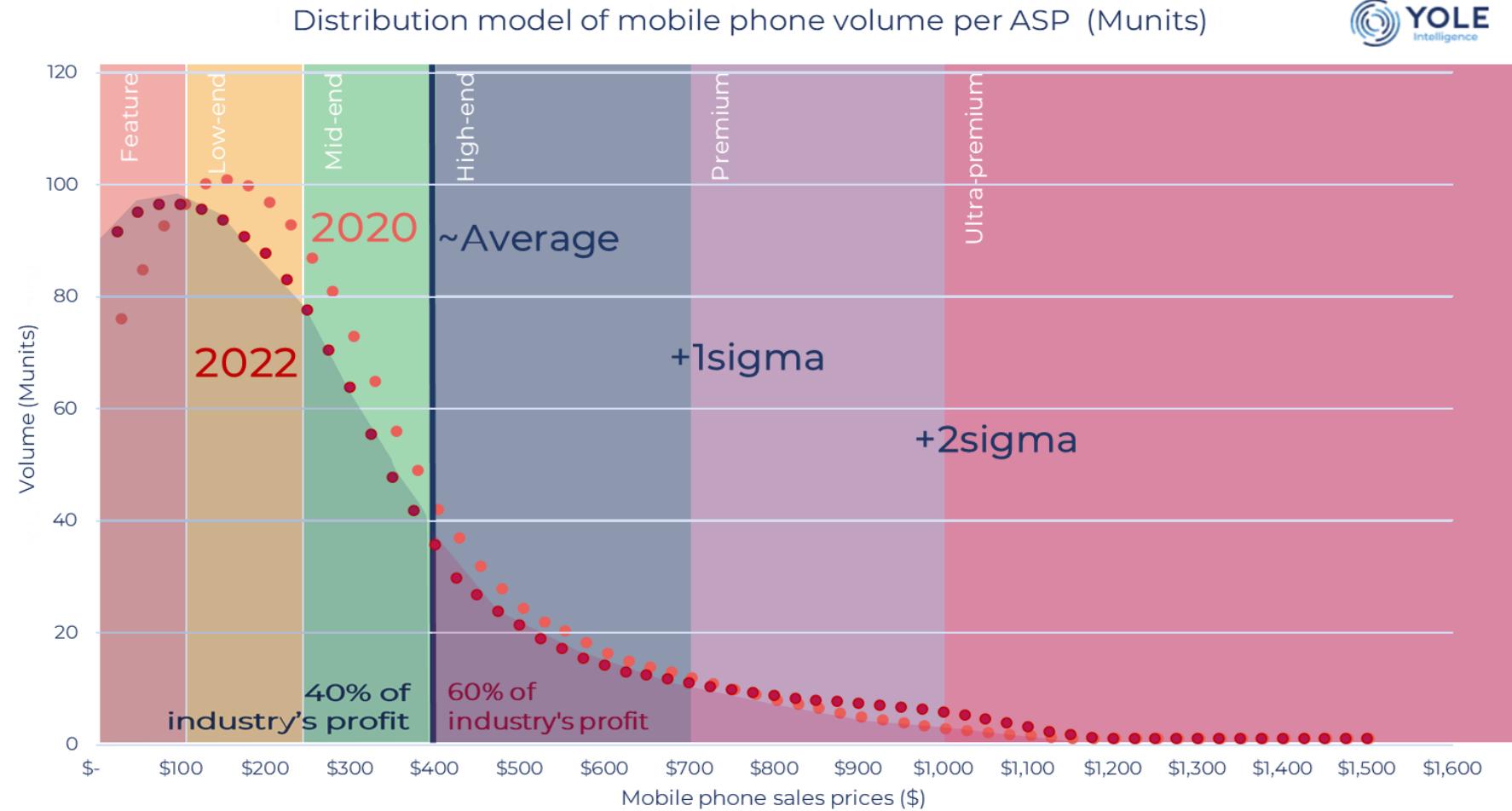
New imaging
and sensing
opportunities?

MOBILE MARKET TRENDS

Mobile phone volume distribution



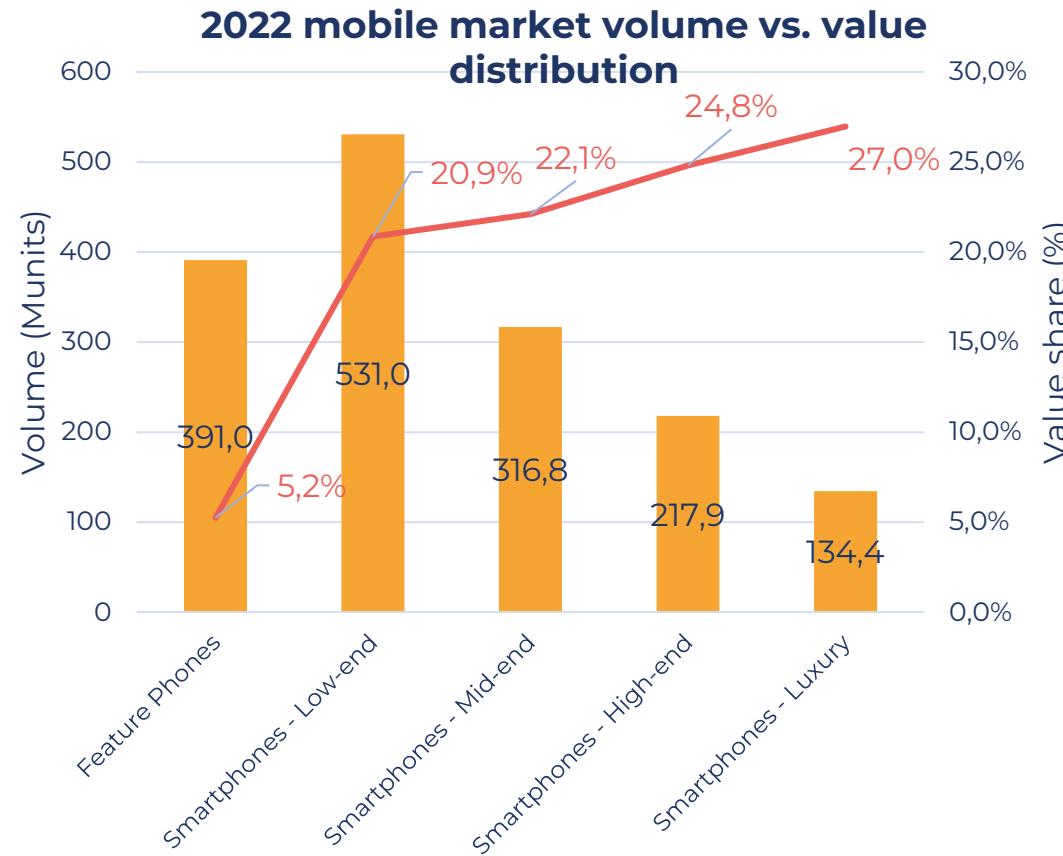
We propose a model for mobile phone volume distribution versus handset selling price.



- Considering the market reality, we have adjusted our distribution model in 2022, adjusting upwards the lower-price feature phone volumes as well as the premium range while adjusting the 'low-end' and 'mid-range' volumes downwards.
- We have updated a mobile phone reference list of more than 60 models, including Samsung, Apple, Huawei, Honor, Xiaomi, Sony, Realme, Oppo, and Vivo, ... and applied this distribution model.

MOBILE MARKET TRENDS

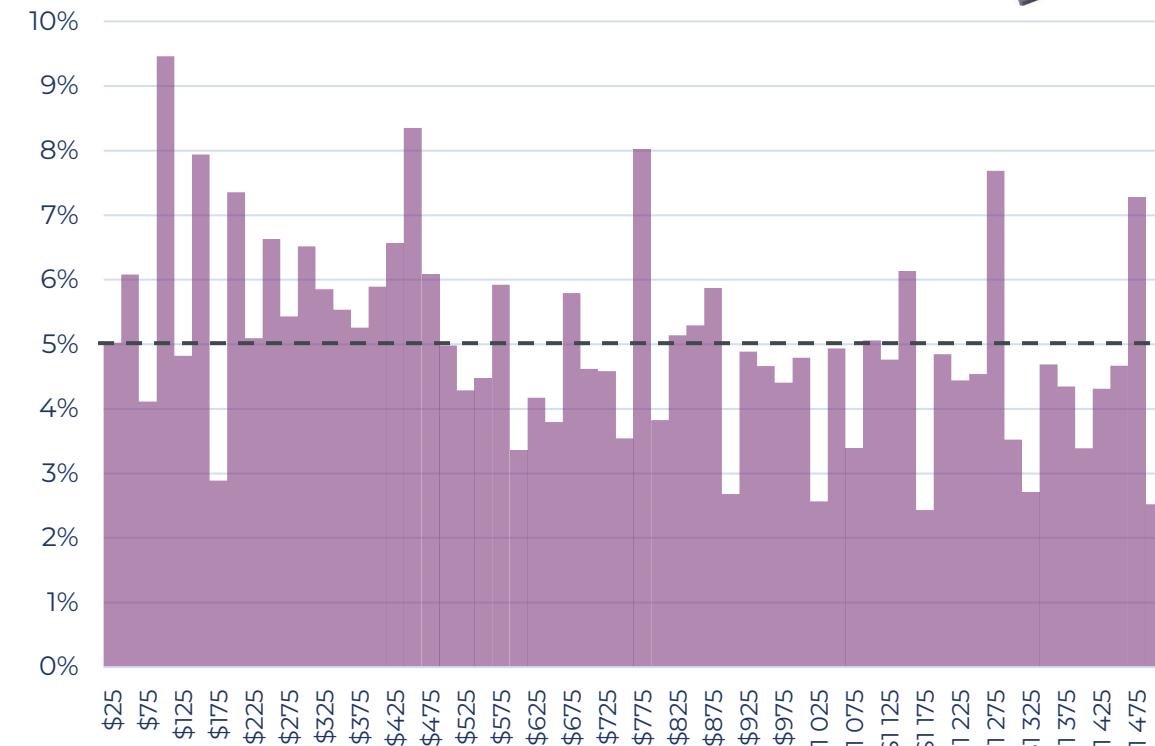
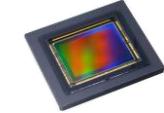
Mobile survey analysis



- The low-end segment (\$100 - \$250) represents the highest volume share at 531M units for 2022.
- The luxury segment (\$700 - \$1,000) represents the highest value share, at 27% of the global \$484B mobile market.



2022 CIS share of the mobile BOM
per phone end-customer price



- CIS spending increases with the end-customer phone price to ~\$30 in the highest segment.
- CIS represents about ~5% of the handset BOM, on average (+/- 2%).

MOBILE MARKET TRENDS

2022 CIS pricing model, by resolution (Mp) and pixel size (µm)



Resolution	Pixel size (µm)												
	0.4	0.5	0.6	0.8	0.9	1	1.1	1.2	1.4	1.6	1.8	1.9	2.0
2Mp	\$0.13	\$0.20	\$0.29	\$0.52	\$0.65	\$0.81	\$0.97	\$1.16	\$1.58	\$2.06	\$2.61	\$2.91	\$3.22
3Mp	\$0.19	\$0.30	\$0.43	\$0.77	\$0.98	\$1.21	\$1.46	\$1.74	\$2.37	\$3.09	\$3.91	\$4.36	\$4.83
5Mp	\$0.29	\$0.45	\$0.65	\$1.16	\$1.47	\$1.81	\$2.19	\$2.61	\$3.55	\$4.64	\$5.87	\$6.54	\$7.25
8Mp	\$0.39	\$0.60	\$0.87	\$1.55	\$1.96	\$2.42	\$2.92	\$3.48	\$4.74	\$6.18	\$7.83	\$8.72	\$9.66
12Mp	\$0.71	\$1.11	\$1.60	\$2.84	\$3.60	\$4.44	\$5.37	\$6.39	\$8.70	\$11.37	\$14.39	\$16.03	\$17.76
16 Mp	\$1.16	\$1.81	\$2.61	\$4.64	\$5.87	\$7.25	\$8.77	\$10.44	\$14.21	\$18.55	\$23.48	\$26.16	\$28.99
20Mp	\$1.51	\$2.36	\$3.39	\$6.03	\$7.63	\$9.42	\$11.40	\$13.57	\$18.47	\$24.12	\$30.53	\$34.01	\$37.69
32Mp	\$2.01	\$3.14	\$4.52	\$8.04	\$10.18	\$12.56	\$15.20	\$18.09	\$24.62	\$32.16	\$40.70	\$45.35	\$50.25
48Mp	\$2.90	\$4.53	\$6.52	\$11.60	\$14.68	\$18.12	\$21.92	\$26.09	\$35.51	\$46.39	\$58.71	\$65.41	\$72.48
64Mp	\$3.76	\$5.87	\$8.46	\$15.03	\$19.03	\$23.49	\$28.42	\$33.82	\$46.04	\$60.13	\$76.11	\$84.80	\$93.96
108Mp	\$4.79	\$7.48	\$10.77	\$19.14	\$24.23	\$29.91	\$36.19	\$43.07	\$58.62	\$76.57	\$96.90	\$107.97	\$119.63

not seen in mobile CIS
R&D / rare
high runner mobile CIS

- There is a diversity of CIS products for mobile with a broad range of resolutions and pixel sizes. For the same pixel size, the price increases linearly with resolution, and for the same resolution, the price increases with the square of the pixel size. This table is a pricing model that fits observed specifications and leading companies' revenues; nevertheless, price variation will occur between vendors. These numbers are only indicative.



MOBILE MARKET TRENDS

Mobile survey analysis: resolution volume breakdown, by player

2022 Mobile camera resolution breakdown
by resolution (in Munits)



- Sony has consolidated its leadership in 12 and 48Mp resolution products. Samsung is still taking advantage of the 64-108Mp range, and Omnivision is getting a significant share of a wide range of product resolutions. Galaxycore is still successful on lower resolution 2-8Mp for Android phones, and STMicroelectronics is the leader for 1.3Mp global shutter products (Apple Face ID).

Computing

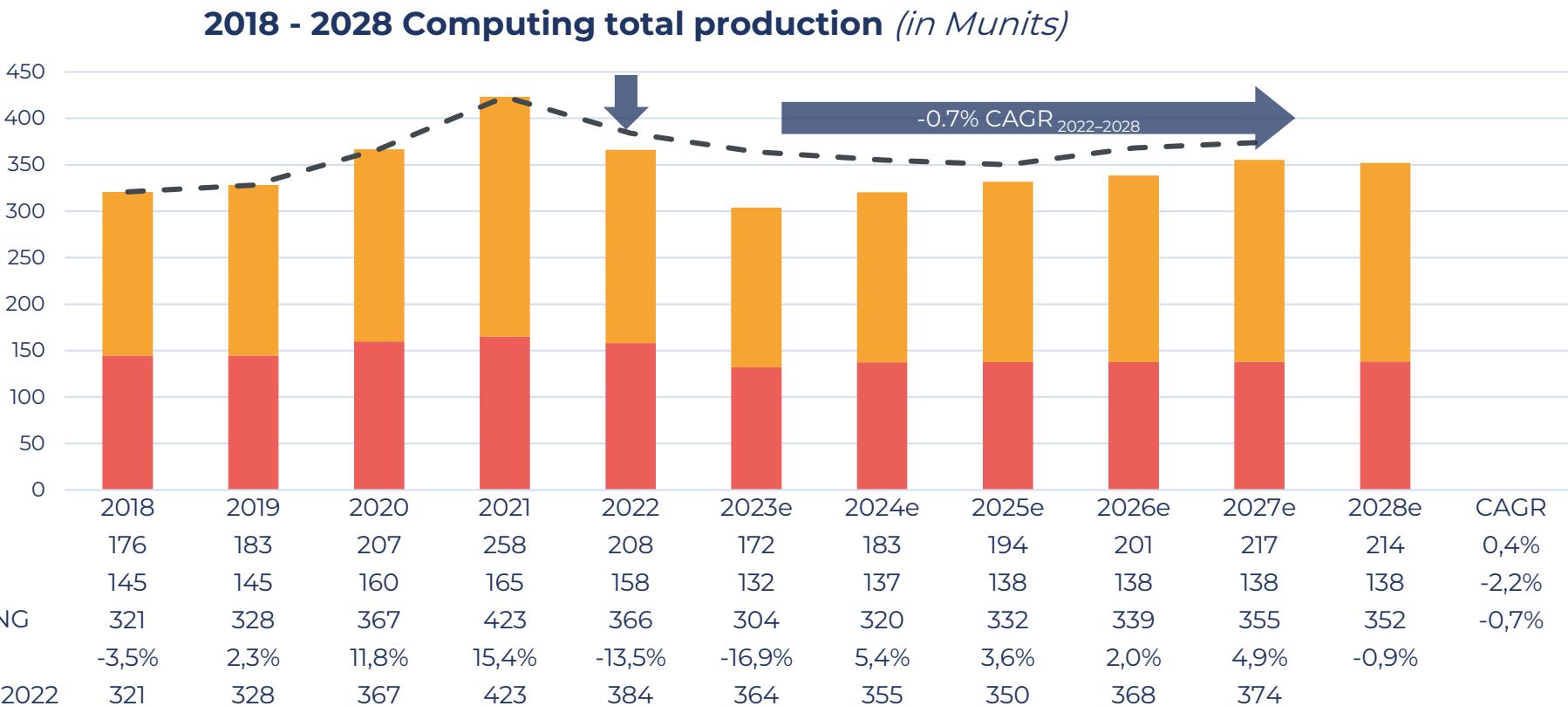


COMPUTING MARKET TRENDS

Market dynamics



Volumes (Munits)



- The computing market suffered from competition with smartphones and was declining until the COVID-19 crisis, which boosted sales in 2020 and 2021 due to lockdowns and stay-at-home policies.
- In 2022, the market decreased, and it is expected to continue falling in 2023 as the COVID-linked bubble is bursting and global inflation is reducing sales of consumer devices. We expect demand to recover slightly in the coming years before reaching its pre-COVID trend around 2028 and then slowly decrease.

COMPUTING MARKET TRENDS

One or two webcams

- Several high-end laptops now integrate a second NIR camera besides the usual webcam. The resolution of both cameras is equivalent.
- This camera can be used for biometrics (unlocking the device using facial recognition) or to enhance webcam performance, especially in low-light conditions.
- In the case of the ThinkPad X13S, the NIR camera can operate in always-on mode for “digital wellness.” The system can track posture and the time spent on the computer.



Few laptops contain a NIR camera, allowing face recognition and image enhancement.

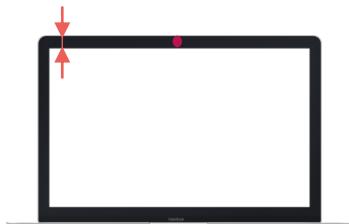


Lenovo ThinkPad X13S

- There is an interest in RGB-IR global shutter CIS for laptops, particularly to support a more compact camera implementation. RGB-IR permits combining imaging with RGB and biometric functions, and the global shutter allows a decrease in VCSEL power. Combining RGB-IR also increases the solution’s compactness, enabling it to fit in a bezel.
- The Z-depth of the laptop screen is no longer changing significantly. The hot topic for laptop manufacturers has become the x & y dimensions of the camera module (thus the CIS) to support the trend of thinner-edge laptop screens.

B	G	R	G	B	G
G	I	R	G	I	R
R	G	B	G	R	G
G	I	R	G	I	R
B	G	R	G	B	G
G	I	R	G	I	R

Example of potential RGB-IR future implementation



Looking for x,y compactness...



COMPUTING MARKET TRENDS

3D sensing proposal for laptop front user detection and identification

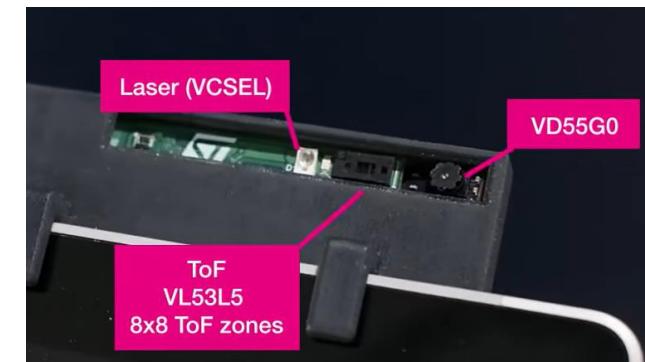
- There is room for further introduction of 3D sensing in laptops, with the example of the Windows Hello application for fast and secure device unlocking.
- As an example, the STMicroelectronics product combines a compact 644 x 604 resolution global shutter with a dToF multizone product to support 3D sensing biometrics:
 - Low power operation: specific architecture and global shutter sensitive to VCSEL short pulse
 - Small format devices to fit in a laptop bezel
 - Enhanced NIR sensitivity
 - Optimized tradeoff on pixel size to optimize sensitivity and field of view
- Extra features could be user detection and laptop unlocking, intruder detection, and gesture recognition.

A new opportunity for small and inexpensive dToF multizone products.

camera system for "Hello Login"



Source: STMicroelectronics, MWC 2022

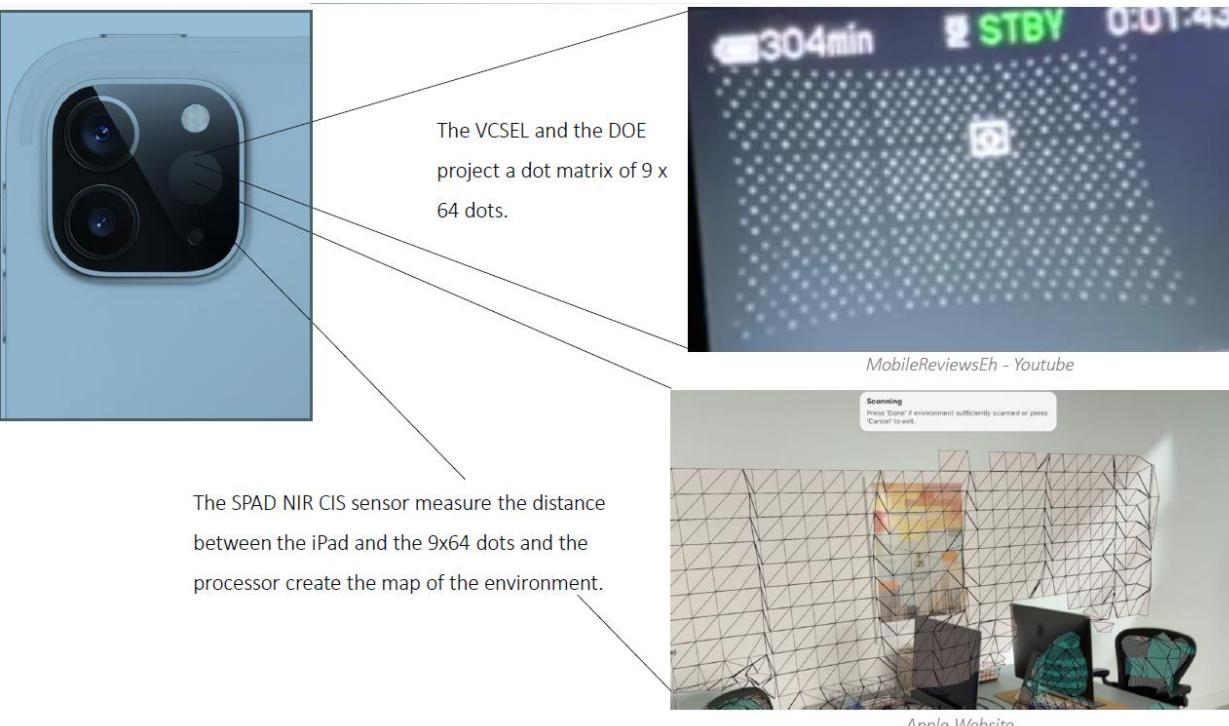




COMPUTING MARKET TRENDS

3D sensing established in tablets...

- Apple brought Face ID to the iPad in 2018 – the first device outside of the iPhone to get a facial recognition feature. In the future, this could be extended to other Apple devices such as the iMac and Apple Watch, the Apple Vision Pro announced for early 2024 will contain the TrueDepth camera also used in Face ID. In general, Face ID on the iPad Pro works a lot like it does on the iPhone.



- iPad's rear ToF LiDAR can get depth information combined with camera data, motion sensors, and computer vision algorithms and perform 3D sensing for AR.

Apple has pushed 3D sensing into its iPad products. What's the next?

COMPUTING MARKET TRENDS

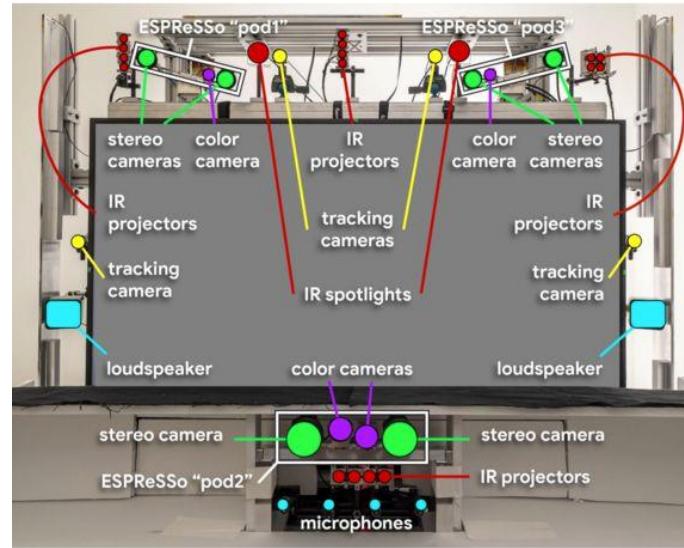
Beyond traditional video calls

- Google recently presented a new prototype linked to their Starline project. This project aims to create a realistic and immersive real-time visual interaction.
- It features many different cameras for 3D data capture, though efforts are being made to improve compactness.



- Event-based imaging could also make true real-time human communication and holographic rendering.
- Enhanced video-calling using eye contact technology is an attractive use-case proposition. This high-end project could lead to a beneficial trend for the PC market.

Looking for immersive and natural remote interactions.



Configuration of Google Starline end of 2022

Most recent prototype of Google Starline (May 2023)





Other consumer



CONSUMER MARKET TRENDS

Market dynamics



2018 - 2028 Consumer photography total production (in Munits)

Volume (Munits)



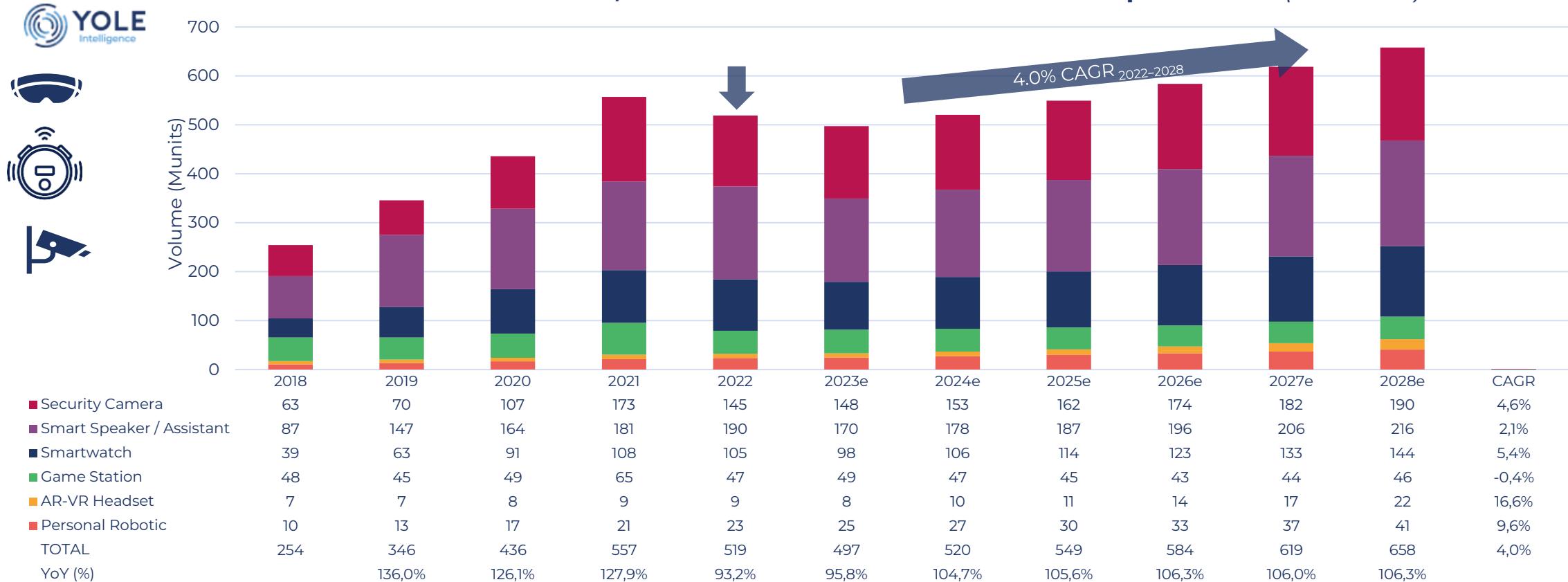
- After a rebound in 2021 in the DSC & DSLR photography market, the consumer photography end systems market should revert to a continuous slight decline in the short term. We are cautious about global drone volume growth since DJI is not a public company.
- The market should stabilize and reach a plateau of around 20 million units shipped in 2026.



CONSUMER MARKET TRENDS

Market dynamics

2018-2028 Consumer smart home, wearables and entertainment total production (in Munits)



- 2022 was lower than expected for smartwatches and game stations. AR-VR and smart home devices (speaker, assistant, etc.) are expected to decline in 2023. The forecast for AR-VR headsets has been slightly reduced as AR use cases are not emerging, and there are delays due to critical technical challenges on the display side. Personal robotics comprises mainly vacuum cleaners and is still one of the most popular consumer products. Home security camera shipments increased dramatically in 2021. We had expected this growth to stabilize in 2022 and 2023. However, it dropped due to supply chain issues. Consumer home security cameras demand should lead to an 4.6% CAGR over the next six years.
- Overall, we expect a 4.0% sustained growth rate in the coming years, with a total volume of 658M units in 2028.



CONSUMER MARKET TRENDS

Consumer drones

Drones use stereo vision for obstacle avoidance. The average number of embedded cameras is tending to increase.



2018 **DJI Mavic 2**



2021 **DJI Air 2s**



2022 **DJI Mavic 3**

	Front:	Stereo	Stereo	Stereo
	Rear:	Stereo	Stereo	Stereo
	Top:	Single ToF (not 3D)	Stereo	Stereo
3D modules	Bottom:	Single ToF	Single ToF	Single ToF
		2	3	4

- Stereo vision is used in drones for obstacle avoidance. Stereo allows longer-range detection in outdoor environments than active 3D sensing. Drones are primarily used in good weather and daytime, so detection processes rarely deal with low light or harsh conditions.
- The ToF ranger is now used for ground detection during landing (1D). ToF is not generally preferred over stereo because the primary use is outdoors, and ToF has a limited sensing range. However, it may be used for indoor drones in the future.
- DJI started the increasing trend in 2017 with the DJI Mavic, quickly followed by other players such as Skydio. For example, the DJI Mavic 3 contains 10 CIS, eight stereo-vision sensors in four different directions, and two RGB cameras: one wide-angle 20MP and one 12MP telephoto.
 - Stereo camera able to detect over longer distances: >20m
 - ToF detection distance: <10m
 - FoV: Stereo > ToF

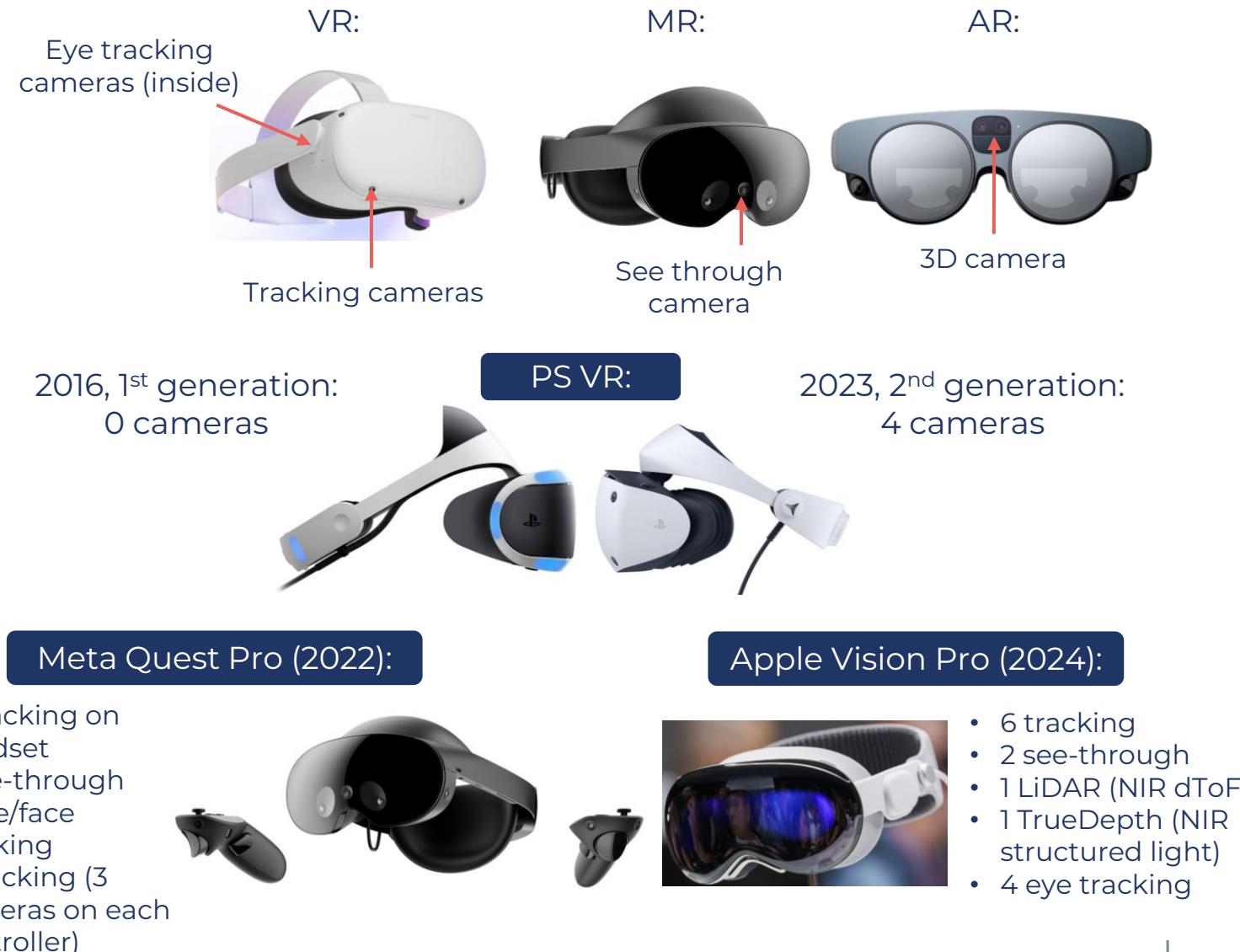
10 cameras,
10 CIS



CONSUMER MARKET TRENDS

More and more image sensors in headsets

- Cameras in XR headsets are used for various functionalities.
 - Tracking cameras (hand, head tracking, gesture recognition, SLAM...)
 - Eye tracking cameras
 - See-through cameras (for mixed reality)
 - 3D cameras (for creative content and augmented reality)
- The average number of tracking cameras per headset is increasing. This is the case with the second generation of PS VR (2nd in terms of volumes), which now has four cameras.
- Recent high-end MR and AR headset models feature more cameras with more advanced functionalities, like 3D and eye tracking.



CONSUMER MARKET TRENDS

Sensor requirements for VR, MR, and AR cameras

- Image sensors used in headsets need to have low power consumption and a very small footprint for more flexibility in system design.
- Tracking (external or internal) cameras usually require enhanced NIR sensitivity and global shutter architecture.
- See-through cameras require higher resolution as well as color capability to ensure high-quality outside-world reconstruction.
- 3D cameras can be used for more advanced augmented reality and creative content applications using ToF or structured light.
- In the near future, headsets will need to be operational in outdoor environments and the camera will need to handle bright light and low light. SWIR, event-based and other ToF and even multispectral imagers can help these devices to become more popular.

Present:

ams-OSRAM Mira220 Mira050

Ams-OSRAM released 2 products with high compactness and low power for the headset market (tracking or see-through).

New products

Omnivision OG0TB

Omnivision introduced a three-layer architecture to satisfy compactness, power and SNR requirements of tracking cameras.

Future:

Laser beam scanning system for long range 3D imaging

VoxelSensors

Multispectral sensor: catching hidden properties of the world

ST life.augmented

Quantum dots SWIR imager

SWIR tracking camera ensures efficient sensing in bright sunlight as well as night conditions.

CONSUMER MARKET TRENDS

Vacuum cleaner robots: from random navigation to 3D sensing (1/2)

- In 2001 and 2002, early cleaning robot models – such as the Electrolux Trilobite and the iRobot Roomba – were released. They used ultrasound, infrared, or bump sensors for **random navigation** and cleaning. Many models have followed the same approach, still used today in lower-end models, with some efficiency but slow and unable to deal with complex obstacles and objects.
- Two main technology branches emerged in 2010 to make these robots smarter and run on straighter lines and not randomly:
 - One of the significant innovations was the introduction of the **laser distance sensor (LDS)** in 2010 with the Neato XV-11 model. This is a low-cost “2D LiDAR” system in the form of a spinning turret. It can perform a 2D map of the room, collecting 2D information at the low robot height level for smarter navigation and cleaning.
 - LDS brings higher accuracy and faster navigation. However, these models do not have a camera for imaging features, so 3D sensing has been introduced since 2019 with imaging camera-based technologies, such as stereo, structured light, and active stereo, that allow better obstacle detection at short and mid ranges.
 - With its Navibot, Samsung introduced in 2010 the use of a monocular camera on the top of the robot to perform **visual SLAM**. However, no models followed until the introduction in 2014 of the Dyson 360Eye. The camera is pointed at the ceiling and uses surrounding landmarks to map the environment with embedded algorithms.
 - Visual SLAM might be slower and less accurate and can underperform in low-light conditions. Hence, in 2020, 3D sensing was introduced at the front, for example, using an iToF sensor as in some Xiaomi models.



Example of an LDS turret

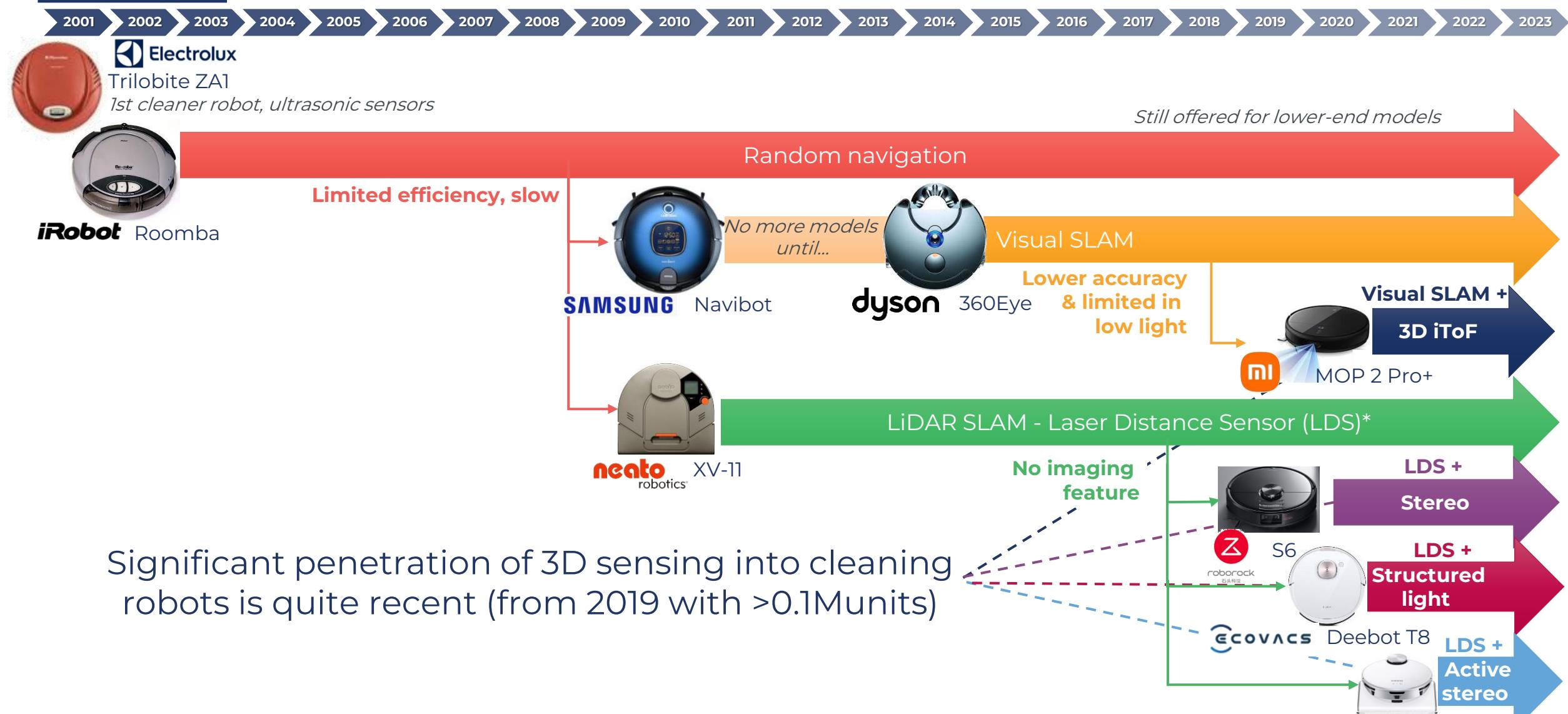


*Example of Visual SLAM
From: iRobot*



CONSUMER MARKET TRENDS

Vacuum cleaner robots: from random navigation to 3D sensing (2/2)





CONSUMER MARKET TRENDS

Smart home devices: smart assistants

Amazon Echo Show 10



amazon echo

Alibaba Tmall Genie CC



TMALL 天猫

Meta Portal Go/Portal+



Meta

Google Nest Hub 2/Max



Nest

Lenovo Smart Display10



Lenovo™

Baidu Xiaodu T10



Baidu 百度
Xiaodu

JBL Link View Smart Display



JBL

Xiaomi Mi Smart Clock + Mi 350° security cam



mi

Smart-assistant market video models are proliferating.



CONSUMER MARKET TRENDS

Smartwatch with camera

Children's smartwatches are alternatives to smartphones, increasingly equipped with a camera.



Children's smartwatches are alternatives to smartphones, but with limited internet surfing capability, and are popular with parents. The main functions are voice and video calls, though video calls require a camera.

In China, BBK and Mitu have been leaders in this market, with over 60% of their smartwatches equipped with cameras.

Note: Due to privacy and security concerns, the European Commission has issued a recall order for smartwatches aimed at children.

Adult smartwatches are useful for video calling (and other features), so some have adopted cameras.



SPIKY
born stylish

Spiky Griffin
With dual cameras





CONSUMER MARKET TRENDS

Different security applications: consumer, commercial, and infrastructure cameras

CONSUMER CAMERAS

- Smart homes:
 - Doorbells
 - Smart door locks
 - Outdoor cameras
 - Indoor cameras, babycams...



Compact camera module market focus

COMMERCIAL CAMERAS

- Smart retail:
 - Store surveillance
 - Autonomous checkout
 - Payments
 - Abnormal behavior detection...
- Smart buildings:
 - People counting
 - Access control
 - Fire detection
 - Parking monitoring...



INFRASTRUCTURE CAMERAS

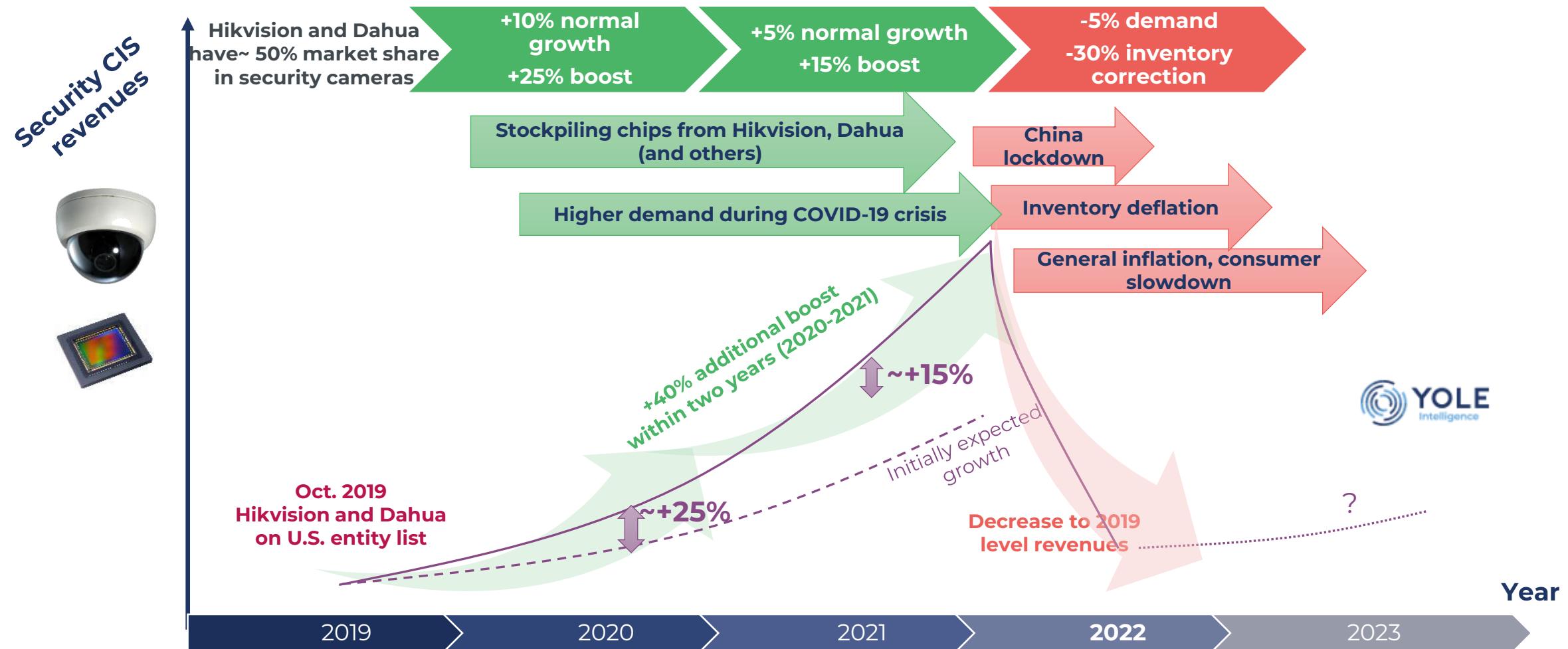
- Smart city:
 - City surveillance
 - Traffic monitoring
 - Public transportation...
- Long-range surveillance:
 - Border control
 - Defense
 - Environment monitoring...





CONSUMER MARKET TRENDS

The security cameras bubble deflated in 2022



- Following the excessive orders of the past years and the weakening of the demand in the consumer field, we estimate security CIS revenues have returned to the 2019 level and should restart growth in 2023.



CONSUMER MARKET TRENDS

Typical price ranges for security cameras

	Sensing & processing	+ Video analytics Detection	+ AI Recognition
SENSING PART: CIS	\$0.3 to \$1.6	\$1.6 to \$8	\$8 to \$100
PROCESSING/COMPUTING PART: ISP & vision processing unit (VPU)	\$1.5 to \$5	\$5 to \$8	\$8 to \$25
CAMERA TOTAL PRICE	\$30 to \$80	\$80 to \$500	\$500 to >\$2000
EXAMPLE	 <i>Blink SPTC210981</i> \$60	 <i>Dahua N45EJ62</i> \$350	 <i>Bosch NDM-7703-A</i> (multi-sensor panoramic) \$1700



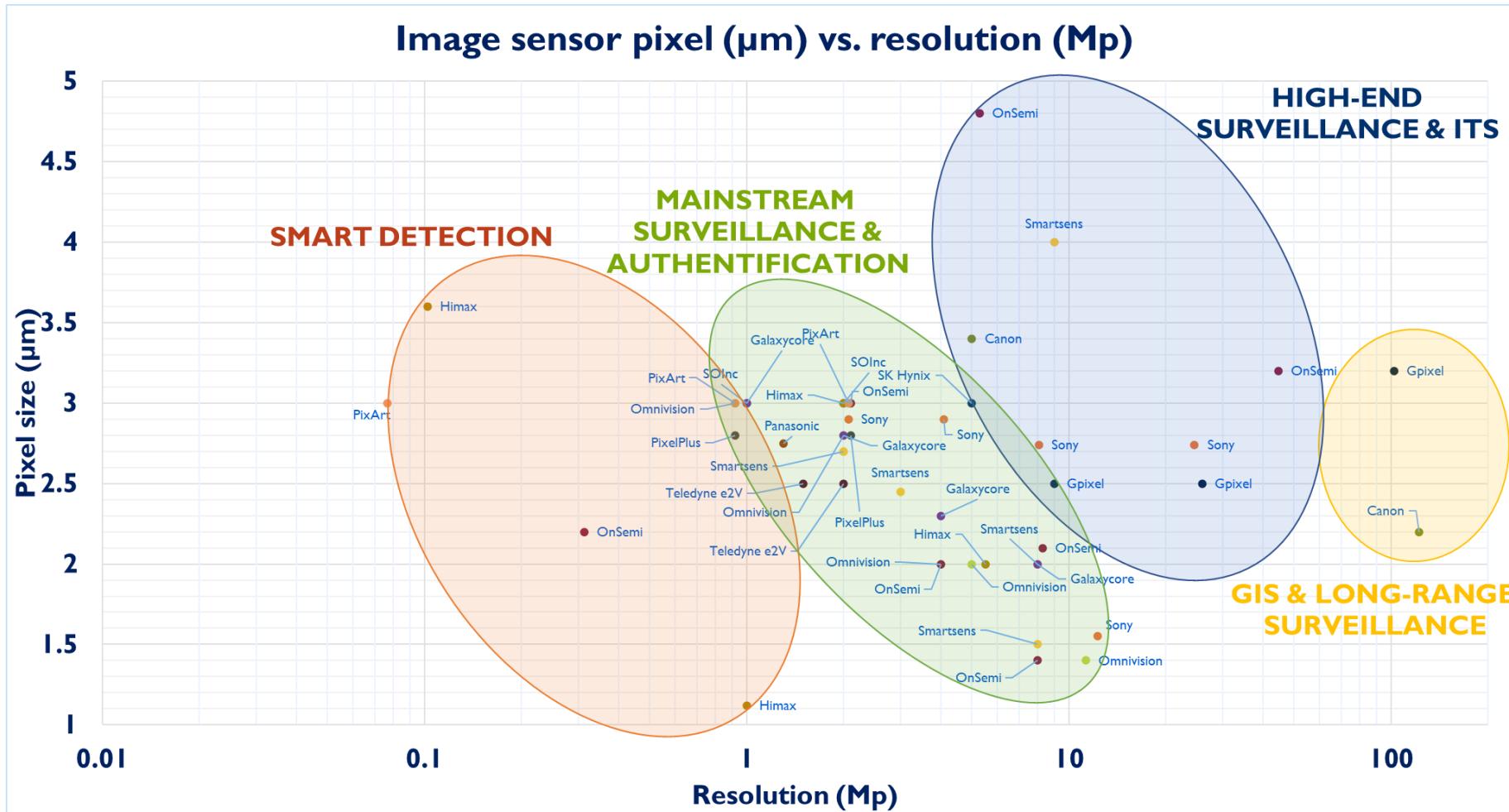
- The CIS value is a very significant percentage of the camera value, especially for high-resolution and multi-sensor cameras at the higher end. Advanced AI computing capabilities' ASP is estimated at \$25.



CONSUMER MARKET TRENDS

Resolution and pixel size domains: the example of security applications

From the mainstream surveillance that represents most CIS shipments, some applications exist in lower and higher-resolution domains:





Automotive

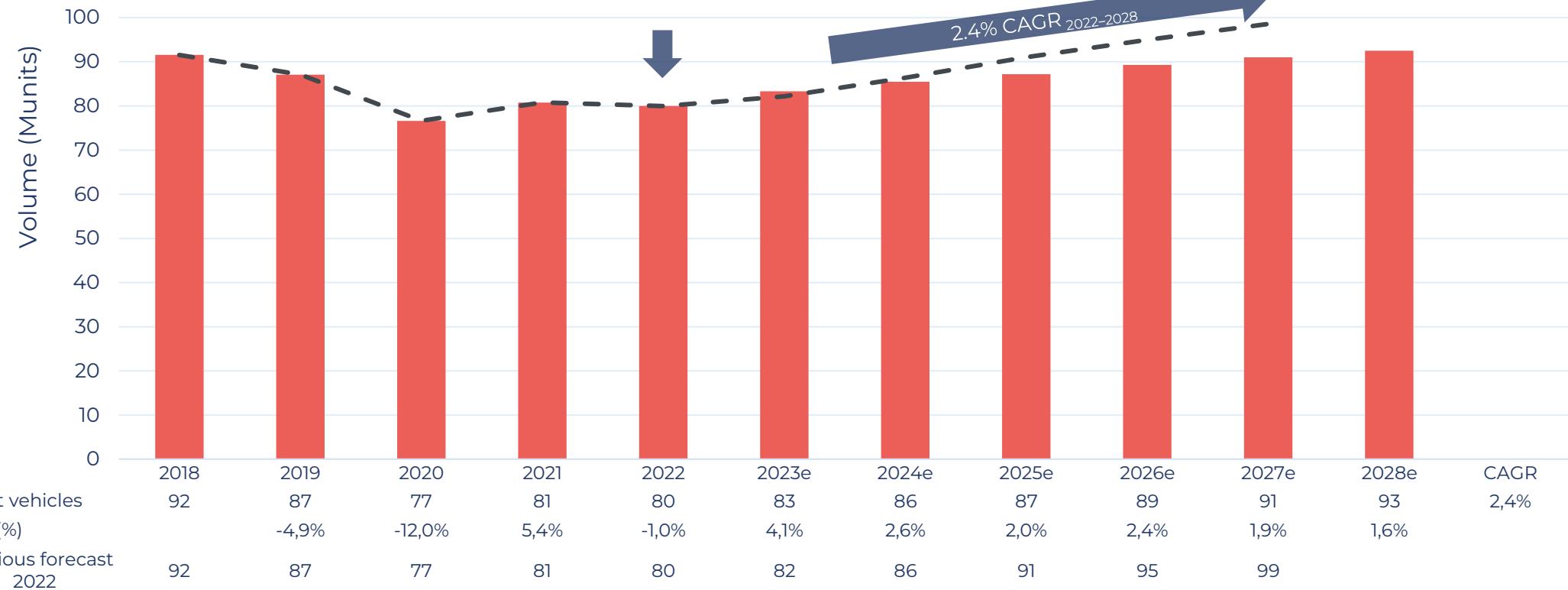


AUTOMOTIVE MARKET TRENDS

Market dynamics



2018-2028 Light vehicles total production (in Munits)

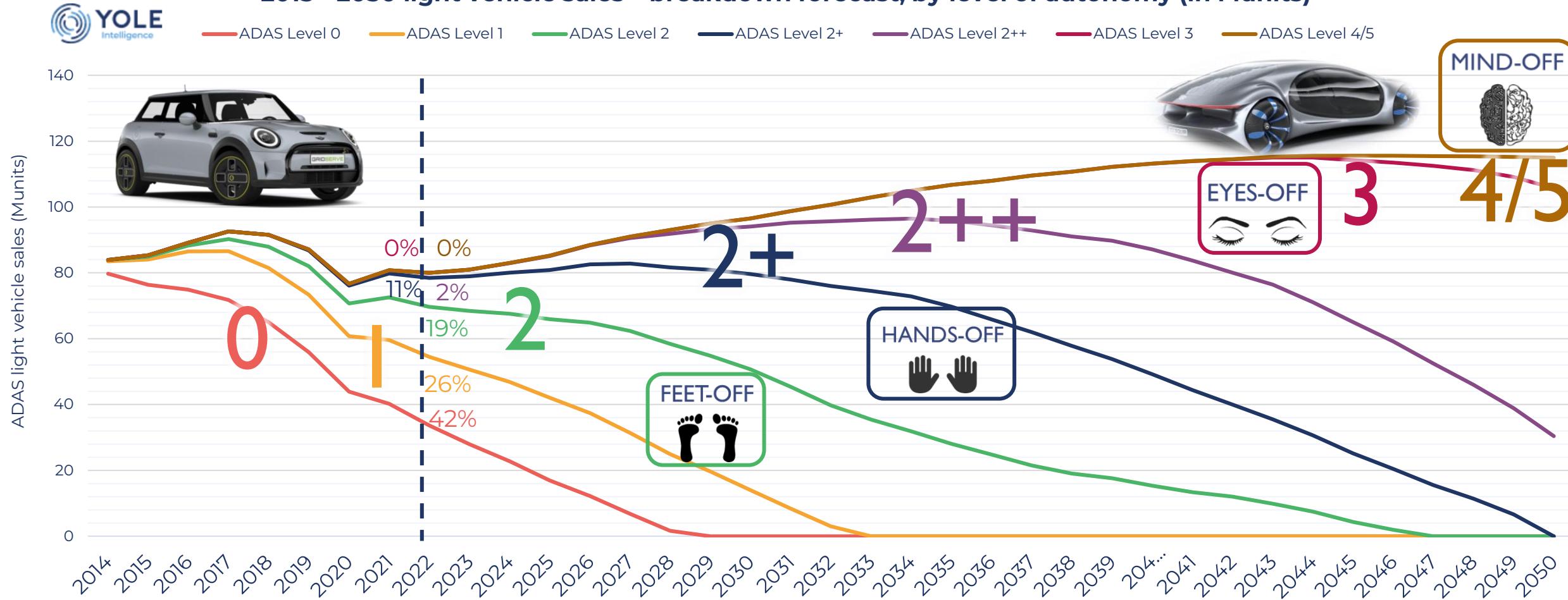


- Light vehicle shipments have recovered since 2020 and the COVID-19 crisis and are now slowly increasing at a CAGR of 2.4%, tracking the global GDP growth.



©Yole Intelligence – February 2023

2015 - 2050 light vehicle sales – breakdown forecast, by level of autonomy (in Munits)



Level 3-4 Removing the driver's responsibility and eyes from the road will take more years than initially expected.



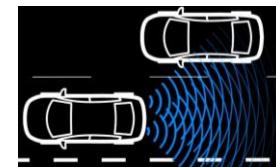
ADAS and safety

ADAS

Pedestrian detection/avoidance



Automatic emergency braking



Blind spot detection



Lane departure warning/correction

System
Camera / 3D LiDAR / Thermal camera

Surround View



e-mirror



360° surround



Rear view

Infotainment and telematics

In-cabin



Occupant monitoring system



Dash recorder



Face authentication



Driver monitoring system



Gesture recognition



Exterior Access (emerging)

User Authentication



Smart doors opening

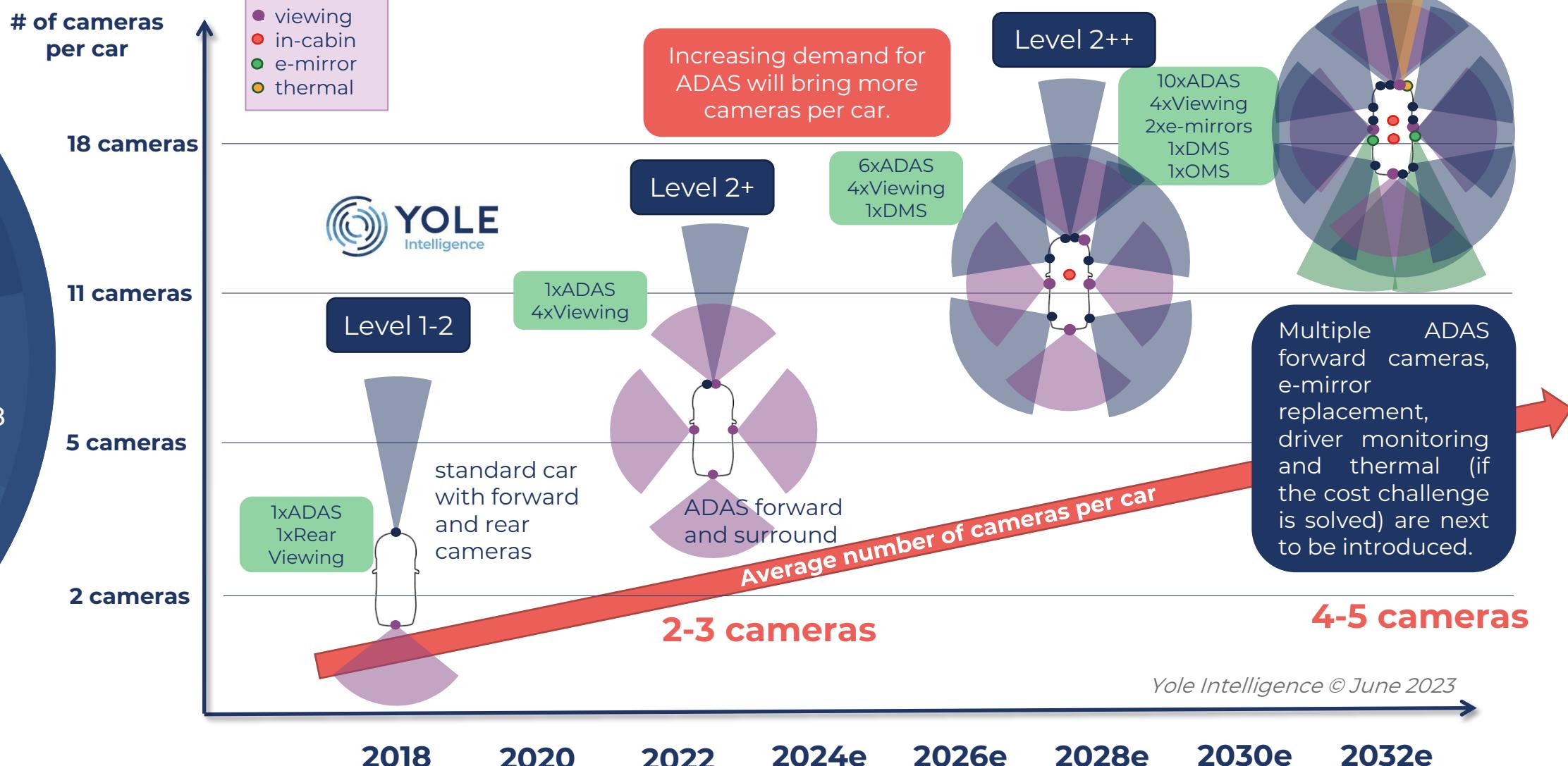
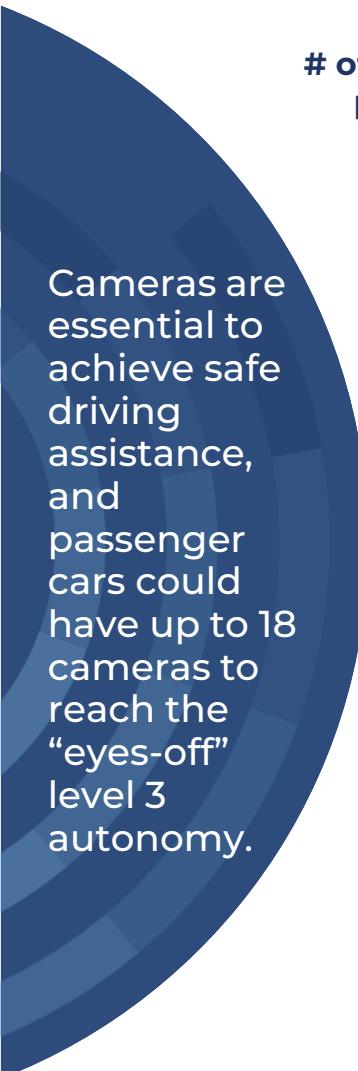


3D camera



AUTOMOTIVE MARKET TRENDS

An increasing number of cameras per car

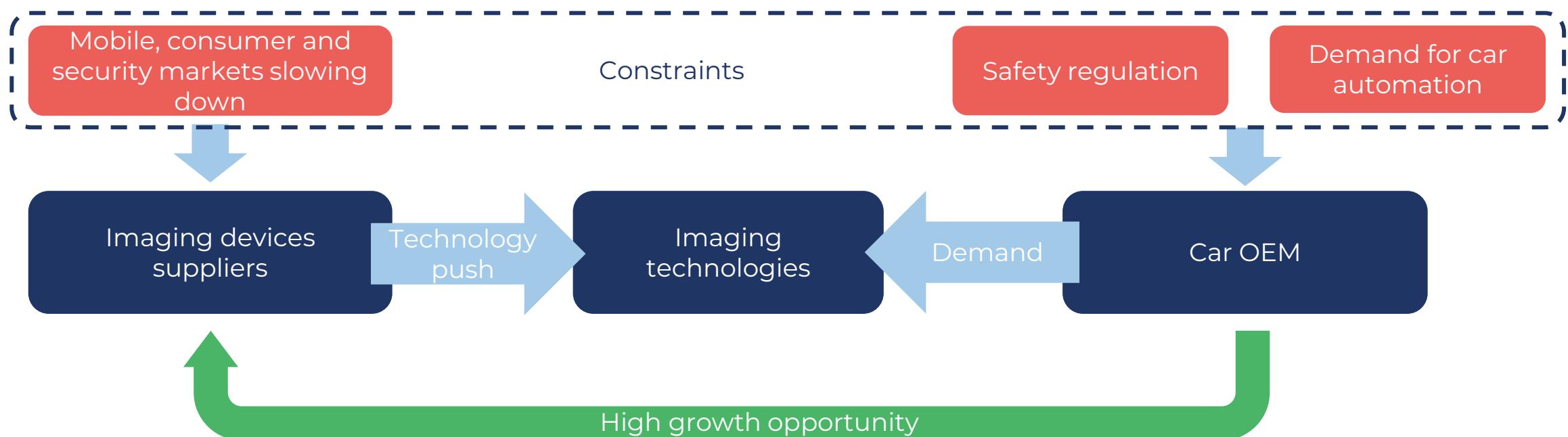




AUTOMOTIVE MARKET TRENDS

Automotive as the new gold rush for the imaging industry ecosystem

- Automotive looks promising for the imaging industry in the coming years.
- On the one hand, safety regulation and increasing demand for car automation encourage and even force car OEMs to integrate more and more imaging technologies.
- On the other hand, imaging leaders such as CIS and CCM suppliers are experiencing a slowdown in the biggest market segments like mobile and consumer. Automotive being a volume-driving market, they are now promoting imaging technologies for this segment.
- Automotive is now a segment with one of the biggest growth potentials for the imaging industry.



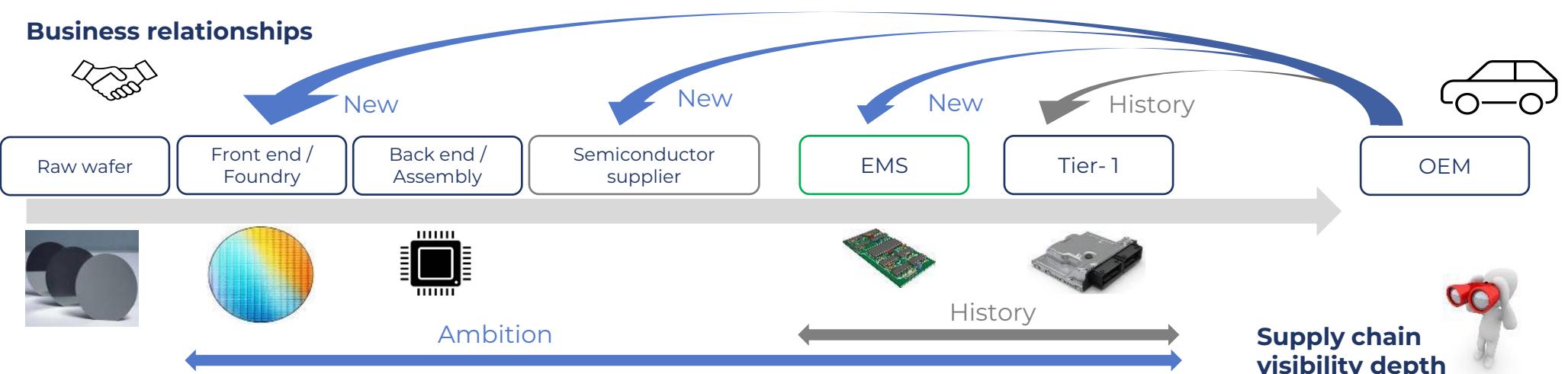


AUTOMOTIVE MARKET TRENDS

New interactions within the automotive supply chain

- Historically, car manufacturers have established strong business relationships mainly with Tier-1 suppliers (Continental, Bosch, Aptiv,...). This is, however, being challenged for many reasons:
 - The boom in electronic content in vehicles and the vehicle's value shift to electronics and services.
 - The emergence of new car makers and new ways of designing and managing the supply chain.
 - The need for car manufacturers to better understand and control their upstream electronic supply chain.
- Nowadays, car manufacturers are becoming involved at different levels of the supply chain – for instance, with electronic manufacturing suppliers (EMS), semiconductor players for processing, power electronics, and foundry services.
- Processors are very specific and are typically only available from a few suppliers. This means that to ensure supply, automotive OEMs are developing solid links with processing players.

Restructuring the relationship between automotive OEMs and players upstream in the automotive semiconductor supply chain.





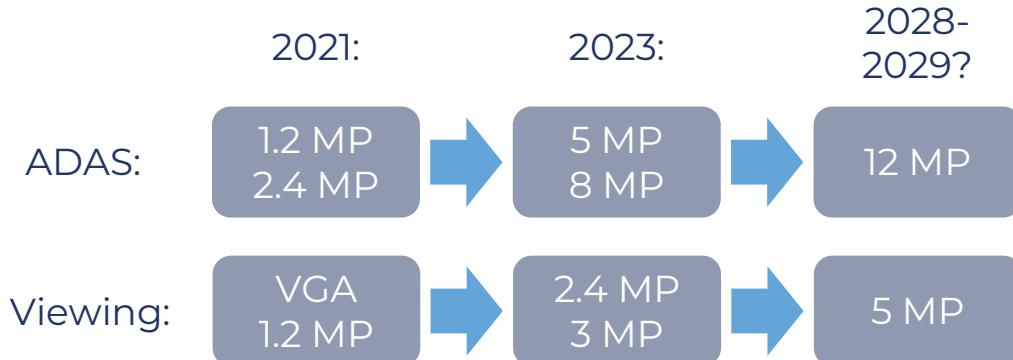
AUTOMOTIVE MARKET TRENDS

Increasing value of automotive image sensors

In ADAS, the product mix is moving toward higher resolution sensors (8MP) and a higher dynamic range.

DMS is evolving towards RGB-NIR and 3D sensing.

ADAS & Viewing:

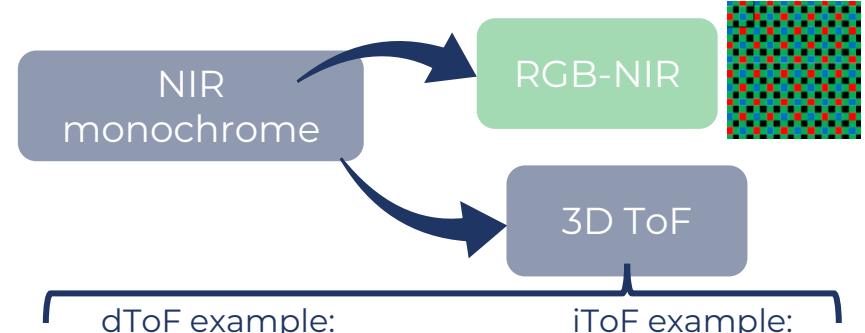


- ADAS cameras require higher resolution to recognize more objects at a longer distance and get more detailed scenes.
- Increasing the display screen dimension in vehicles requires higher-resolution viewing cameras.
- ADAS cameras are also evolving toward higher dynamic ranges.



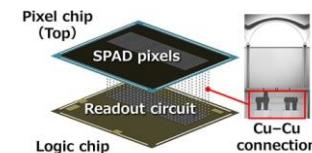
New Onsemi Hyperlux product with 150dB dynamics

DMS/OMS:



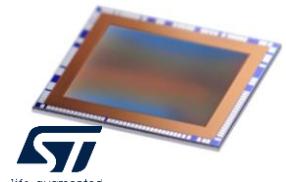
dToF example:

SONY



IMX459 dToF SPAD depth sensor 168(V) x 597(H)

iToF example:



VD55H1 iToF 0.54MP

- Most DMS systems are now based on NIR monochrome imagers. RGB-NIR implementation is expected to dominate the market in the near future, providing more complete information.
- The 3D feature is also of interest to DMS and OMS. In 3D, iToF is expected to be the mainstream technology, while Sony advertises its dToF SPAD sensor for such applications.



AUTOMOTIVE MARKET TRENDS

Comparison of cameras for different applications

For more details: see our report
Imaging for Automotive 2023



Higher resolution and HDR are the trends for automotive ADAS cameras, while a high field of view is essential for viewing cameras.

Rear & surround view cameras



ADAS forward cameras



ADAS side and rear cameras



DMS/OMS cameras



Thermal cameras



Not in this report's scope

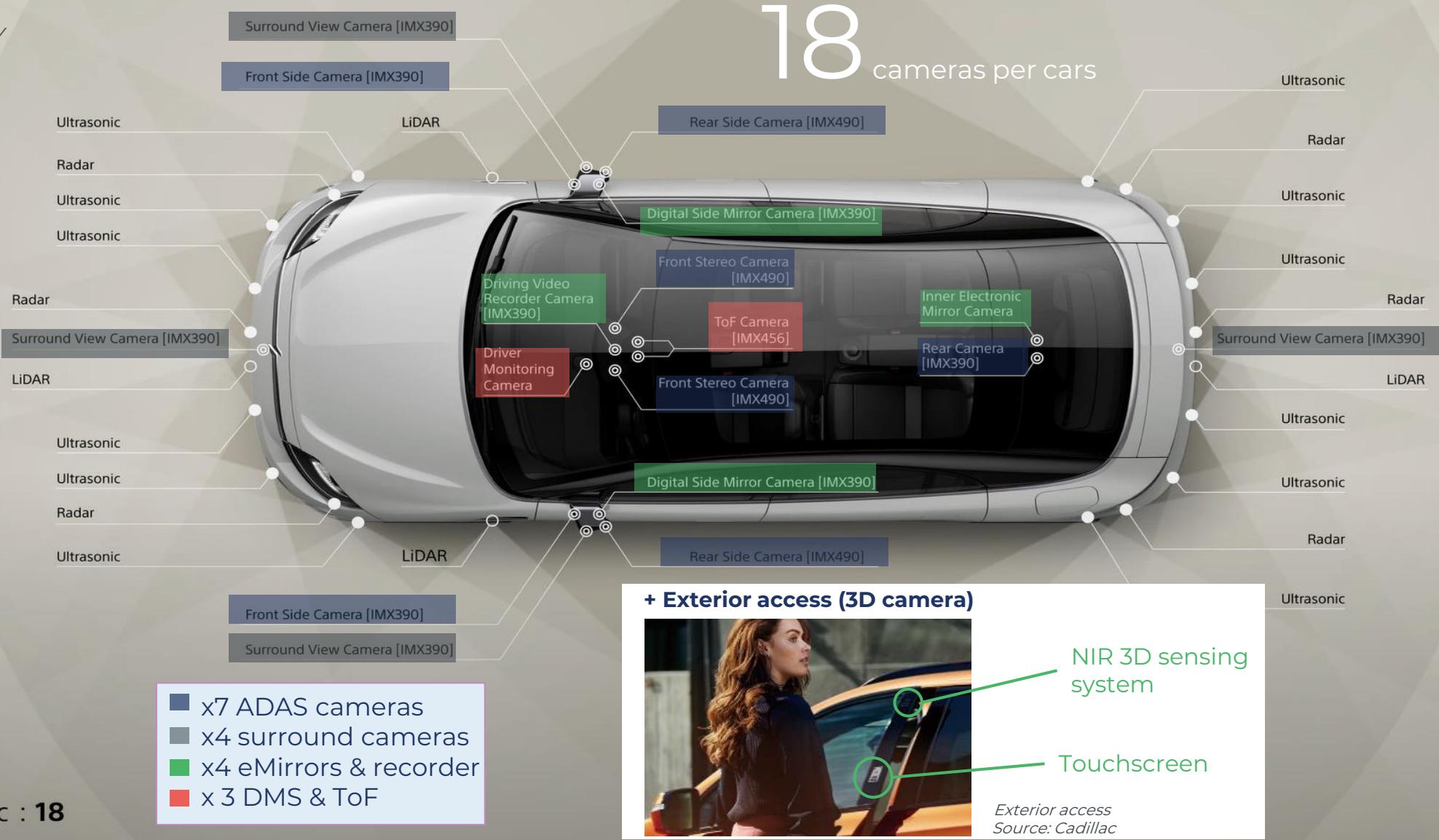
	Rear & surround view cameras	ADAS forward cameras	ADAS side and rear cameras	DMS/OMS cameras	Thermal cameras
Resolution	1.2 MP up to 3 MP	Up to 8.3 MP	1.3 up to 3 MP	0.3 up to 5MP	0.3 MP
Pixel Pitch	2.1 up to 6 µm	~ 2.1 µm	2.1 up to 4.2 µm	~ 2.2 to 3 µm	~12 µm
Field of View	~ 120 – 190° FoV	~ 30 to 120° FoV	~ 120 – 190° FoV	~ 60 – 120° FoV	~ 40 – 60° FoV
Frame Rate	30 up to 60 fps	~ 36 fps up to 60 fps	~ 60 fps	60 up to 120 fps	30 or 60 fps
Dynamic Range	~ 120 dB	Up to 140 dB	Up to 140 dB	~ 70 dB	/
Color Filter Array	<ul style="list-style-type: none"> • Color • RCCB 	<ul style="list-style-type: none"> • Color • RCCB • RYYCy 	<ul style="list-style-type: none"> • Color • RCCB • RYYCy 	<ul style="list-style-type: none"> • Mono • RGGB • RGB-IR • IR (3D) 	/
Shutter	Rolling	Rolling	Rolling	<ul style="list-style-type: none"> • Global • Rolling 	Rolling
Type of Data	<ul style="list-style-type: none"> • RAW • RGB-IR • Compressed 	RAW	RAW	<ul style="list-style-type: none"> • RAW • RAW RGB-IR 	<ul style="list-style-type: none"> • RAW • Compressed
Operating Temperature	-40°C to +125°C				
Connector	LVDS or ethernet	LVDS or ethernet	LVDS or ethernet	MIPI	LVDS or ethernet



AUTOMOTIVE MARKET TRENDS

Up to 18 cameras could be implemented per vehicle.

Courtesy of Sony



Camera / ToF : 18

Radar / Ultra Sonic : 18

LiDAR : 4



AUTOMOTIVE MARKET TRENDS

TESLA new hardware 4.0 configuration to be implemented in model Y

x 8 Exterior cameras
x 1 In-cabin camera

9 cameras are expected to be implemented in the 2023 Tesla Model Y.





AUTOMOTIVE MARKET TRENDS

Driver monitoring – Use cases (non-exhaustive list)

Multiple use cases can be enabled for safety, comfort, or security applications.



Safety

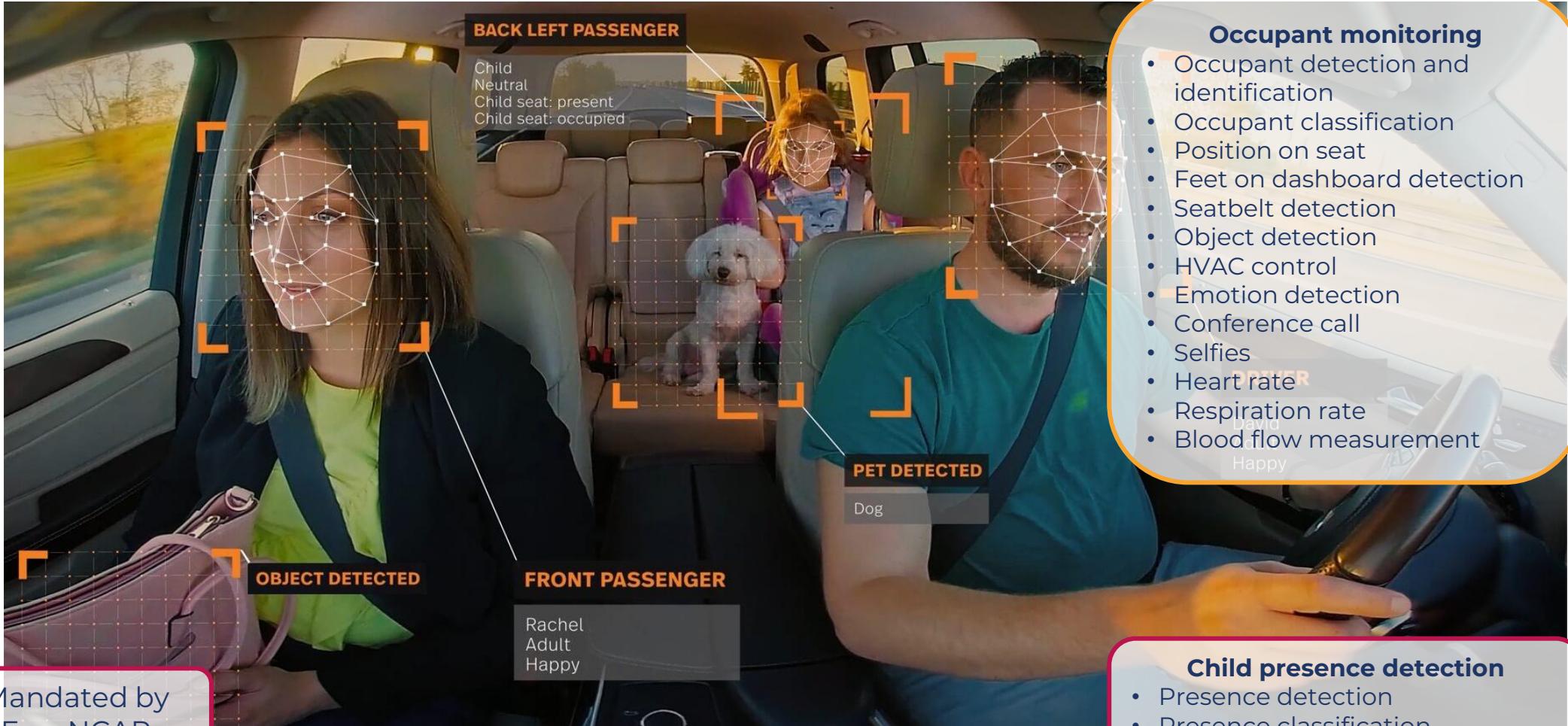
User experience



AUTOMOTIVE MARKET TRENDS

Occupant monitoring – Use cases (non-exhaustive list)

There are multiple use cases for occupant monitoring, where child presence detection appears as a priority by Euro NCAP.





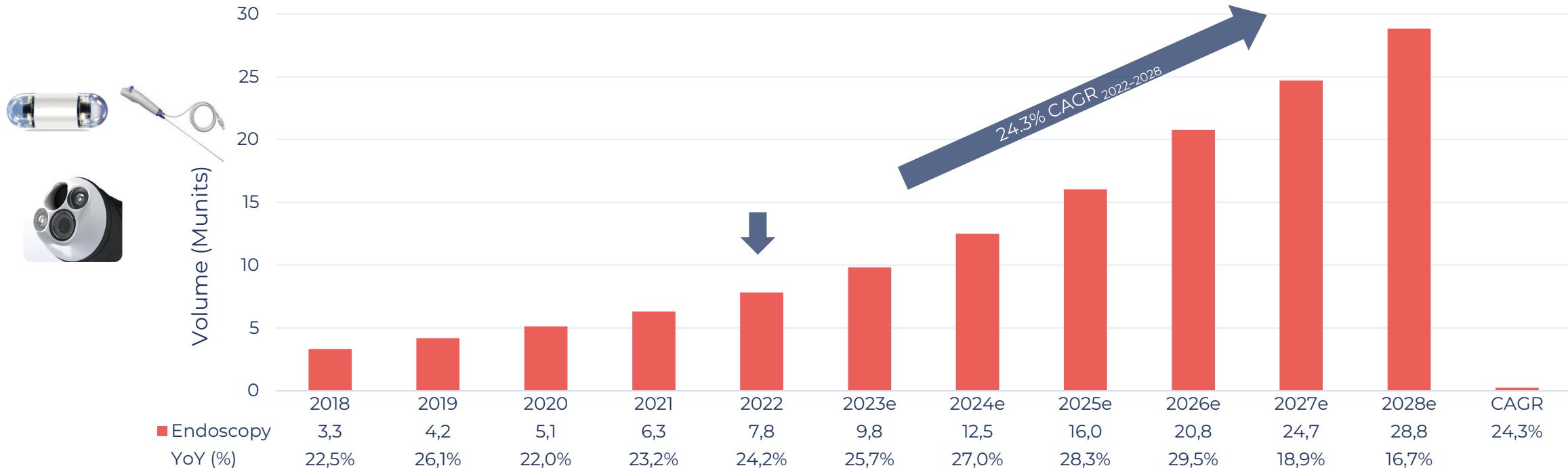
Medical

MEDICAL MARKET TRENDS

Market dynamics for endoscopy



2018-2028 Medical endoscopes total production (in Munits)



- Endoscopy is an established application, promising to grow even further in the coming years, supported by the adoption of disposable endoscopy products. Though today, it is mainly limited to specific applications like bronchoscopy, urology, and laryngoscopy, disposable endoscopy products are expected to reach other segments like gastroenterology.



MEDICAL MARKET TRENDS

The different types of endoscopes

The market is changing completely from a reusable product to a disposable product business model, with a myriad of new system makers.



A **fiberscope** is a flexible endoscope containing a flexible fiber-optic bundle that transmits an image from the instrument's tip to a video camera at the opposite end.

A **videoscope** is a flexible endoscope with a video chip at the distal end. It **increases the image quality** and offers **new functions** like 3D imaging and hyperspectral imaging.

Disposable or capsule endoscopes are designed to be discarded after use.

Low cost
No cross-contamination
No reprocessing



MEDICAL MARKET TRENDS

Evolution of imaging technologies

In recent years, there have been some changes in the technology platform in the field of endoscopy.

From CCD to CMOS

- To improve the integration (more functions on the chip)
- Low power consumption and less heat production



4K HD

- More precision imaging
- Easier update
- Improves the reliability of surgeon's judgment on resection



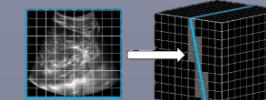
Fluorescence endoscopy

- Differentiated technology
- Clearer imaging of blood vessels and other tissues



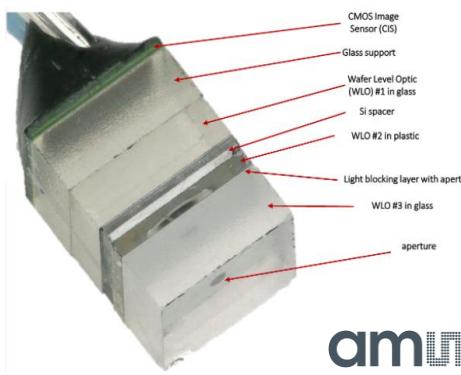
3D endoscopy

- Provides better information such as depth, position, etc.
- Improves the speed, accuracy, and precision of surgery

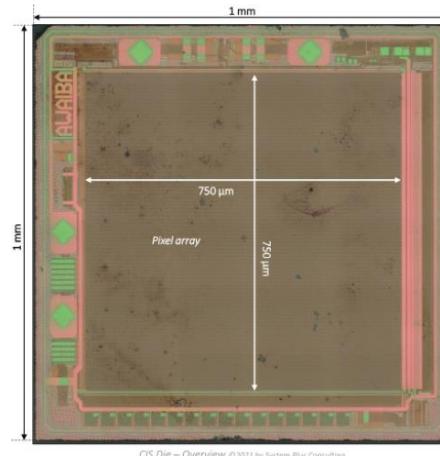




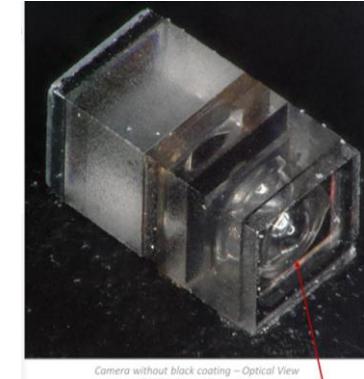
Ams NanEye camera



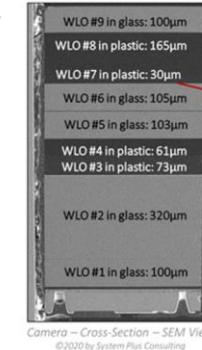
CIS top view



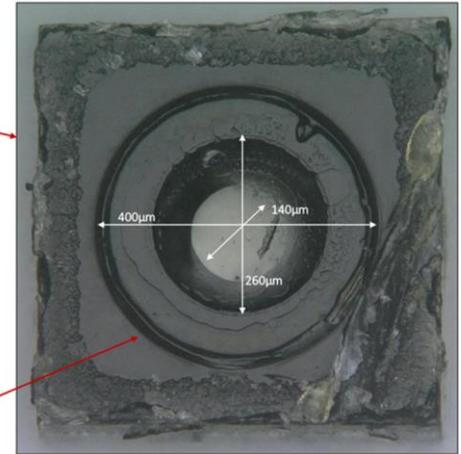
Omnivision OVM6948 camera



OMNIVISION™



Wafer optics stacked lens



- The OVM6948 CameraCubeChip is a camera module measuring 0.66mm x 0.66mm. Thanks to backside illumination, it provides excellent image quality and better low-light performance to help reduce LED heat, along with improved sensitivity. The resolution is about 40k pixels. The NanEye is slightly bigger and includes an FSI image sensor operating at a higher resolution: about 62k pixels.
- These ultra-small 'chip-on-tip' camera modules, fully packaged with wafer-level optics, can be integrated into an endoscope with a diameter as small as 1 mm. CIS's low light performance and reduced optical formats are critical for endoscopy applications.

Model	Resolution	Package dimensions
Ams NanEye	200 x 200	0.66 x 0.66 x 1.16mm ³
Omnivision OVM6848	250 x 250	1 x 1 x 1.43mm ³
Omnivision OCH2B	1,500 x 1,500	2.5 x 2.5 x 3.6 mm ³



Industrial

INDUSTRIAL MARKET TRENDS

Market dynamics



2018-2028 Industrial imaging modules shipment forecast (in Munits)



- Barcode readers represent most of the volume for imaging modules shipments in this market, benefiting from a projected CAGR of nearly 9% over the 2022 - 2028 period. The barcode reader is miniaturizing with more intelligence and requires a very high degree of integration for its camera module.



INDUSTRIAL MARKET TRENDS

Logistics: towards full automation

Warehouse

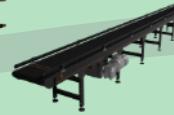
Starting point



AGV
(2010)



Robot



Belt conveyor



AGV
(2019)



Autonomous truck
(2021)

Port



AGV
(2017)



Crane



Autonomous
ship
(2035)

 YOLE
Intelligence

Ending point



Delivery
drone



Delivery
robot



Belt conveyor



AGV
(2019)



Autonomous truck
(2021)



AGV
(2017)



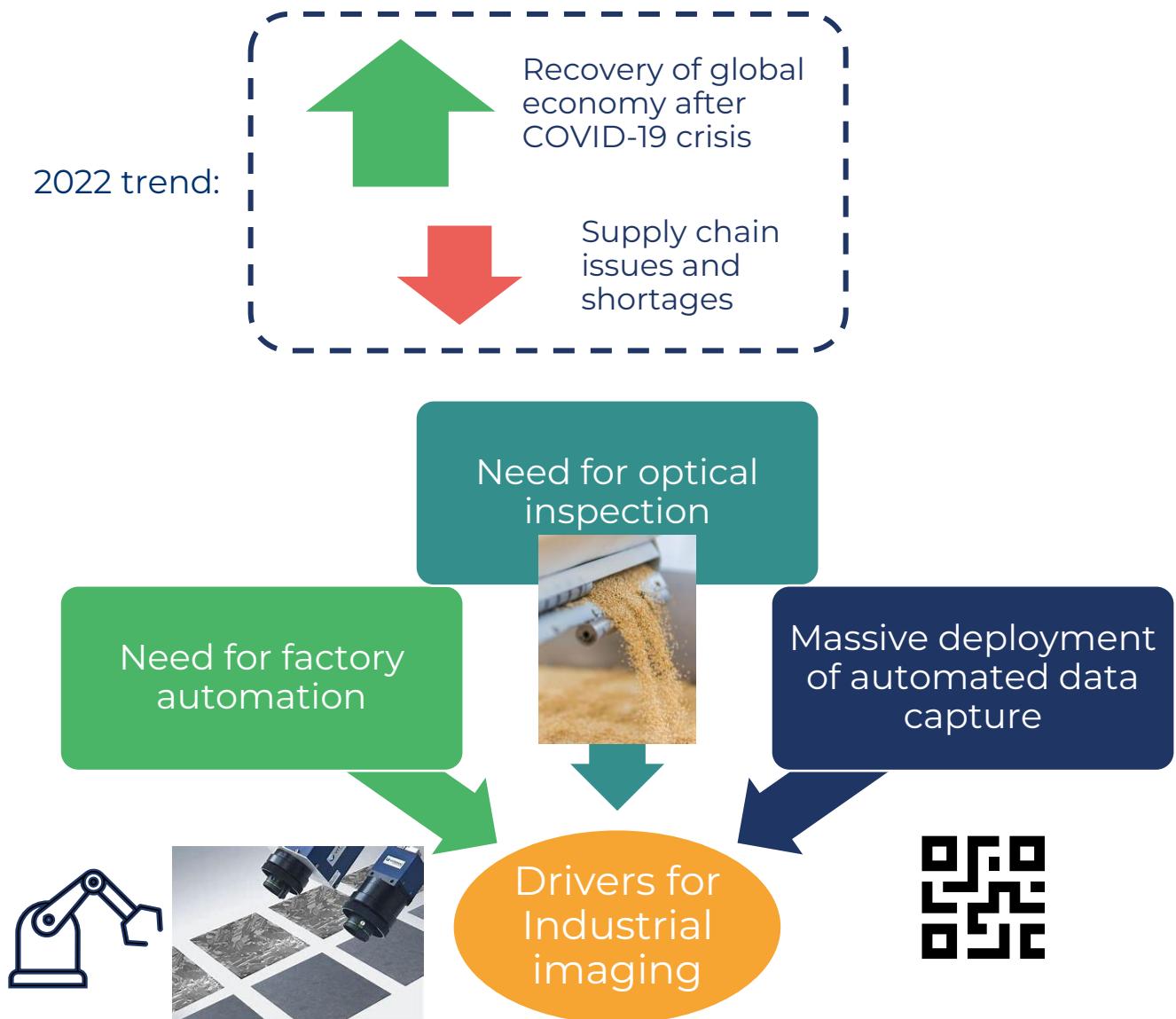
Crane

Port

INDUSTRIAL MARKET TRENDS

General trends

- In 2022, industrial vision experienced a good year with a high level of demand due to the recovery of the global economic situation following the COVID-19 crisis.
- Industrial vision OEMs experienced supply chain issues on some critical electronic components. Local lockdowns in China also affected sales during the beginning of 2022.
- Firstly, drivers for industrial imaging arise from the need for factory automation. Cameras are used to improve throughput or reduce costs.
- Secondly, cameras are used to read bar codes and QR codes, which are now used in logistics and retail and widely spread in everyday life.





INDUSTRIAL MARKET TRENDS

Barcode reader technology has spread in the industry

Definition

Automated data readers perform a well-defined task: capture the **data** from a visual code and transform it into letters and numbers. The quality of visual codes has evolved steadily, from the first patent in 1952 to 2D codes such as the Data Matrix, which can code up to 2335 letters and is readable despite up to 40% coverage.

Applications have also extended to **hospitals** with patient monitoring and **factory** automation with Direct Part Marking (DPM).

Industries

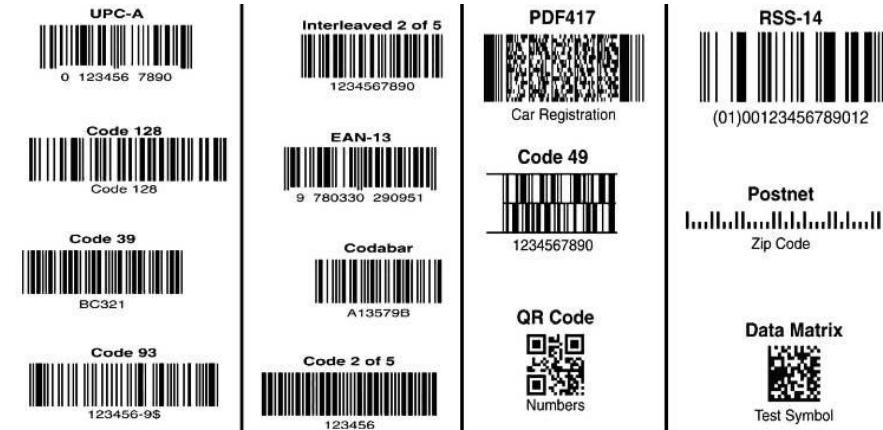


Barcode reading in the **retail** industry.



Mail coding using an Intelligent Mail Barcode.

Various codes have been used



Patient management using a barcode bracelet in a hospital.

Since the 70s, Automatic Data Collection (ADC) has expanded into various industries.



INDUSTRIAL MARKET TRENDS

Automatic Data Capture (ADC): code scanning is everywhere

The code connects money and personal information through the smartphone and has been widely used in daily life.



Scan to play



Scan to travel



Scan to access



During the COVID-19 outbreaks, personal travel information could be accessed by scanning a health code. This facility remained after the pandemic and is boosting the opportunities for barcode reader applications.



Conclusion



- Despite a decline in 2022, lower longer-term expectations of smartphone shipments of about 10% and a slowdown in the increase of the average number of cameras per smartphone, higher-end products, and new sensing opportunities will sustain the Mobile CIS market in the coming years. Automotive cameras are experiencing large growth enabled by in-cabin, viewing, and ADAS applications. Safety regulations and increasing demand for car automation encourage car OEMs to integrate more imaging technologies. Automotive is now one of the segments with the biggest growth potential for imaging products and, in more general, imaging solutions providers. Factory automation is the main driver for the growth of Industrial imaging, requiring high-end industrial cameras; logistics automation with matrix code readers is still the high-volume industrial application. The camera module industry has evolved offering more complex modules, bringing actuator, larger resolution, larger formats, etc., then transitioning to multi-camera trends and now opening the way for new multi-sensing modalities with even more intelligence brought closer to the sensing module.
- Mobile:** Despite a decrease in 2022 and lower longer-term expectations for smartphone shipments by about 10%, and a slowdown in the increase of the average number of cameras per smartphone, higher-end CIS products and new sensing opportunities will sustain the mobile CIS market in the coming years. The transition from imaging to sensing is continuing. We see additional sensing cameras, including front-facing structured light and under-screen optical fingerprint cameras, and a rear 3D ToF camera for improved photography and AR applications. Emerging imaging cameras, such as event-based and multispectral function cameras, are also coming to the market. From a mobile survey analysis considering a distribution model for mobile shipments (including more than 60 models), in 2022, the 12Mp, 48Mp, and 64Mp generated the most revenues, showing the shift toward higher resolution products (48-108Mp) these past few years.
- Computing:** The computing market suffered from smartphone competition and was declining until the COVID-19 crisis boosted sales in 2020 and 2021 due to lockdowns and stay-home policies. In 2022, the market shrank, and it is expected to continue declining in 2023 as global inflation depresses sales of consumer devices. Beyond the already established 3D sensing applications, there is a trend for increased use of dual image sensors, including RGB and NIR, or single RGB-NIR sensors for user detection features. In the coming years, we expect demand to recover slightly compared with its pre-COVID trend around 2028, with a -0.7% CAGR over the period. Enhanced video-calling using eye-contact technology is an attractive use case, although it has remained in development.
- Other Consumer:** The consumer photography has already been affected by smartphone adoption, but the COVID-19 situation and the demand for more personal electronics worsened the situation. 2022 was lower than expected for smartwatches and game stations, and AR-VR and smart home devices (speaker, assistant, etc.) are expected to decrease in 2023. The forecast for AR-VR headsets has been reduced slightly as AR use cases are not emerging, and there are delays due to critical technical challenges on the display side. Overall, we expect a 4.0% sustained growth rate for these applications in the coming years in end system numbers, with 658M units by 2028. Low-end surveillance cameras are increasingly turning to compact camera modules to reduce cost and size, integrated with wireless technology, and rapidly expanding to home security and other application scenarios. Depending on the variety of applications, it could be a doorbell, smart lock, baby monitor, or even a pet camera. Following the excessive orders of the past years and the weakening of demand in the consumer field, we observe that Security CIS revenues have decreased, returning to the 2019 level. However, growth should restart in 2023.
- Automotive:** The imaging growth is fueled by the increasing levels of vehicle autonomy and driven by safety regulations set by organizations such as Euro NCAP, the European Commission (Europe), IIHS (US), J-NCAP (Japan), and C-NCAP (China). ADAS forward cameras are currently the automotive industry's most widely adopted camera systems. They are in 68% of all new cars. The forward ADAS market currently offers monocular, stereo, and triple camera options, with the majority being monocular cameras due to their lower cost, representing 74% of the current cameras. Rear and 360° surround view cameras are the dominant applications in the viewing camera market. 360° surround view systems are becoming increasingly popular, even in low-end cars, not only for visualizing the vehicle's surroundings but also for parking assistance and remote automated parking. In-cabin safety applications primarily involve driver monitoring systems (DMS) to alert drivers when they are distracted. DMS systems are gaining popularity due to regulations. Dash recorder applications are particularly prevalent in the Chinese market, enhancing the user experience. Additionally, face authentication for exterior access is an emerging application mainly found in high-end cars.



MARKET SHARES & SUPPLY CHAIN

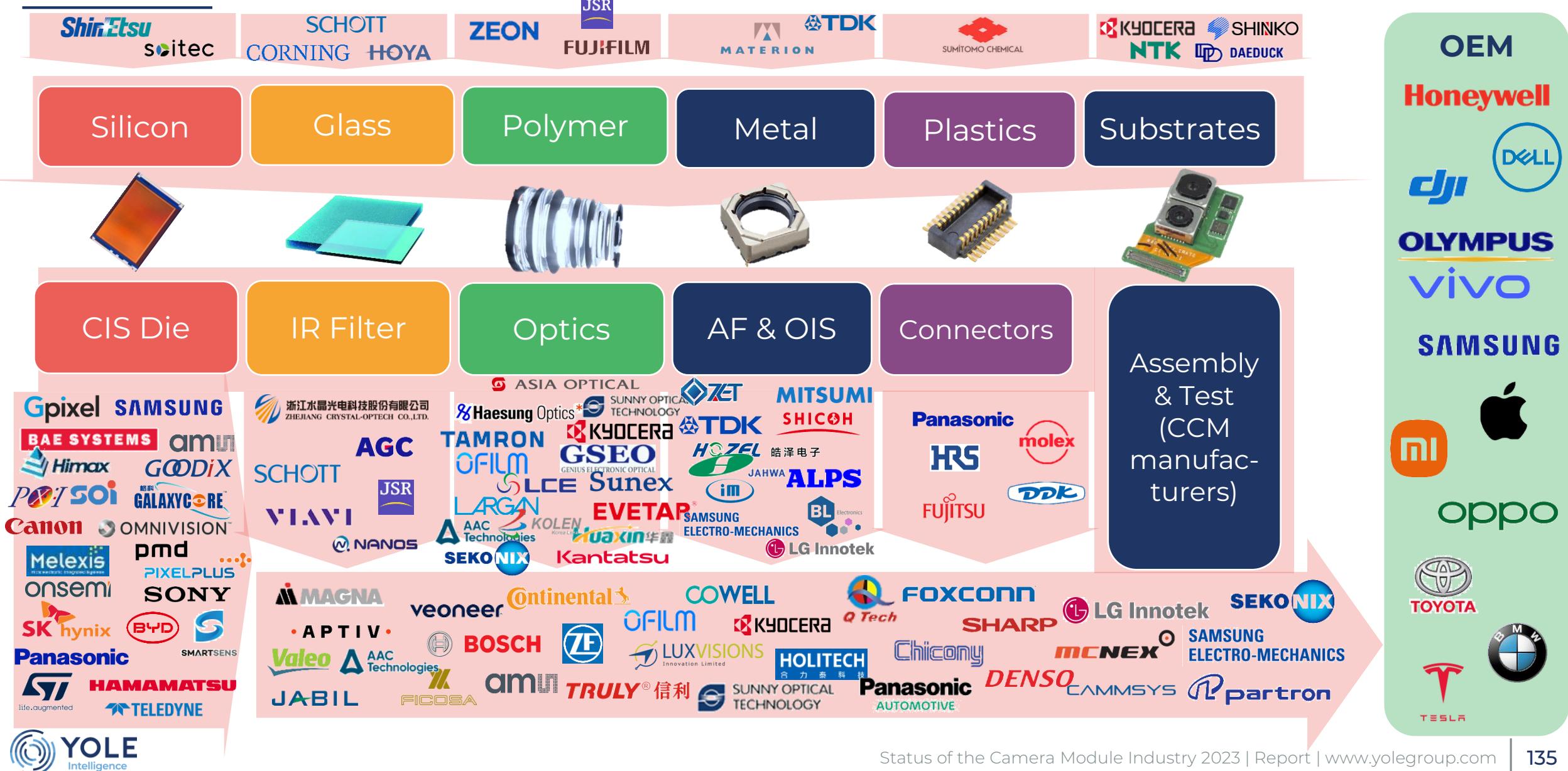


Camera module industry supply chain



CAMERA MODULE INDUSTRY SUPPLY CHAIN

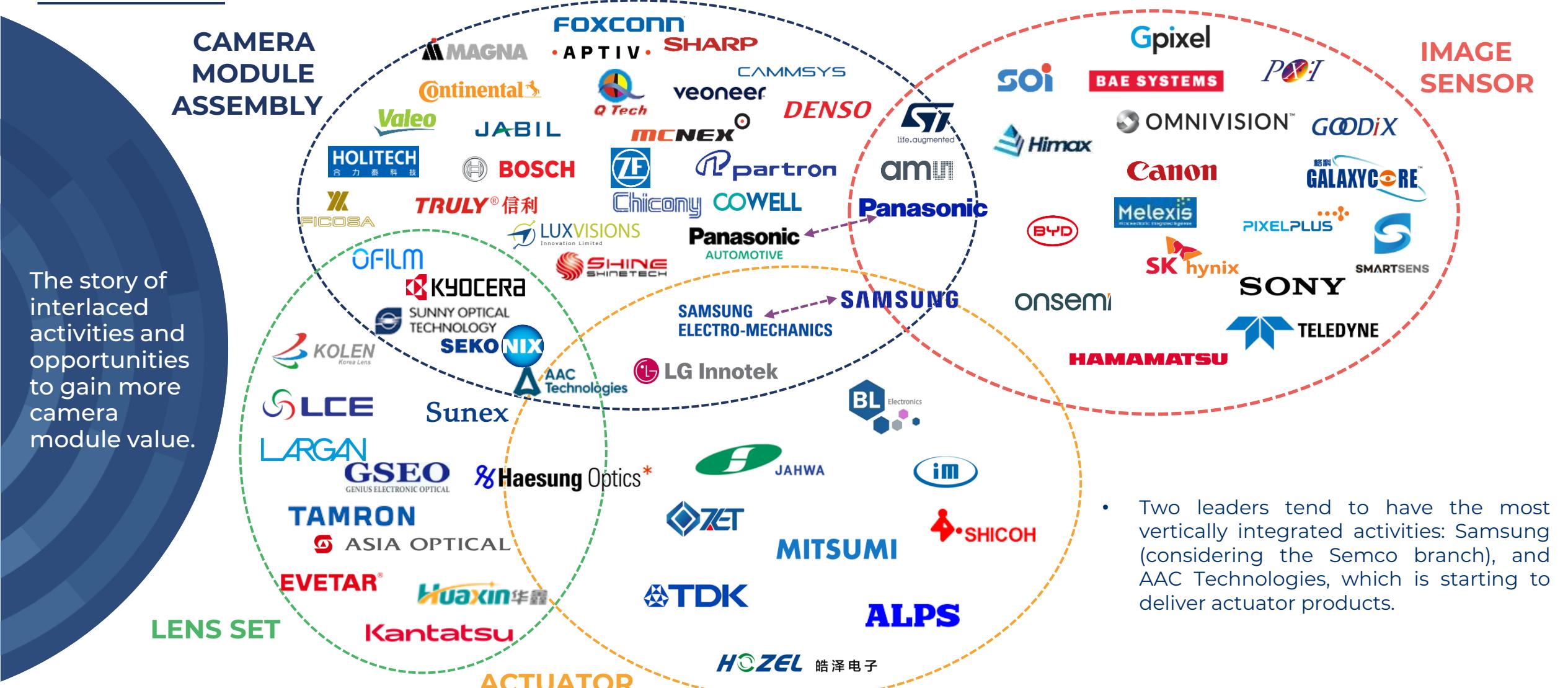
General supply chain (non-exhaustive)



CAMERA MODULE INDUSTRY SUPPLY CHAIN



Activity mapping



The story of interlaced activities and opportunities to gain more camera module value.

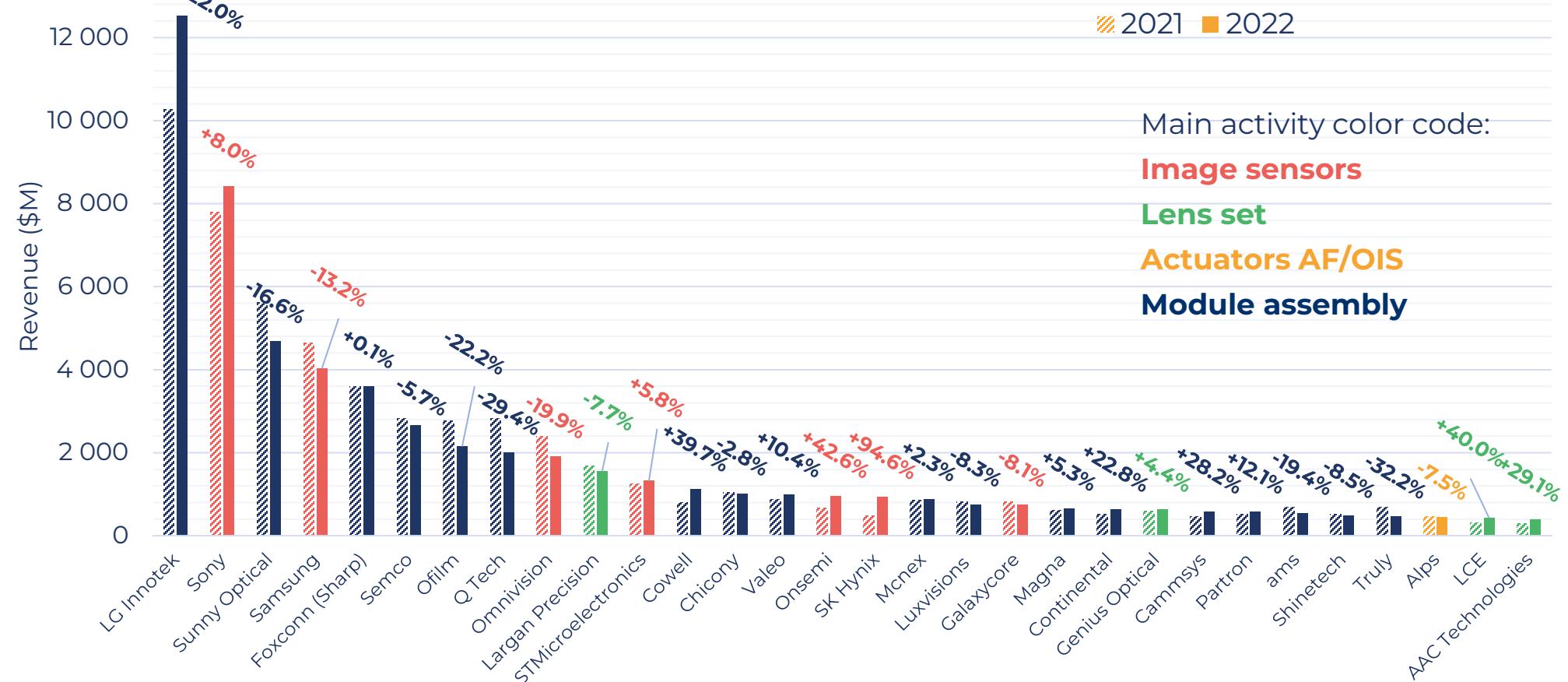
- Two leaders tend to have the most vertically integrated activities: Samsung (considering the Semco branch), and AAC Technologies, which is starting to deliver actuator products.

CAMERA MODULE INDUSTRY SUPPLY CHAIN

Camera module industry revenue ranking



2021-2022 revenue ranking of the main players in the camera module industry (in \$M)



2021 2022

Main activity color code:

Image sensors

Lens set

Actuators AF/OIS

Module assembly

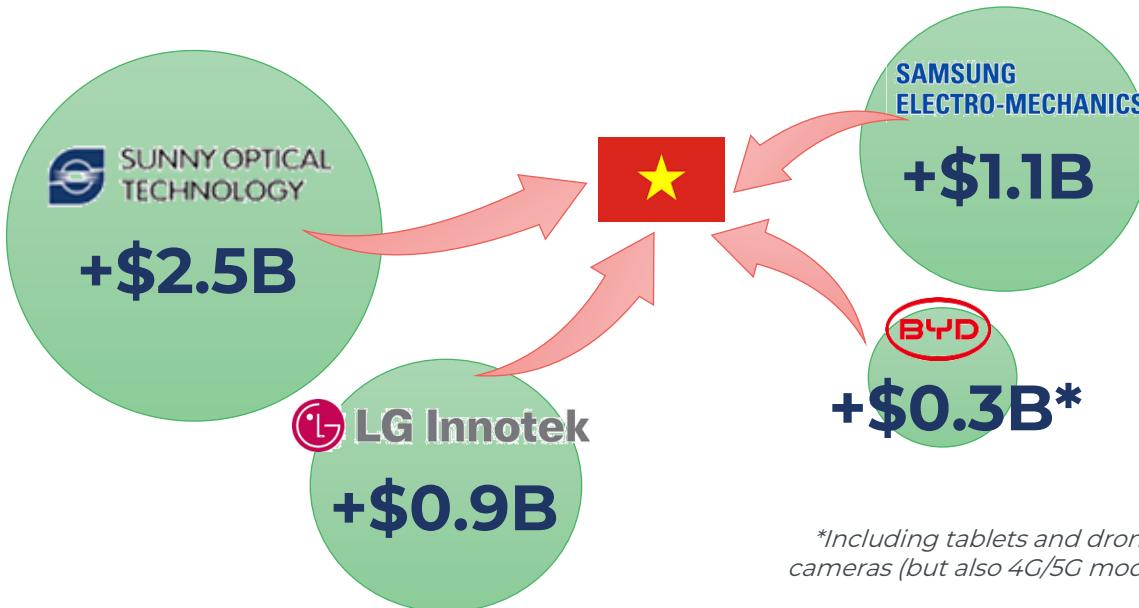
- Beyond their main activity generating most of the revenue, some leaders are involved in several activities: Suny Optical also for lens set, LG Innotek and Semco for actuator, Ofilm in lens set, AAC Technologies in module assembly and actuator, etc.
- If we add revenues from Samsung CIS and Semco activities, Samsung group could rank 3rd with revenues close to \$6.7B, being the most vertically integrated complete CCM solution provider.



CAMERA MODULE INDUSTRY SUPPLY CHAIN

Camera module industry focussing investments in Vietnam

Major investments announced in CCM production capacity in Vietnam factories since 2022:



\$6B investment in Vietnam CCM production capacity

Other CCM companies operating production and investing in Vietnam:



DRIVING FORCES

- Relative political stability
- Lower labor cost
- Alternative supply chain from China



POTENTIAL RISKS

- Infrastructure stability (power outage in 2023)
- Workforce shortage



CAMERA MODULE INDUSTRY SUPPLY CHAIN

Noteworthy news selection from the past two years

2021

	Oct 20, 2021	AAC Technologies invested in SWIR Vision Systems Inc.
	Dec 20, 2021	Zhonglan Electronic Technology acquired part of Kantatsu's lens business in China

2022

	April 29, 2022	Sunwin IPO in Shenzhen stock market was approved
	Jan 06, 2022	Canon and Tier IV have formed a strategic partnership to produce dedicated ADAS cameras

2023

	Jan 30, 2023	Alps Alpine begins mass production of SMA actuators
	May, 2023	Sony releases Xperia 1 V Smartphone with its triple stack CIS
	Mar, 2023	Onsemi acquires GlobalFoundries East Fishkill facility with 12-inch wafer, 65nm node capability
	Jun 26, 2023	LG Innotek is investing \$1.1B to create a new CCM fab in Vietnam and double its capacity there by 2025
	Jun 2023, Magna completes acquisition of Veoneer Active Safety Business	

June August Oct. Dec. Feb. April June August Oct. Dec. Feb. April June August

CAMERA MODULE INDUSTRY SUPPLY CHAIN

Mobile camera module supply chains



Top OEMs

System OEM

Module assembly

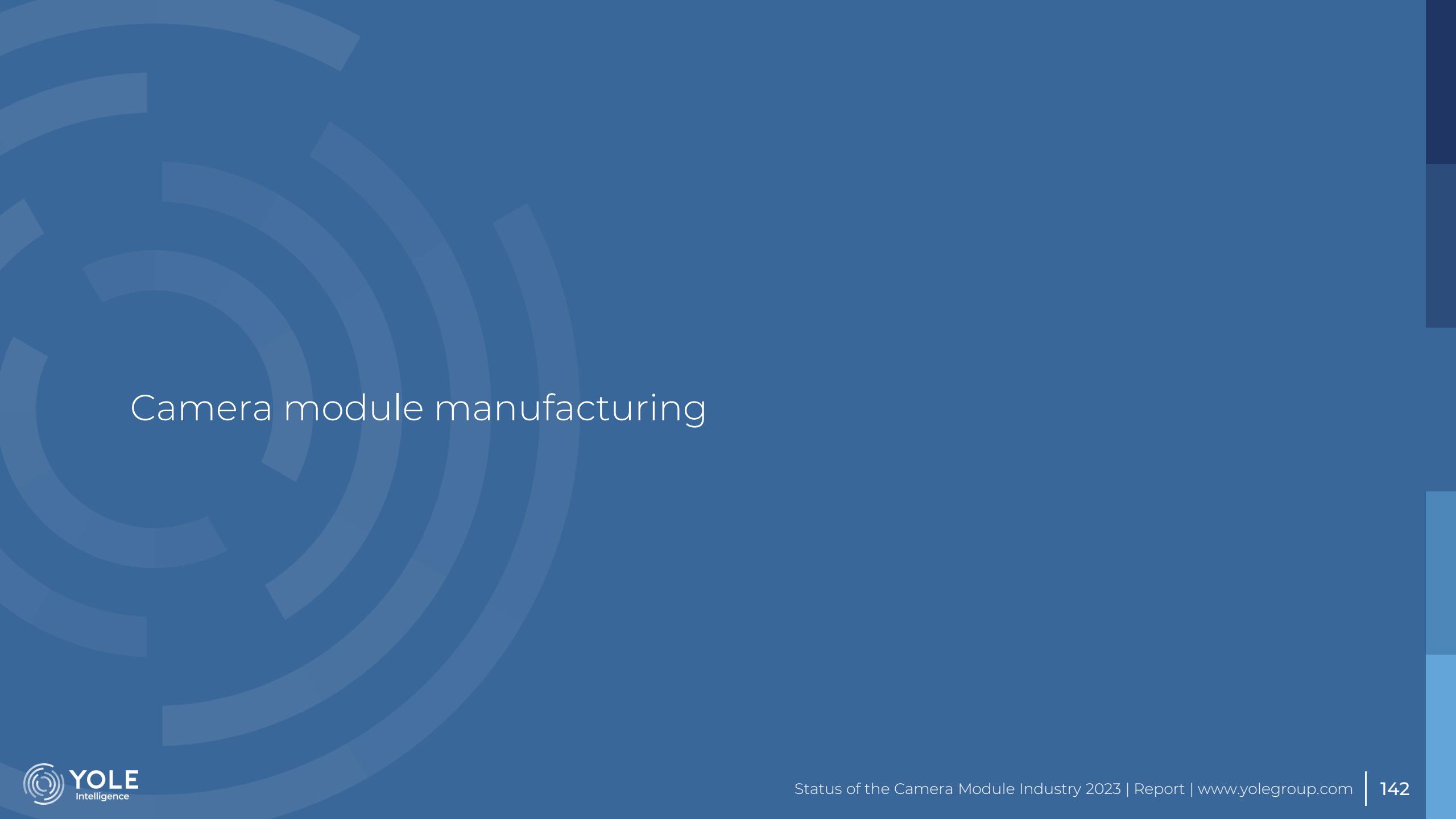
AF & OIS VCM

Optics

Image Sensor



Camera module industry market shares



Camera module manufacturing



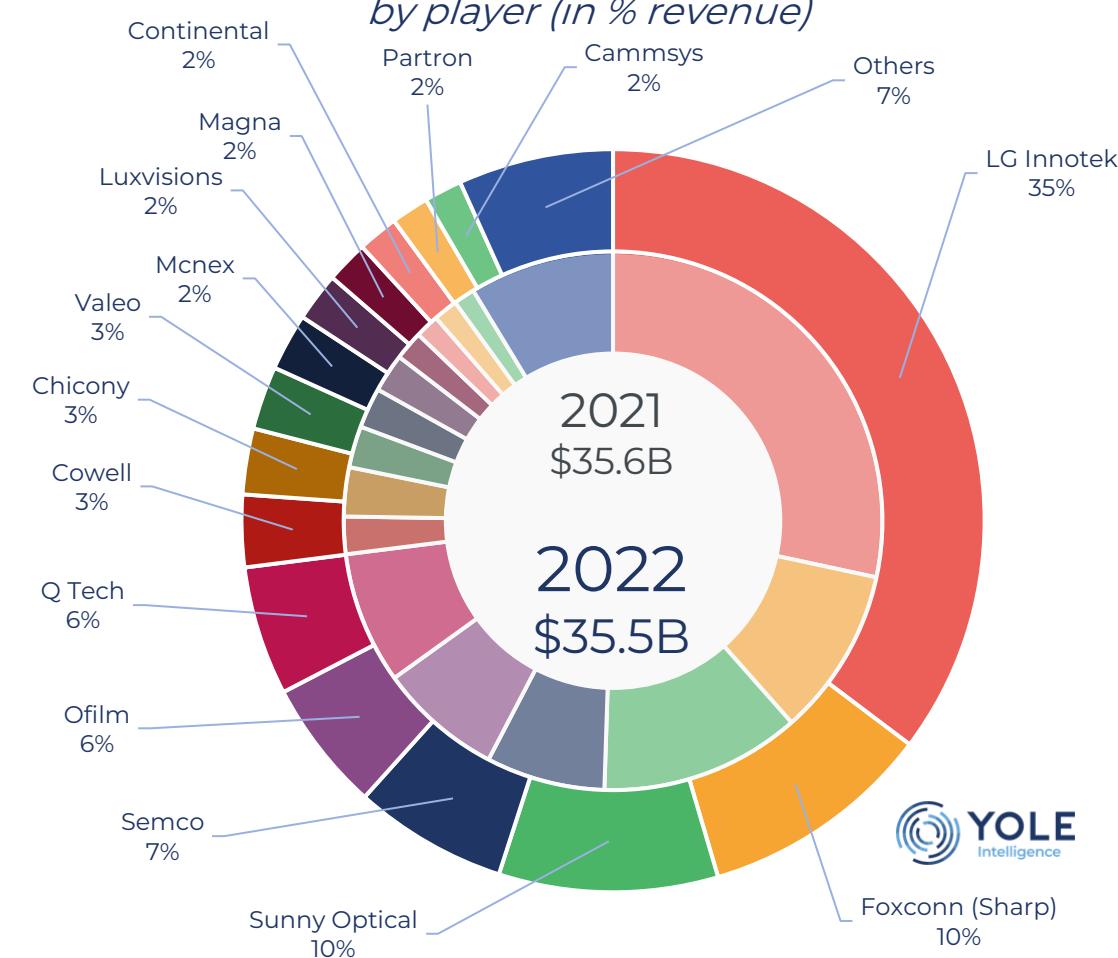
CAMERA MODULE MANUFACTURING MARKET SHARES

by player, in \$M (Yole data)



Revenue (\$M)	2021	2022	YoY (%)
LG Innotek	\$10,108	\$12,527	23.9%
Foxconn (Sharp)	\$3,600	\$3,605	0.1%
Sunny Optical	\$4,290	\$3,385	-21.1%
Semco	\$2,543	\$2,373	-6.7%
Ofilm	\$2,646	\$2,029	-23.3%
Q Tech	\$2,826	\$1,995	-29.4%
Cowell	\$799	\$1,116	39.7%
Chicony	\$1,048	\$1,018	-2.8%
Valeo	\$886	\$978	10.4%
Mcnex	\$862	\$882	2.3%
Luxvisions	\$821	\$753	-8.3%
Magna	\$619	\$652	5.3%
Continental	\$511	\$627	22.8%
Partron	\$520	\$583	12.1%
Cammsys	\$455	\$583	28.2%
Others	\$3,095	\$2,397	-22.6%
TOTAL	\$35,629	\$35,502	-0.4%

2022 Camera Module market share by player (in % revenue)



Luxvisions acquired 63% of Cowell E Holdings in 2022, the parent company of Cowell Electronics, so the actual share of Luxvisions group of companies, including Cowell activity, would represent a 5% market share. We kept them separated as Cowell seems to operate quite independently.



CAMERA MODULE MANUFACTURING MARKET SHARES

By player, top seven

The top 7 companies achieved more than 75% market revenues.



LG Innotek

LG Innotek, after having achieved high growth in 2021, continued on this trend in 2022, still benefiting from the growth of Apple's mobile phone sales and the increased camera ASP in its served market. LG is not only in mobile phone cameras - favored by top players, but is also receiving large orders for automotive cameras as it has been confirmed in 2022 as a major supplier for Tesla vehicle cameras - which will consolidate its leading position in the camera industry.

**FOXCONN
SHARP**

Foxconn and **Sharp** are in the same Hon Hai group. They provide cameras to Apple (front cameras) and other Android smartphone cameras such as Nokia (HMD), Motorola, Huawei, etc. In 2022, they shipped nearly 500 million camera module units and delivered stable revenues over the past years. It is also significantly involved in Computing and other non-mobile consumer camera module productions.



**SUNNY OPTICAL
TECHNOLOGY**

Sunny Optical had been suffering from the ban on Huawei in 2021, and its revenue declined further in 2022, due to the lowering of the Mobile market. However, it is one of the CCM players that manufacture lenses, that have been approved to enter Apple's supply chain. In addition, Sunny is also actively expanding in new fields, such as Automotive, a sector in which it has doubled its revenues in two years, XR, and machine vision.

**SAMSUNG
ELECTRO-MECHANICS**

Samsung Electro-Mechanics (Semco) had passed Ofilm and Q Tech to reach fourth place. CCM's business is closely tied to the market for Samsung's mobile division, also serving other customers such as Xiaomi. Semco has technical advantages in multi-camera and periscope cameras, from the past acquisition of Corephotonics. They also supply actuator solutions with VCM and lens design. Being a highly vertically integrated camera module supplier, it developed its Automotive camera module business, which decreased its exposition to Mobile recent fluctuations.

OFILM

Ofilm, its camera module business has suffered since 2019, with a financial crisis, major customer Huawei ban, removal from Apple's supply chain, and having to sell some of its production lines. It was removed from the U.S. entity list in 2022, and its revenues continued to decrease further to reach \$2.0B, being obviously exposed to the lower expectations of the Mobile market.



Q-Tech has become a major supplier to Chinese mobile OEMs. Its revenue has grown steadily as its share of high-resolution cameras has expanded, serving OEMs such as Vivo, Oppo, Xiaomi, Huawei, and Lenovo... for imaging cameras and also fingerprint modules. After having gradually moved up the CCM rankings, its revenues significantly decreased in 2022, as it was quite exposed to the Mobile market.

COWELL

Cowell is involved in Mobile, Computing and Automotive camera modules. It supplies some of the Apple iPhone front camera modules. In 2021, Luxivisons acquired 63% of Cowell E Holdings, the parent company of Cowell Electronics, that is in charge of the camera module manufacturing. Its revenues surged in 2022, probably because of new design-wins in XR, Automotive, and the expansion of its Mobile camera business towards higher-end products.



CAMERA MODULE MANUFACTURING MARKET SHARES

Announcing some supply chain transition?

Opposite dynamics in 2022 for South Korean vs. Chinese suppliers.

Geo. area	2021	2022	YoY growth
South Korea	41%	48%	↗
China	37%	30%	↘
Taiwan	13%	13%	↔
Europe	6%	6%	↔
North America	2%	2%	↔
Japan	1%	1%	↔
Others*	1%	1%	↔
TOTAL	100%	100%	

*Not strictly identified related revenues origin

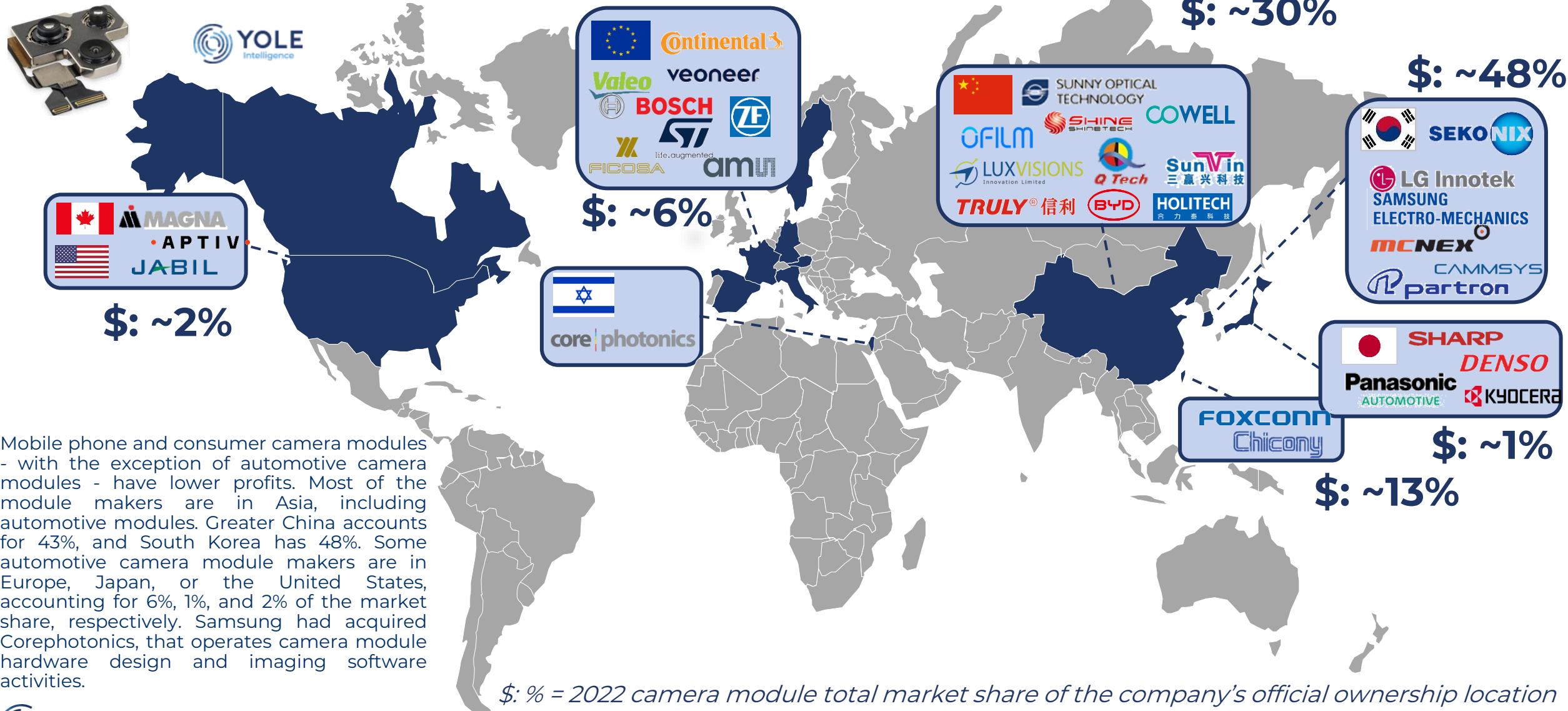
- In 2022, there is clearly a revenue shift from China-based companies to South Korean camera module manufacturers. Looking closer, it is actually a shift to the sole main benefit of LG Innotek, which increased its market share from 28 to 35%.
- This is not due to the difference in exchange rates of CNY and KRW versus USD as both currencies have experienced similar trends in 2022 vs. 2021.





CAMERA MODULE MANUFACTURING MARKET SHARES

Competitive map of the TOP Camera Module players



Mobile phone and consumer camera modules - with the exception of automotive camera modules - have lower profits. Most of the module makers are in Asia, including automotive modules. Greater China accounts for 43%, and South Korea has 48%. Some automotive camera module makers are in Europe, Japan, or the United States, accounting for 6%, 1%, and 2% of the market share, respectively. Samsung had acquired Corephotonics, that operates camera module hardware design and imaging software activities.



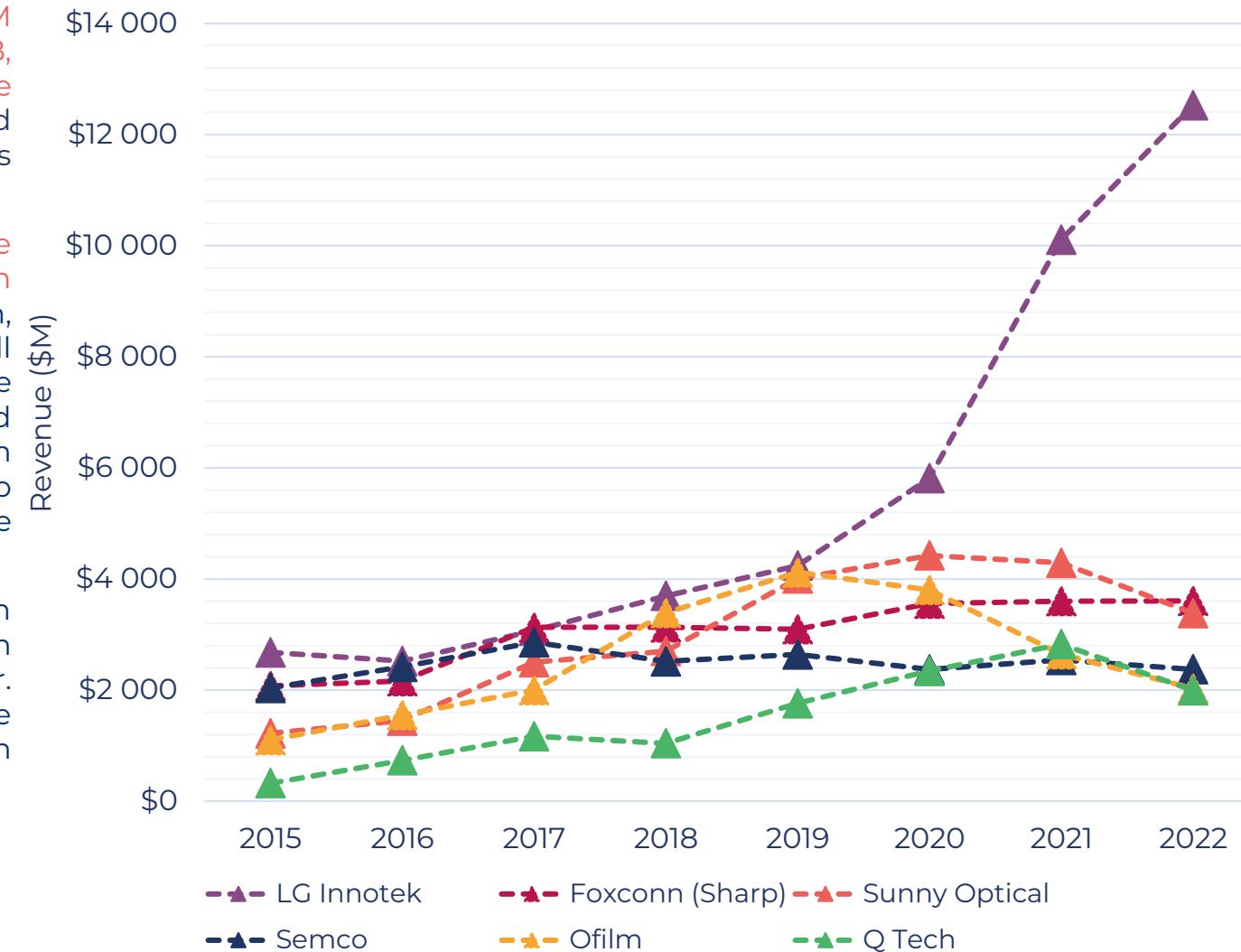
CAMERA MODULE MANUFACTURING MARKET SHARES

Camera module - historical market revenue (in \$M)

- The module industry continued to grow in 2021 after the recovery from the COVID-19 epidemic. Nevertheless, CCM revenues have slightly decreased in 2022 from \$35.6B to \$35.5B, as a soft landing after the largely inflated growth from the previous years. The general inflation worldwide in 2022 resulted in a significant slowdown in consumer product sales, such as smartphones (-10%).
- In this context, CCM manufacturers continued to experience different fortunes, and previous revenue trends have been exacerbated in 2022: LG continued on its tremendous growth, with 24% YoY, and could outperform its competitors, still supplying all rear triple-camera and sensing cameras to Apple and getting new opportunities in Automotive. Q Tech continued to grow until 2021 due to increased high-resolution cameras in its product mix and being a supplier for Xiaomi, Oppo, and Vivo camera modules. However it suffered from the decline in the smartphone market in 2022, the same for Sunny Optical.
- Sunny Optical and Ofilm show decreasing revenue. The main reason for this is the restrictions on Huawei - an innovator in mobile phone cameras - and another significant customer. Foxconn (Sharp) and Semco have been quite stable in revenue these past few years, the latter getting more diversified in Automotive.

Companies revenues evolution

Camera modules (in \$M)



A large, abstract graphic on the left side of the slide consists of several concentric circles in varying shades of blue, creating a sense of depth and motion.

CMOS image sensor



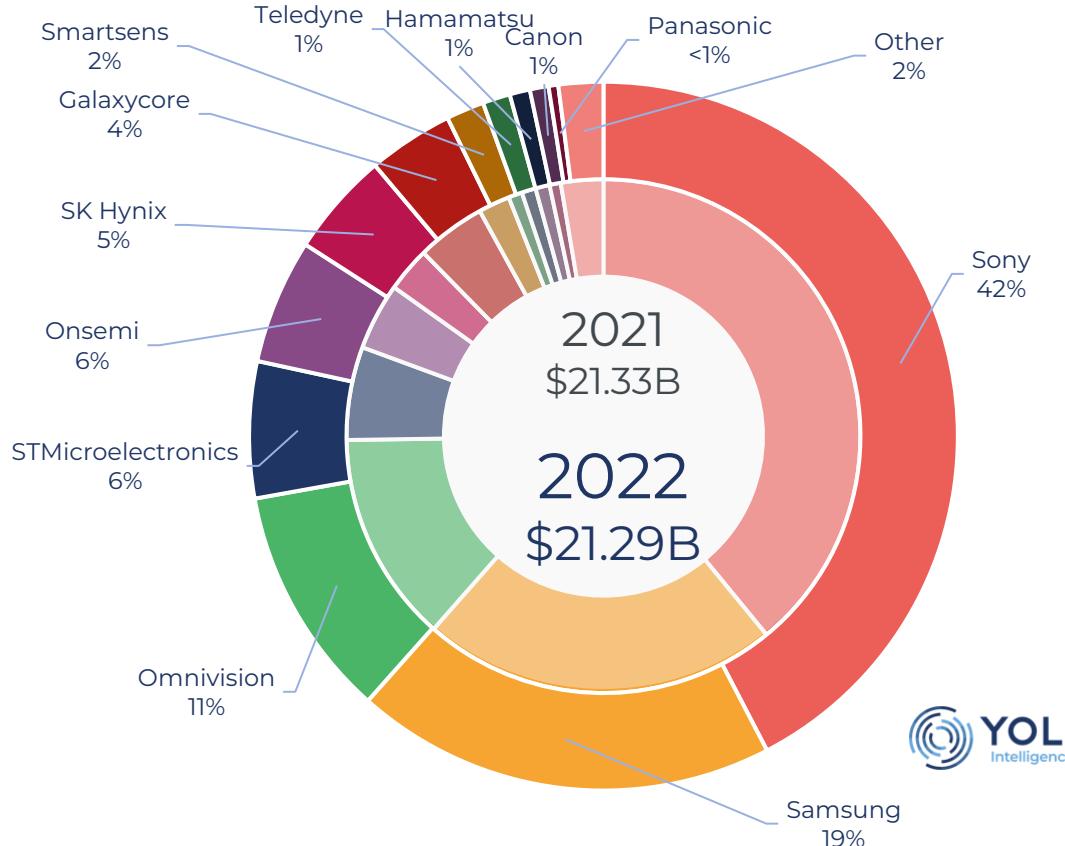
CMOS IMAGE SENSOR MARKET SHARES – FOR ALL APPLICATIONS

by player, in \$M (Yole data)



Revenue (\$M)	2021	2022	YoY (%)
Sony	\$8,330	\$9,020	8.3%
Samsung	\$4,785	\$4,091	-14.5%
Omnivision	\$2,830	\$2,257	-20.2%
STMicroelectronics	\$1,250	\$1,326	6.1%
Onsemi	\$899	\$1,212	34.8%
SK Hynix	\$600	\$1,011	68.5%
Galaxycore	\$929	\$831	-10.5%
Smartsens	\$423	\$369	-12.8%
Teledyne	\$185	\$268	44.9%
Hamamatsu	\$189	\$197	4.2%
Canon	\$190	\$182	-4.2%
Panasonic	\$150	\$94	-37.3%
Others	\$568	\$434	-23.6%
TOTAL	\$21,328	\$21,292	-0.2%

**2022 CMOS Image Sensor market share
by player (in revenue)**



Two-digit positive or negative growth for numerous companies, showing that 2022 has been a transition year with lower volumes, similar revenues, increased ASP, and different segment dynamics in Mobile, Consumer, Automotive, Security, and Industrial imaging applications.



CMOS IMAGE SENSOR MARKET SHARES – FOR ALL APPLICATIONS

By player, top five

The top 4 companies remain unchanged, with Onsemi rushing into the top 5.

SONY

Sony grew in 2021 after the bubble burst in 2019 and 2020, but less than average. In 2022, however, Sony increased its CIS revenues significantly by about 8%, whereas the total market slightly decreased by -0.2%. Sony benefited from its higher grip on high-resolution sensors – such as the adoption of its 48MP by Apple iPhone 14 – and difficulties encountered by its competitors, including Samsung and Omnipvision.

SAMSUNG

Samsung, after having benefited across its entire IDM business model with no dependence on external wafer sourcing and anticipated capacity increase, experienced an abrupt stop in 2021. Samsung LSI is a CIS OEM and an external foundry for several players, such as Galaxycore. Its 108Mp mobile CIS product has helped to generate significant revenue, but because of some market share loss on lower resolution products and possibly some production difficulties, its revenues slumped significantly. However, it seems well-positioned to expand further into the Automotive CIS market.

OMNIVISION™

Omnivision had been a significant market-share winner in 2021 with 17% YoY growth but saw a significant revenue decrease in 2022 of about 20%. We believe that it is more a supply issue than a demand limitation, particularly for the mobile market because the market dynamics and some of its competitors have not been that affected. In addition, it has been exposed to the decreasing Security CIS market, being the usual leader in this market.



onsemi

STMicroelectronics, after having surpassed the \$1B landmark in 2018, has hit the ceiling with its Apple Face ID global shutter product, complemented by dToF multizone detectors. While its current business remains largely dependent on a large single customer – Apple – it is expanding into Consumer, Computing, and Automotive CIS products.

Onsemi continued its double-digit growth in 2022, with an exceptional 34% revenue growth boosted by the Automotive and Industrial markets. It also ensured its supply source with potentially significant new production slots at TSMC and probably benefited from a very substantial CIS ASP increase, particularly in the Automotive market.



CMOS IMAGE SENSOR MARKET SHARES – FOR ALL APPLICATIONS

By player

The followers remained unchanged, with some changes in rankings.



SK Hynix has gradually increased deliveries of 8MpP and 12Mp CIS to Samsung Electronics, taking some share from Samsung LSI in CIS mobile, probably due to severe production issues at Samsung's fab (maybe in Austin, Texas). We also believe SK Hynix has introduced some 48Mp CIS products to the mobile market, generating significant revenues in 2022.



Galaxycore greatly benefited from the multicamera trend, with sales boosted in 2020 and 2021 in the final run-up to its IPO. It has invested in its new fab, which started production at the end of 2022 but suffered in 2022 from the decline in Mobile sales, the slowdown of Consumer, and the dramatic drop in the Security CIS market. We expect it will expand into the Automotive CIS market in the future.



Smartsens, after impressive growth figures in 2020 and 2021, focused its strategy on security cameras and, therefore, was impacted by the market drop in 2022. It limited its fall in revenue with significant growth in the Automotive business in China and is developing its product portfolio in Mobile and Industrial applications.



Teledyne e2V remains a key player in Medical and Industrial and is a strong leader in the Defense and Aerospace market, benefiting from the thriving Industrial CIS market.



Hamamatsu has also benefited from the high momentum in Industrial and Medical products. High demand for performance is playing a vital role in the expanded value proposition of this high-end specialty player.



Canon is still a leader in the declining Consumer photography market. Canon's CIS business for security cameras has grown in the past years, and it has developed a strong product portfolio for higher-end products, including the Industrial, Defense and Aerospace markets.

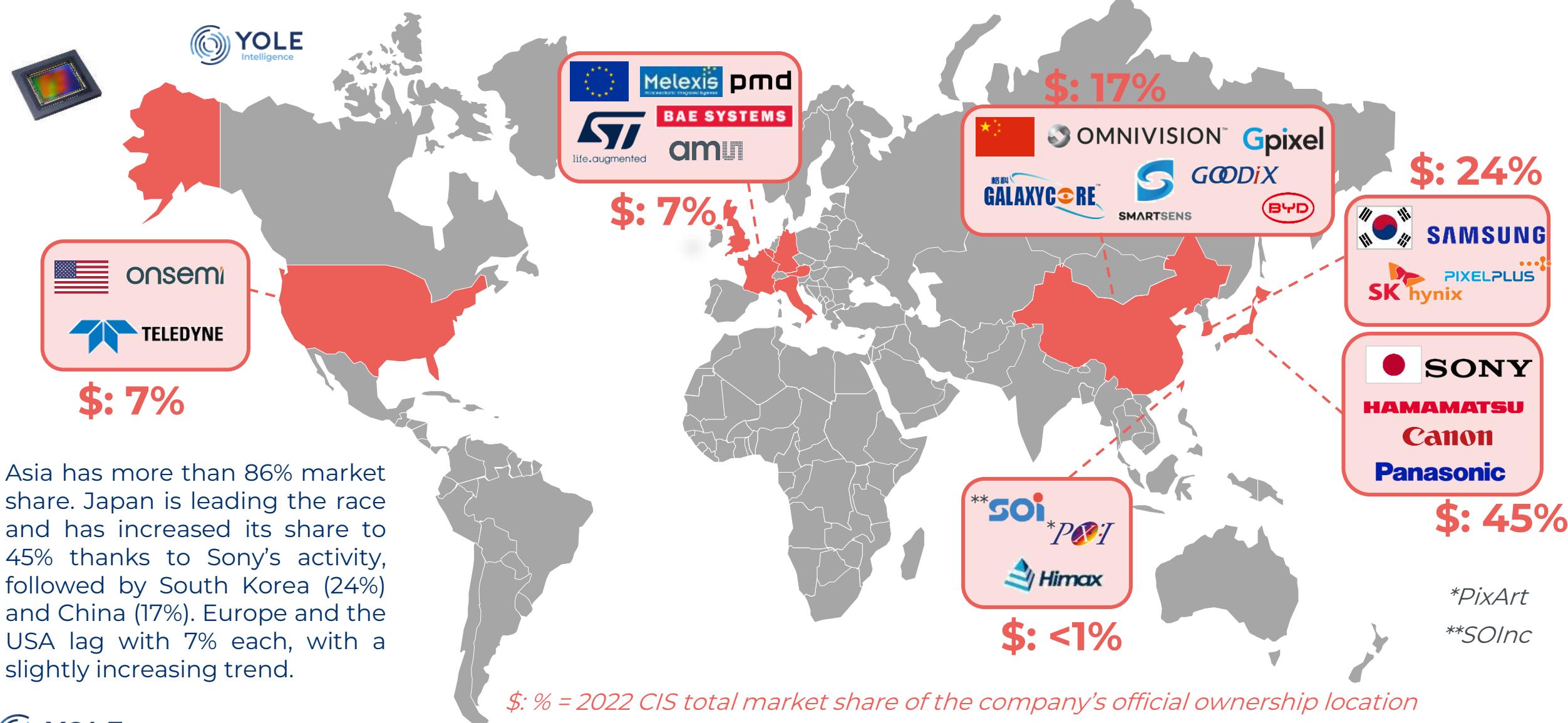


Panasonic has been active in the past in the Industrial, Automotive, and Security segments. However, it was also negatively impacted by the decrease in the Consumer photography market. At the end of 2019, it sold its 49% share in its TPSCo foundry to Nuvoton and transitioned into a pure fab-less player. In September 2022, it was officially announced that Panasonic would no longer support semiconductor products. Therefore, we consider for 2022 some residual revenue of Panasonic that should rapidly tail off.



CMOS IMAGE SENSOR MARKET SHARES – FOR ALL APPLICATIONS

Competitive map of the TOP CIS players

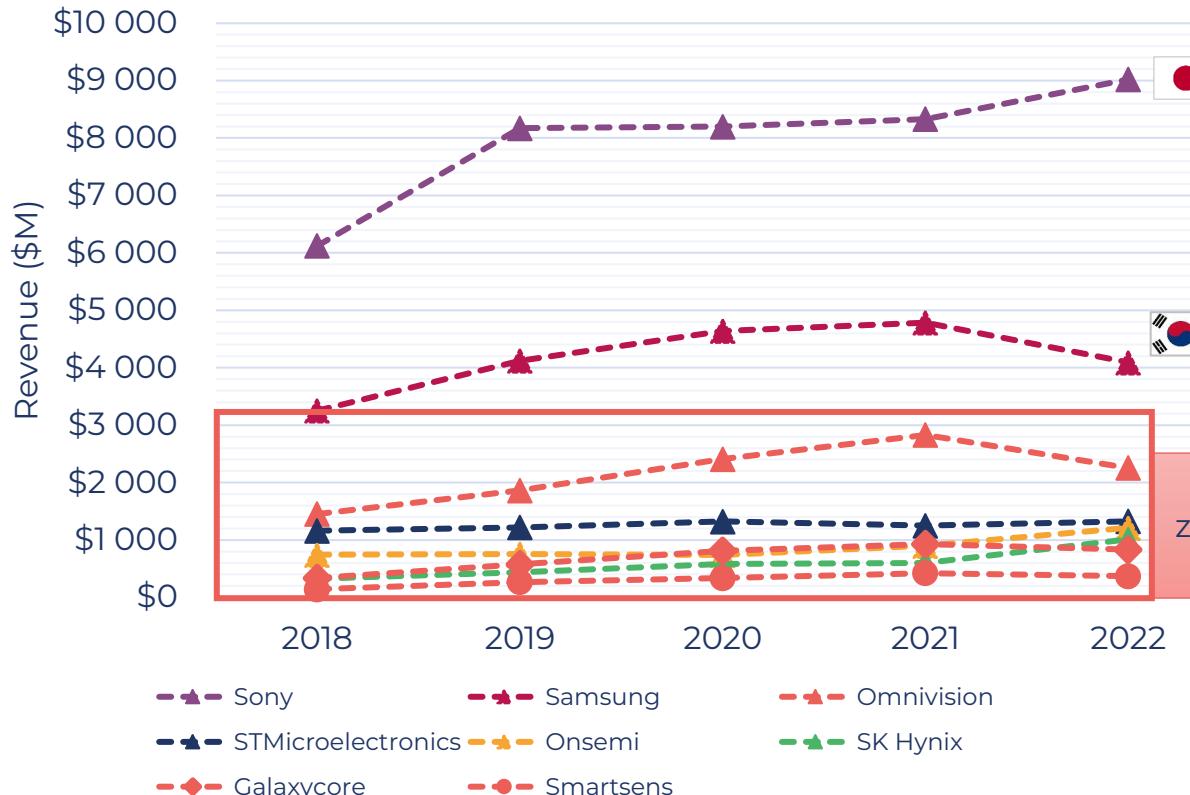


CMOS IMAGE SENSOR MARKET SHARES – FOR ALL APPLICATIONS

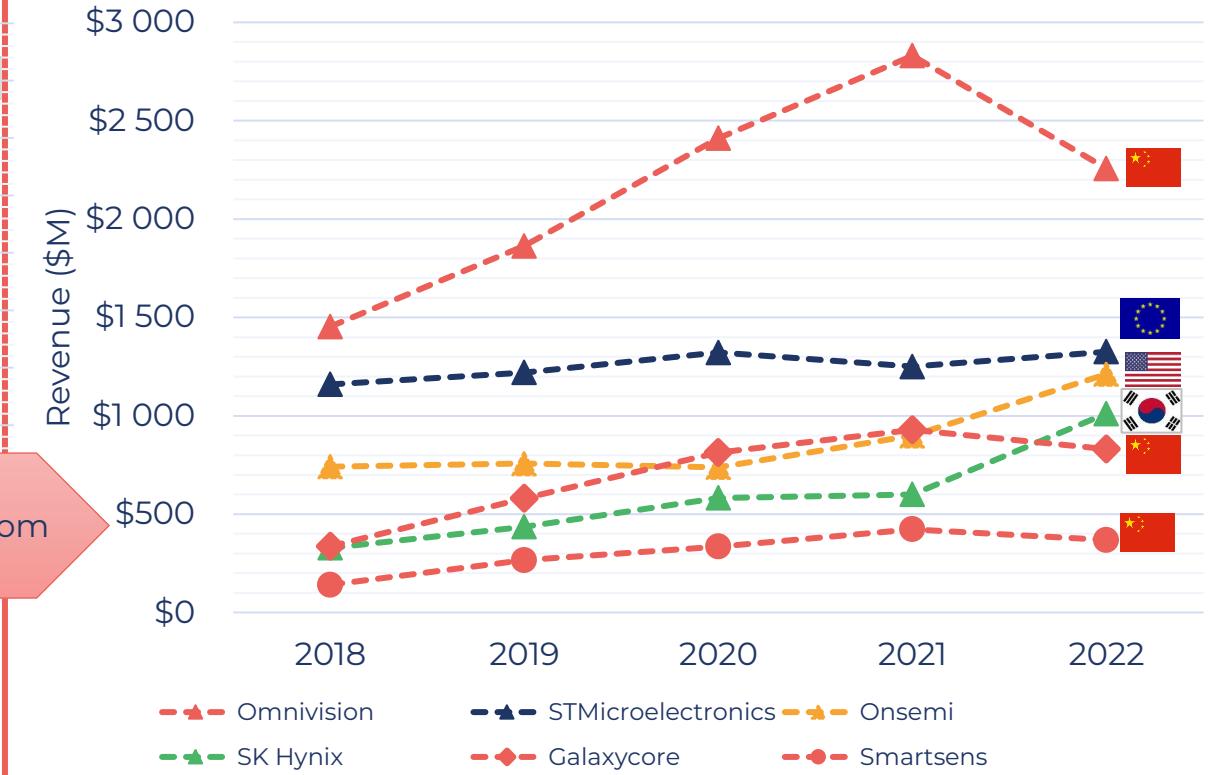
2018-2022 TOP 8 CIS companies' revenue evolution



Companies' revenue evolution
CMOS image sensors (in \$M)



Companies' revenue evolution
CMOS image sensors (in \$M)



- The revenue of Chinese-owned CIS leaders Omniprecision, Galaxycore, and Smartsens declined, while that of Sony, Onsemi, SK Hynix, and STMicroelectronics increased. Samsung was the exception, being quite exposed to the mobile and consumer markets.



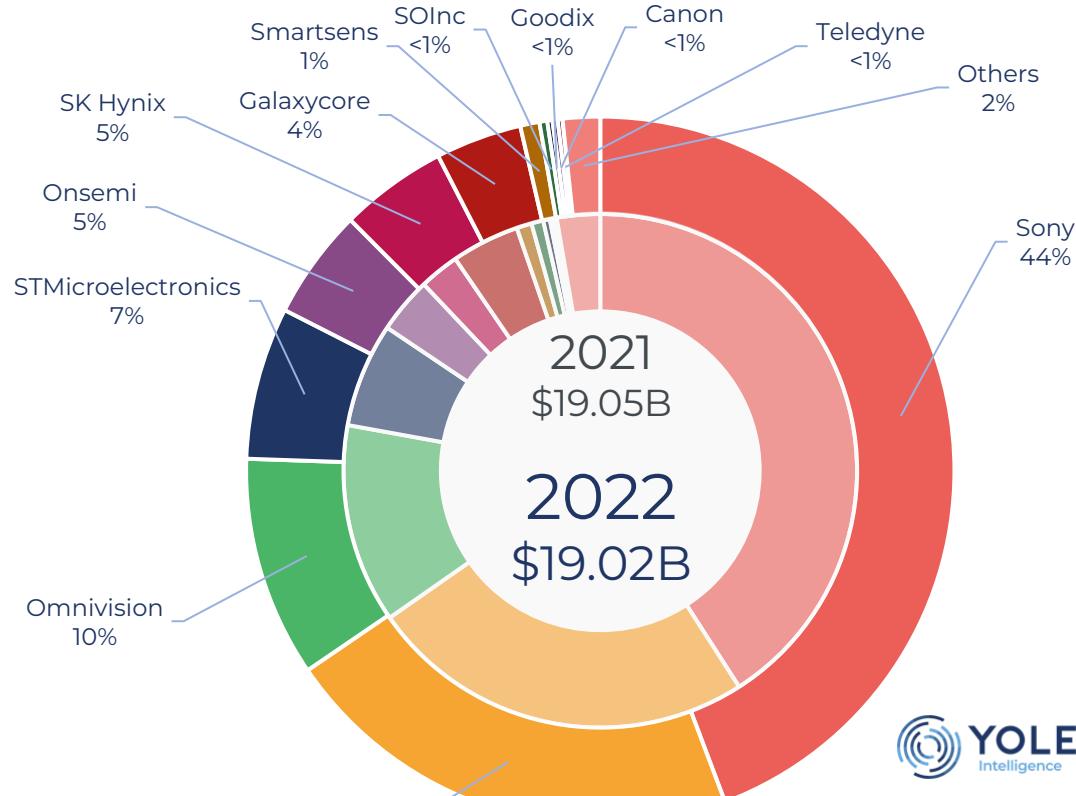
CMOS IMAGE SENSOR MARKET SHARES – FOR CAMERA MODULE ONLY

by player, in \$M (Yole data)



Revenue (\$M)	2021	2022	YoY (%)
Sony	\$7,795	\$8,421	8.0%
Samsung	\$4,649	\$4,035	-13.2%
Omnivision	\$2,391	\$1,915	-19.9%
STMicroelectronics	\$1,250	\$1,323	5.8%
Onsemi	\$672	\$958	42.6%
SK Hynix	\$479	\$932	94.6%
Galaxycore	\$815	\$749	-8.1%
Smartsens	\$181	\$167	-7.7%
SOInc	\$143	\$68	-52.4%
Goodix	\$79	\$45	-43.0%
Canon	\$44	\$45	2.3%
Teledyne	\$39	\$41	6.2%
Others	\$518	\$325	-37.4%
TOTAL	\$19,055	\$19,024	-0.2%

2022 CIS for camera module market share
by player (in % revenue)



Important note: considering the scope of the CCM report, we exclude CIS revenues related to non-compact camera modules (defense & aerospace, some industrial, medical, and consumer photography applications) and remove the related revenues generated by these applications for each CIS player.

A large, abstract graphic consisting of several concentric circles in varying shades of blue, creating a sense of depth and motion.

Optics lens set

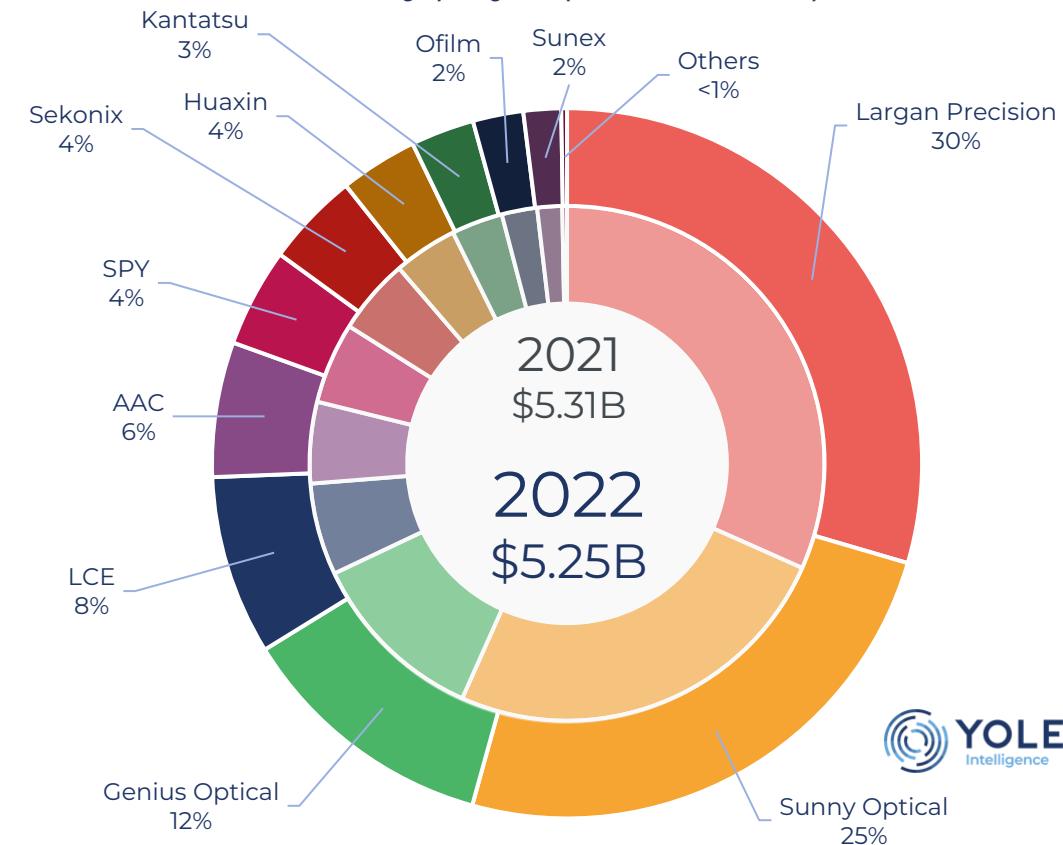


OPTICS LENS SET MARKET SHARES by player, in \$M (Yole data)



Revenue (\$M)	2021	2022	YoY (%)
Lagan Precision	\$1,681	\$1,552	-7.7%
Sunny Optical	\$1,328	\$1,301	-2.0%
Genius Optical	\$599	\$625	4.4%
LCE	\$307	\$429	40.0%
AAC Technologies	\$271	\$323	18.9%
SPY	\$270	\$236	-12.6%
Sekonix	\$252	\$225	-10.7%
Huaxin	\$213	\$186	-12.7%
Kantatsu	\$171	\$152	-11.1%
Ofilm	\$118	\$121	2.3%
Sunex	\$83	\$90	8.4%
Others	\$16	\$14	-12.4%
TOTAL	\$5,309	\$5,254	-1.0%

2022 Optics lens sets for camera module market
share by player (in % revenue)



The “Others” category is estimated to be less than \$20M. We possibly included some players activity that could not always be entered in this report’s scope, for example, non-camera module high-end optics, as it is difficult to differentiate. However, that shows that it is a far less fragmented market than the camera module manufacturing one.



OPTICS LENS SET MARKET SHARES

By player, top five



Largan Precision has gained a significant competitive advantage with several major patents on 5p and 6p lenses and has now upgraded to 7p and 8p lenses. In 2020 and 2021, its revenues started to decline as some of its low-end products had been taken by competitors, and because of the slow replacement of high-end products and price erosion. The decline continued in 2022, affected by slowing opportunities for the Mobile and Computing markets. Largan has also started to serve the Automotive market.



Sunny Optical experienced the same situation as Largan, with a more limited impact as its revenues declined for the past two years. In 2022, it suffered from a -17% shipment decrease for Mobile lens sets but benefited from a +16% increase in Automotive. It is quite active in R&D activity to reinforce its offer for Automotive lens sets, including high resolution from 8 to 17Mp cameras, and large sensor and periscope camera opportunities in Mobile.



Genius Optical is serving Mobile, Autootive but also Consumer XR and medical endoscopy applications. 47% of its revenue is attributed to optics for camera modules with resolution higher than 10Mp, and it is also achieving significant revenues in XR and 3D sensing ToF products. They are expected to strengthen their position as being a major supplier for Apple.



LCE serves Mobile, Consumer, and Automotive markets. It is benefiting from its leadership in Automotive lens sets, ranking 2nd place behind Sunny Optical: in 2022, its global revenues surged by 40%, passing the \$400M. This is certainly due to major design wins with Automotive CCM manufacturers and Tier 1. It has also developed tight relationships with historical customers such as Lenovo, Samsung, and Foxconn.



AAC Technologies continues to increase the development of its optoelectronic business, especially the lenses while continuing to optimize the manufacturing efficiency of its WLO glass hybrid lens sets, and strengthening the product research and development of plastic lenses. It is on a continuous and strong revenue increase, that progressed by 18% in 2022 YoY. It is more closely connected with Xiaomi in Mobile. It has started small-scale mass production of OIS actuators and increased its shipments for camera modules beyond \$50M in revenues. The vast majority of its revenues are still optics lens sets.

The top 5 companies achieved more than 81% market revenues.



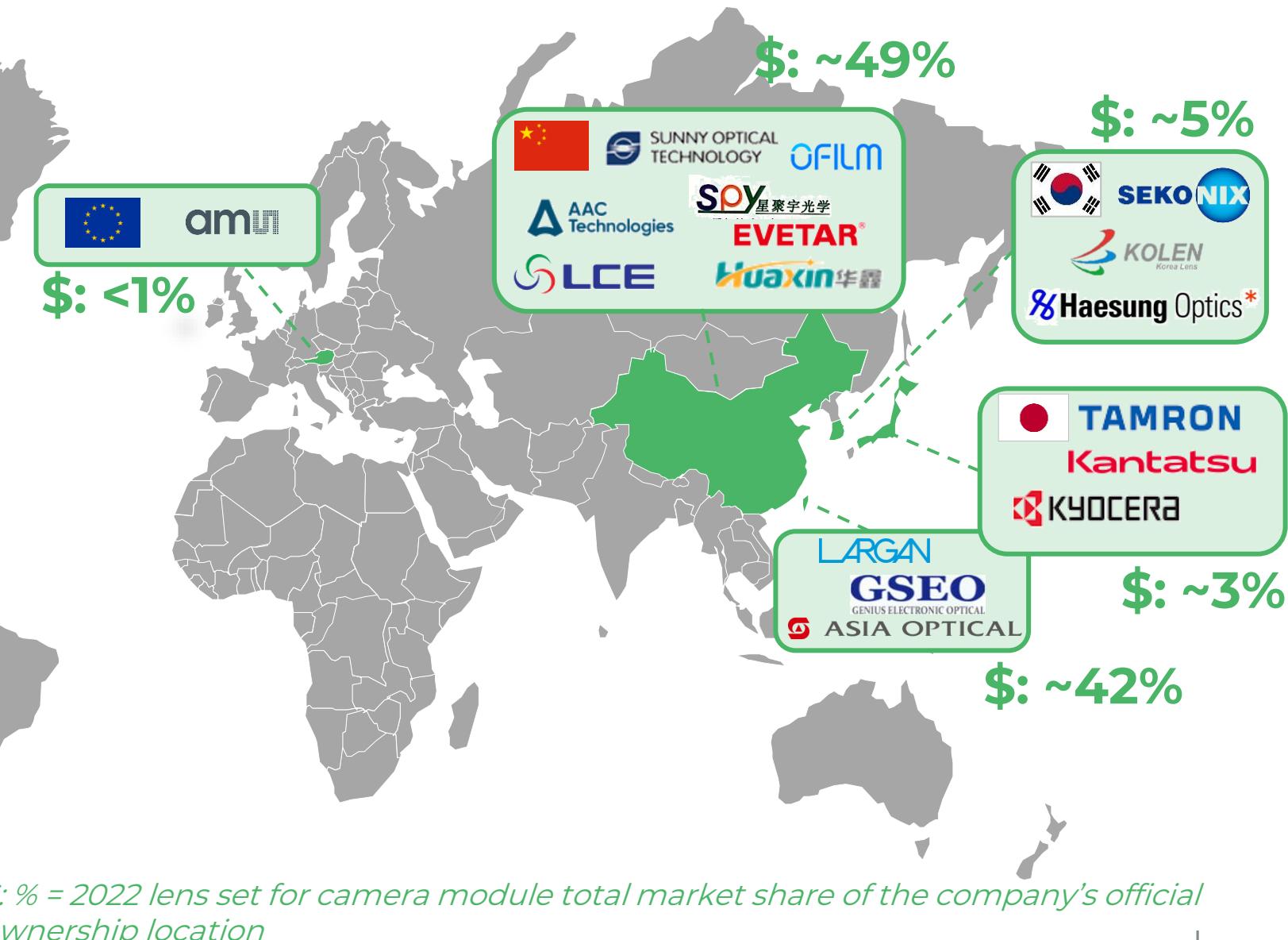
OPTICS LENS SET MARKET SHARES

Competitive map of the TOP optics lens set players



\$: ~1%

More than 90% of the optics lens set revenues are generated by leading companies based in Greater China. The rest of the world suppliers, including Japan, South Korea, USA, and Europe, have achieved 9% revenue with a strong contribution for Automotive, Medical, and Industrial markets lens sets with companies such as Tamron, Kyocera, Sekonix, Sunex, am...

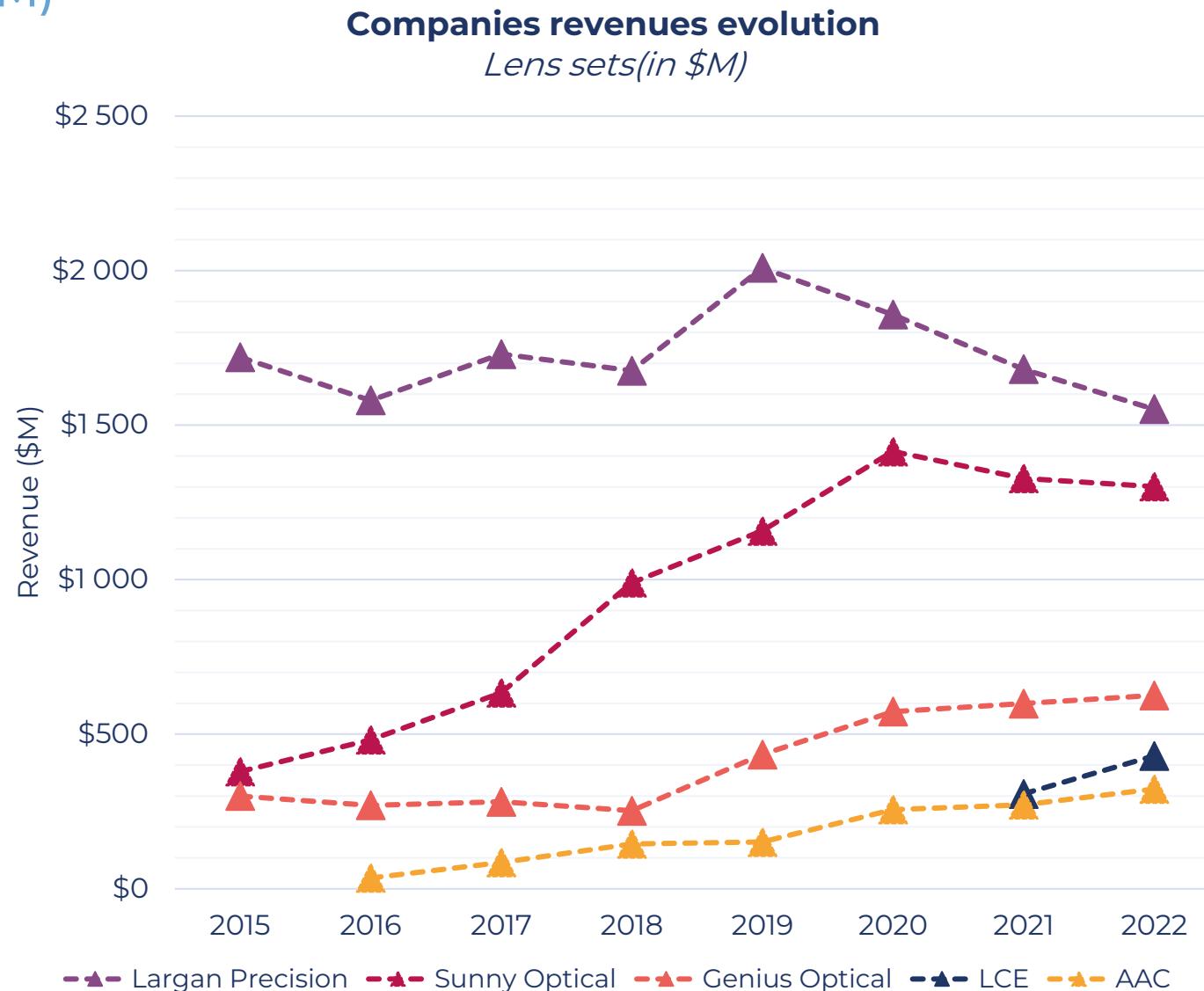




OPTICS LENS SET MARKET SHARES

Lens set - historical market revenue (in \$M)

- The lens set for the camera module industry has followed roughly the same trend as for CCM manufacturing revenues, with continuous growth until 2021, after the recovery from the COVID-19 epidemic. Nevertheless, lens sets revenues slightly decreased in 2022 from \$5.31B to \$5.25B, as a soft landing after the largely inflated growth from the previous years, following a significant slowdown in consumer product sales, such as smartphones (-10%).
- Interestingly, Largan could not pass the \$2.0B milestone as challenged by its competitors and had to share its growth with Sunny Optical, Genius Optical, LCE, AAC, and other smaller players, which have experienced solid and continuous growth and have come with lower pricing for the low-end products.
- For the lens market, the update speed of new camera modules has slowed down, which has led to a decline in the income of the two top players these past three years. The use of multiple cameras has also caused their revenue to decline since it has spawned some new players. It is easier to enter this market and provide low-pixel camera modules. And as their technology is being developed, they are grabbing some of the share of the top players.





Actuator

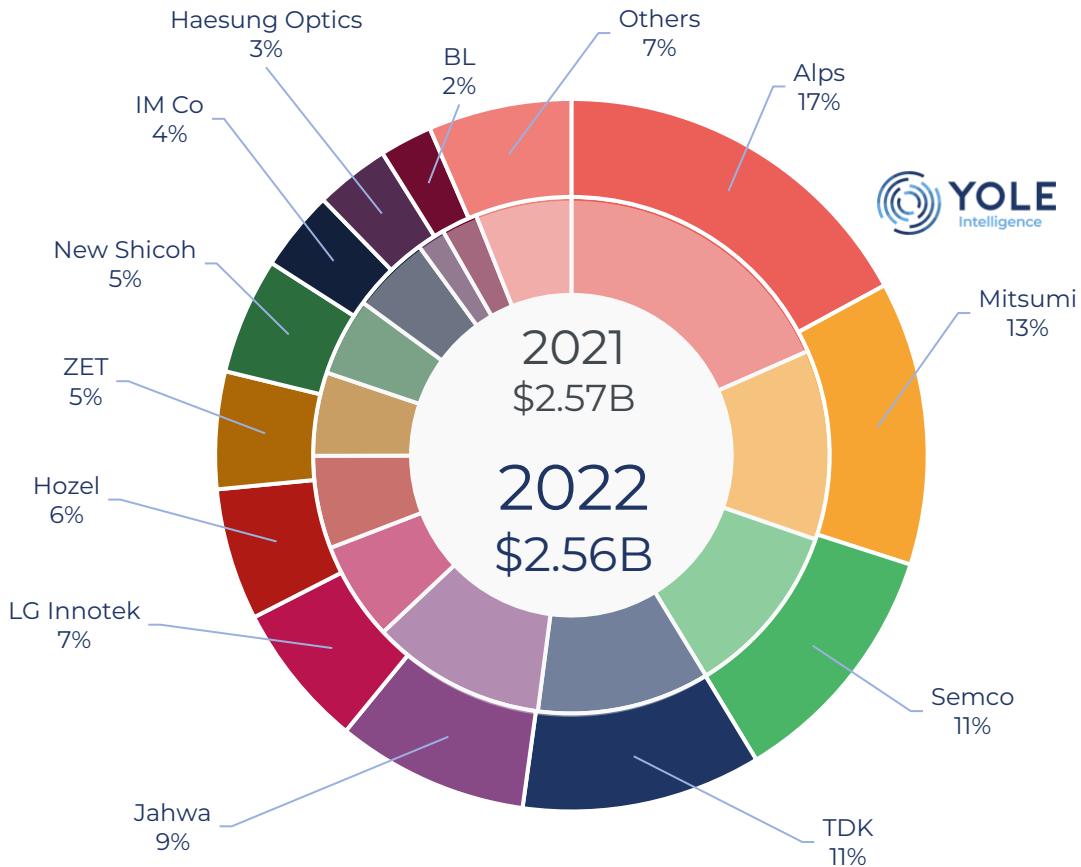


ACTUATOR MARKET SHARES by player, in \$M (Yole data)

2021-2022
actuator
revenue
breakdown
by player.

Revenue (\$M)	2021	2022	YoY (%)
Alps	\$472	\$437	-7.5%
Mitsumi	\$305	\$329	7.9%
Semco	\$282	\$290	2.8%
TDK	\$277	\$278	0.4%
Jahwa	\$280	\$223	-20.4%
LG Innotek	\$158	\$168	6.3%
Hazel	\$149	\$153	2.7%
ZET	\$134	\$136	1.5%
New Shicoh	\$125	\$135	8.0%
IM Co	\$126	\$93	-25.9%
Haesung Optics	\$45	\$86	92.6%
BL	\$58	\$61	5.2%
Others	\$154	\$166	7.8%
TOTAL	\$2,565	\$2,556	-0.4%

2022 Actuators for camera module market
share by player (in % revenue)



"Others" include Yova, Jot and AAC Technologies (China). Haesung Optics retired from the camera module manufacturing and lens set business and has started to deliver OIS actuators for two years.



ACTUATOR MARKET SHARES

By player, top six



ALPS

Alps is the primary source for Apple and took advantage of the upgrade of the iPhone camera from lens-shift to sensor-shift. Nevertheless, it might enter a tough competition for new actuator opportunities in advanced camera modules such as periscopes, as challenged by Jahwa and LG Innotek there. It remained the market leader in 2022 despite a revenue decrease YoY, mainly attributed to JPY vs. USD unfavorable exchange rate in 2022. Beyond VCM products, it has developed high-volume manufacturing of SMA actuators and also plans to develop piezo actuators that should allow it to get new design wins and confirm its leadership position.

MITSUMI

Mitsumi is the 2nd source for Apple and possibly increased its share there, as it achieved 7.9% YoY revenue growth. It provides sensor-shift technology and has developed a high-speed ultrasonic actuator that has a long-stroke advantage. Its devices have also been found in Vivo smartphones, and it is probably expanding in other smartphone models.

SAMSUNG ELECTRO-MECHANICS

Semco obviously serves its own CCM business, mainly for Samsung mobile devices, which ensures steady growth for this division. Its actuator activity takes advantage of a highly vertically integrated business, being a leader in camera module manufacturing, image sensors, and actuators. It benefited in the past from its acquisition of Corephotonics, the company that brought many core CCM innovations to the market, including dual and periscope cameras, and several actuating technologies.

TDK

TDK, in recent years, dropped out of the top three very quickly, as predicted, mainly because other Android OEMs could not fill the gap left by its main customer, Huawei. But it could stabilize its revenues, with a strong competitive technology. In addition, it has diversified in other Consumer applications such as drone photography, XR, and robotics.

JAHWA

Jahwa has been a leading supplier of ball-type OIS/AF actuators, supplying Samsung, Oppo and Xiaomi. It suffered a strong revenue decrease in 2022 YoY (-20%), probably challenged by the striving Chinese suppliers New Shicoh, Hozel, and ZET, that deliver cost-effective solutions, particularly for AF actuators. It is not clear if Jahwa can spend the required significant effort on technology development to bring new performing products and regain market share.

LG Innotek

LG Innotek, the undisputed CCM manufacturing leader, has also developed its product portfolio for actuators. However, its revenues for the actuator's devices have been quite stable since 2018. It is probable that it got new design wins, including the iPhone 15 Pro Max new periscope zoom actuators.

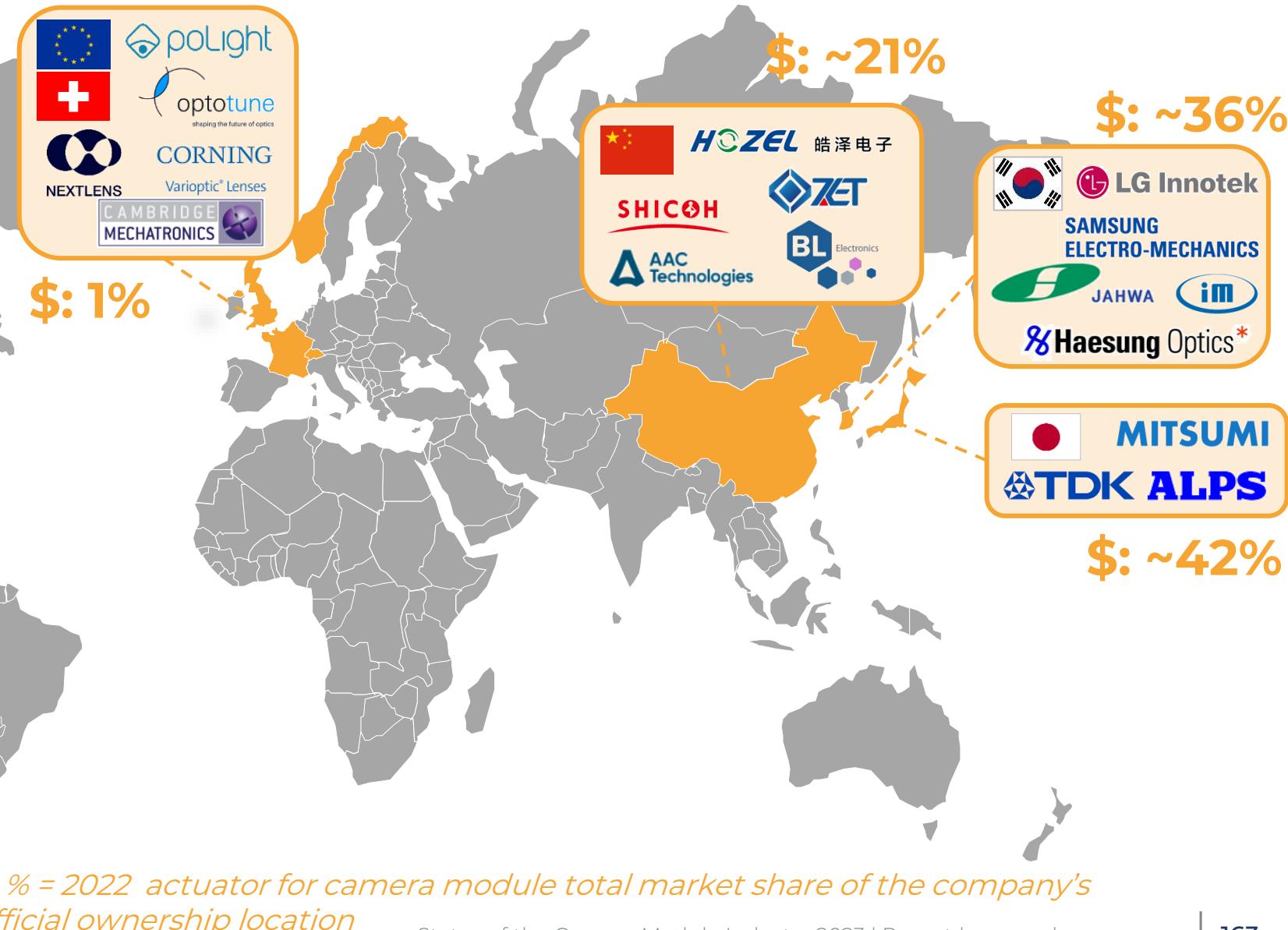


ACTUATOR MARKET SHARES

Competitive map of the TOP actuator players



The actuator business has become a Japanese stronghold, with company revenues thriving to 42% market share. The Korean ecosystem is keeping its leadership at 36% while Chinese newcomers are constantly expanding. In Europe, numerous innovative leading companies are proposing alternatives such as tunable lenses or new actuators. Some of these companies, particularly in Japan, have been historically also involved in hard drive disk magnetic head products.

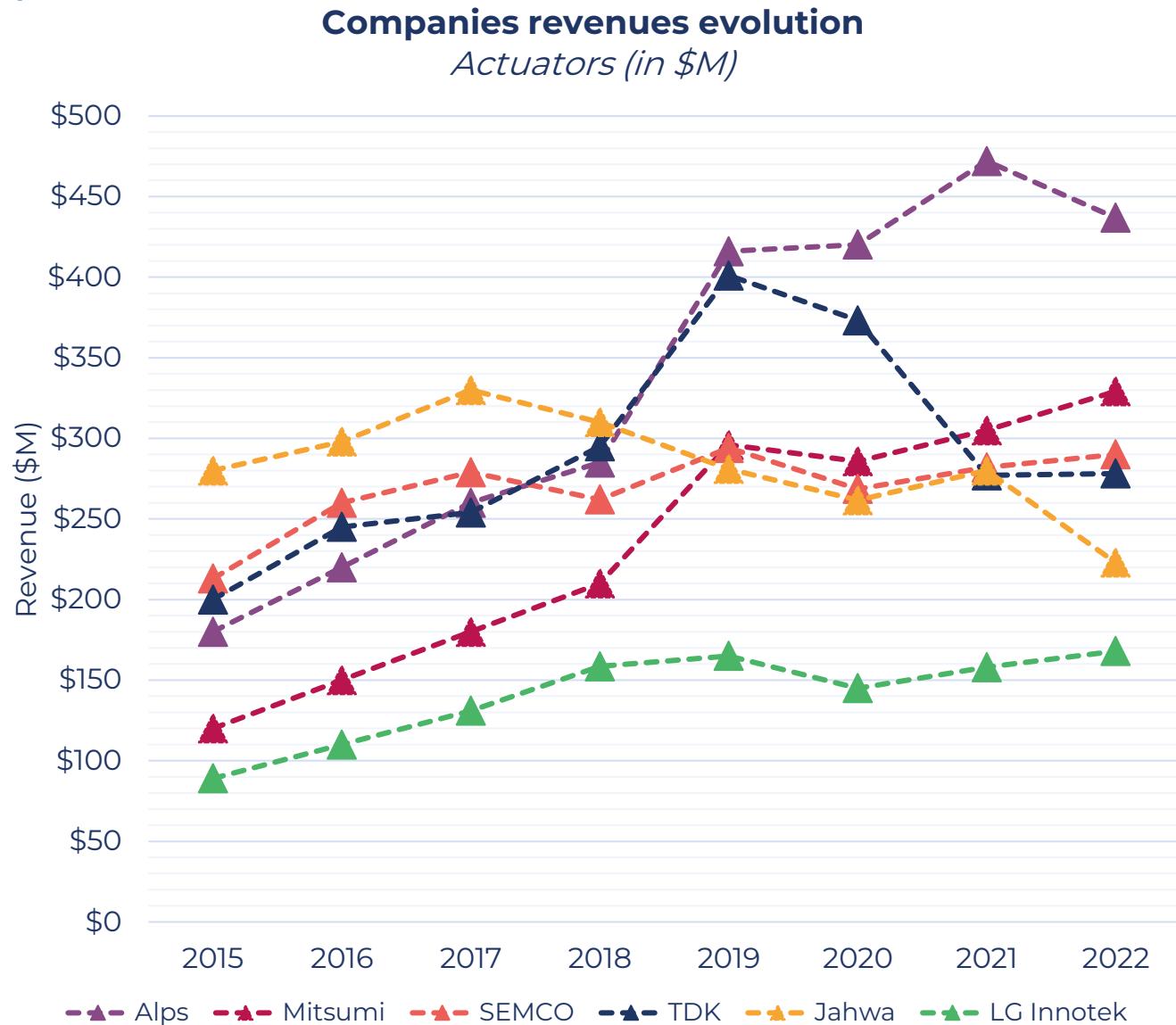




ACTUATOR MARKET SHARES

Actuator - historical market revenue (in \$M)

- CCM actuators revenues have slightly decreased in 2022 from \$2.57B to \$2.56B, following a significant slowdown in consumer product sales, such as smartphones (-10%).
- With the further penetration of AF into middle-end mobile phones, the new OIS technologies such as sensor-shift being increasingly adopted, and the spread of these solutions into the different smartphone cameras, it is expected that the AF & OIS actuator will continue growing in the coming years, supported by new technologies introduction to deliver better performance and cost-effective actuating solution.
- Interestingly, leading Japanese companies, Alps, Mitsumi, and TDK had outperformed the Korean ones, Semco, Jahwa, LG Innotek, in terms of revenue growth from 2015, except TDK, which encountered a large decline from 2020 due to its high exposition to its major declining customer, Huawei, following the ban imposed by the U.S.





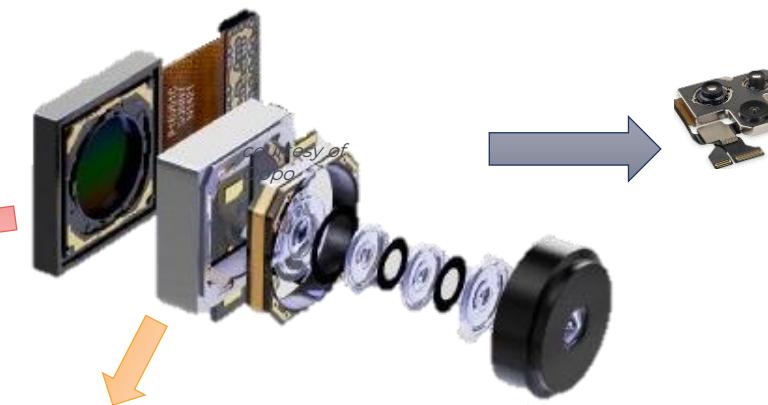
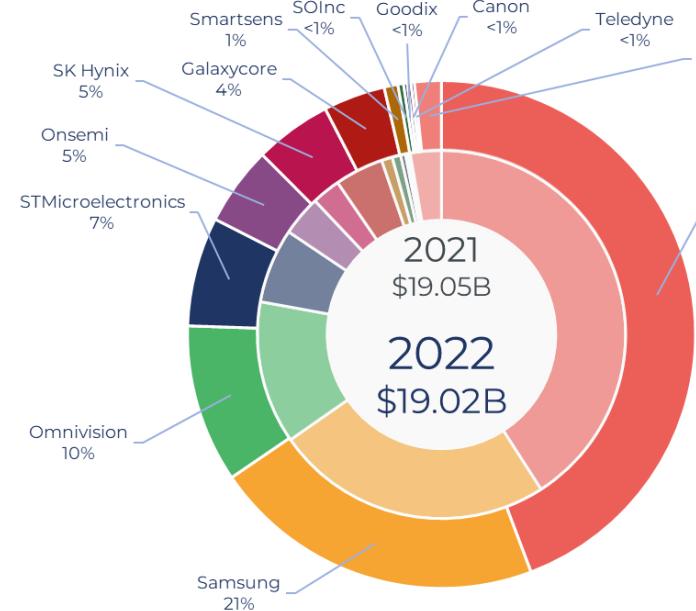
Conclusion

MARKET SHARES & SUPPLY CHAIN

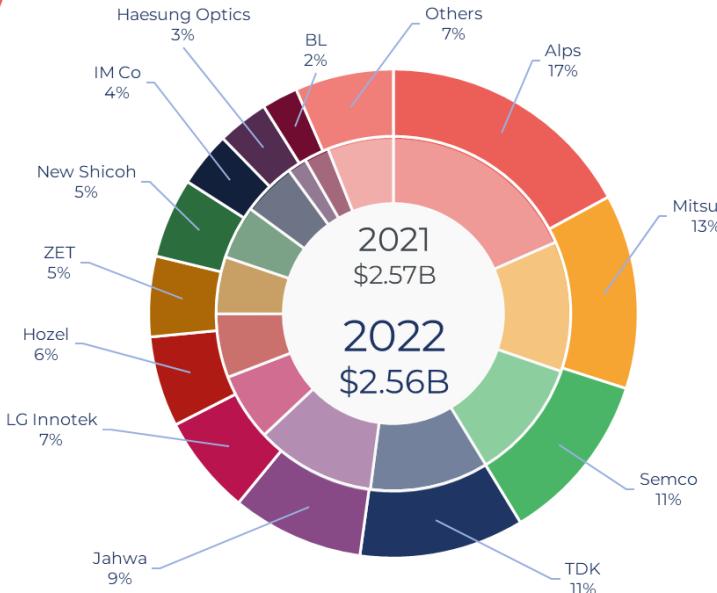
Conclusion



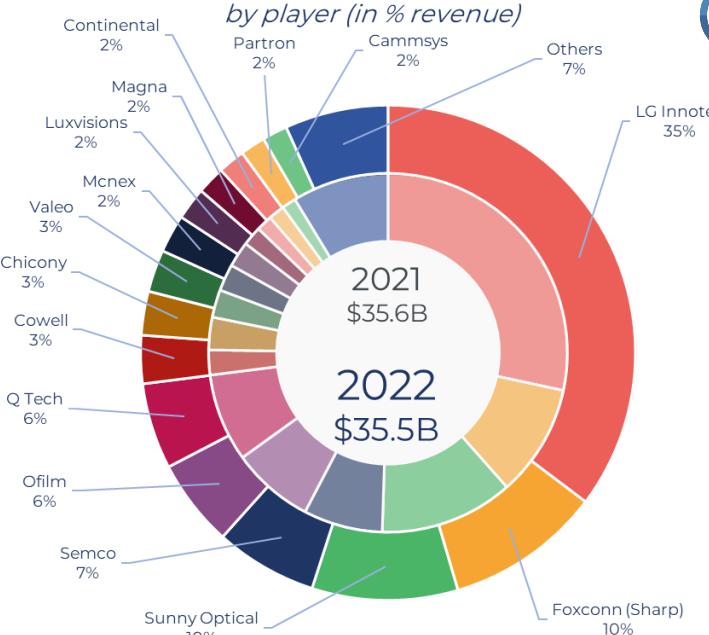
2022 CIS for camera module market share by player (in % revenue)



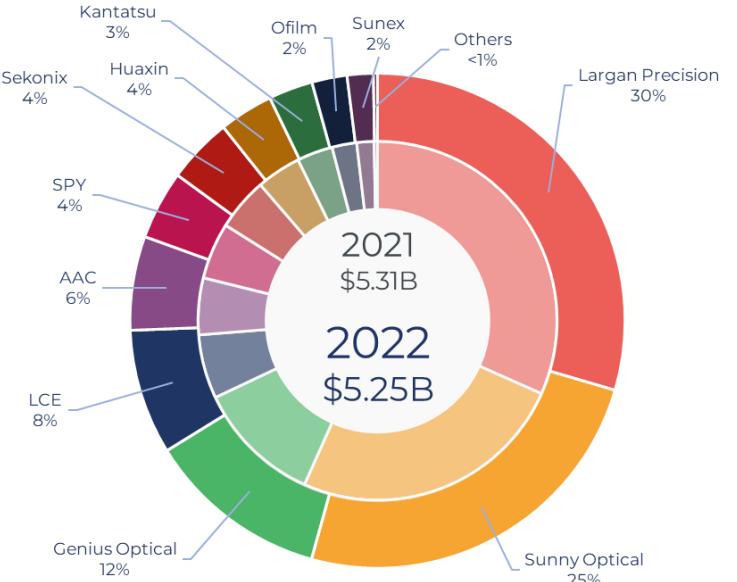
2022 Actuators for camera module market share by player (in % revenue)



2022 Camera Module market share by player (in % revenue)



2022 Optics lens sets for camera module market share by player (in % revenue)





MARKET SHARES & SUPPLY CHAIN

Conclusion

- CCM revenues have slightly decreased in 2022 from \$35.6B to \$35.5B, as a soft landing after the largely inflated growth from the previous years. The general inflation worldwide in 2022 resulted in a significant slowdown in consumer product sales, such as smartphones (-10%). In this context, CCM manufacturers continued to experience different fortunes, and previous revenue trends have been exacerbated in 2022: LG's continued on its tremendous growth, with 24% YoY, and could outperform its competitors, still supplying all rear triple-camera and sensing cameras to Apple and getting new opportunities in Automotive. Q Tech also continued to grow until 2021 due to an increase in high-resolution cameras in its product mix and being a supplier for Xiaomi, Oppo, and Vivo camera modules. However, Sunny Optical and Ofilm, show decreasing revenue. The main reason for this has been the past restrictions on Huawei. Foxconn (Sharp) and Semco have been quite stable in revenue these past few years, the latter getting more diversified in Automotive.
- For CIS, 2022 has been a transition year with similar revenues to the year before and a slight decline in overall volumes. However, a significant transformation is underway in the CIS market structure, as evident in the growth of the Automotive segment and the increase in CIS average selling price. Sony is again increasing its commanding position while Omnisvision has retreated to close to its pre-COVID market share. Samsung also reduced its footprint, apparently to the benefit of SK Hynix. Onsemi, which had been sliding for a few years, saw an exceptional 2022 boosted by the Automotive and Industrial markets. Galaxycore and Smartsens have retreated, apparently due to the disinflation of the low-end Mobile and Security camera markets. The geographically competitive CIS landscape is marked by the economic conflict between the U.S. and China.
- More than 90% of the optics lens set revenues are generated by leading companies based in Greater China, with the lens set revenues that have decreased in 2022 from \$5.31B to \$5.25B. Interestingly, Largan could not pass the \$2.0B milestone as challenged by its competitors and had to share its growth with Sunny Optical, Genius Optical, LCE, AAC, and other smaller players that have experienced solid and continuous growth. For the lens market, the update speed of new camera modules has slowed down, which has led to a decline in the income of the two top players these past three years. AAC is the leader in WLO glass manufacturing, advocating for glass-plastic hybrid lenses.
- CCM actuators revenues have imperceptibly decreased in 2022 from \$2.57B to \$2.56B. Interestingly, Japanese actuator leading companies Alps, Mitsumi, and TDK had outperformed the Korean ones Semco, Jahwa, LG Innotek in terms of revenue growth from 2015, except TDK which encountered a large decline from 2020 due to its high exposition to its major declining customer, Huawei, following the ban imposed by the U.S. Among the AF and OIS actuator supply chains, new entrants have mastered the simpler AF technology, reduced costs, and gradually gained some market share. However, high-end OIS actuators are still concentrated among the top players.
- With the slowdown in the Mobile and Computing market, there are overall ongoing investments to either secure capacity, develop in-house technologies, or license them as a strategic vision to get further market share. CCM manufacturers and CIS giants are dominating the revenue ranking: LG Innotek, Sony, Sunny Optical, Samsung, Foxconn... In the race to build and strengthen an alternative supply chain, major investments have been announced in CCM production capacity in Vietnam factories, with more than \$6B investment since 2022. Finally, even if there was an evolution in the market share rankings caused by the slowing growth of the Mobile and Consumer market and the thrive of Automotive, the leaders are still there, and there is only a small space for new entrants to gain a foothold.



TECHNOLOGY TRENDS



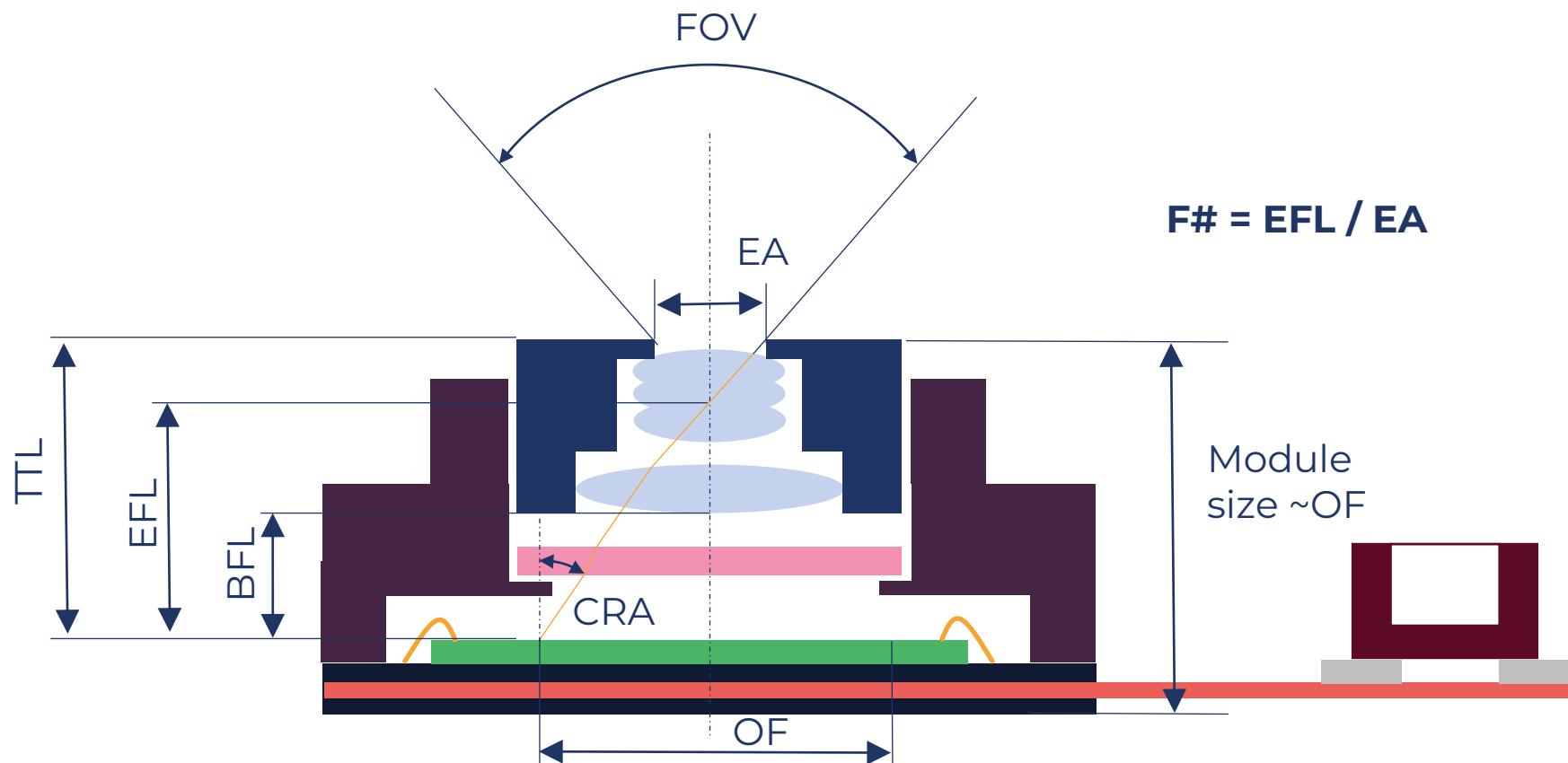
General trends

TECHNOLOGY TRENDS

Optics glossary

- EA Effective Aperture
- BFL Back Focal Length
- CRA Chief Ray Angle
- EFL Effective Focal Length

- FOV Field Of View
- OF Optical Format
- TTL Total Track Length



Innovation path for the CCM industry

Manufacturing

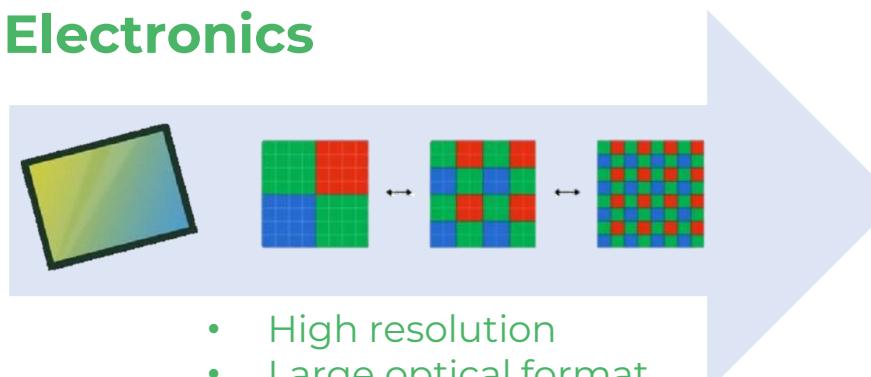
- Active alignment process
 - COB
 - Flip-chip

Camera diversity

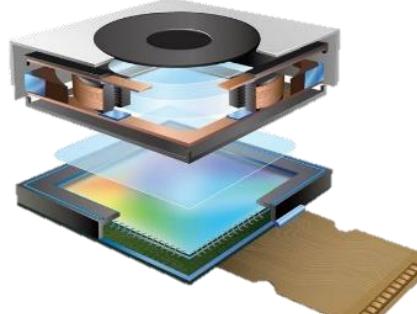
- 3D sensing camera
 - Under-display camera
 - Multi-camera...



Electronics



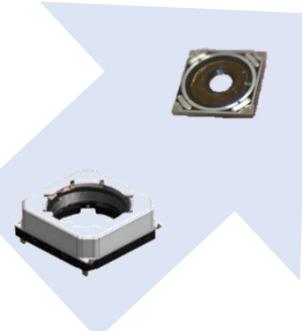
- High resolution
 - Large optical format
 - In-pixel hybrid stack
 - PDAF
 - Quantum dots
 - Curved sensor



Optics



- High number of lens elements
 - ✓ 7p, 8p and 9p
 - Periscope
 - Hybrid Lens (WLG glass+ Plastic)
 - Free-form lens
 - Metalens

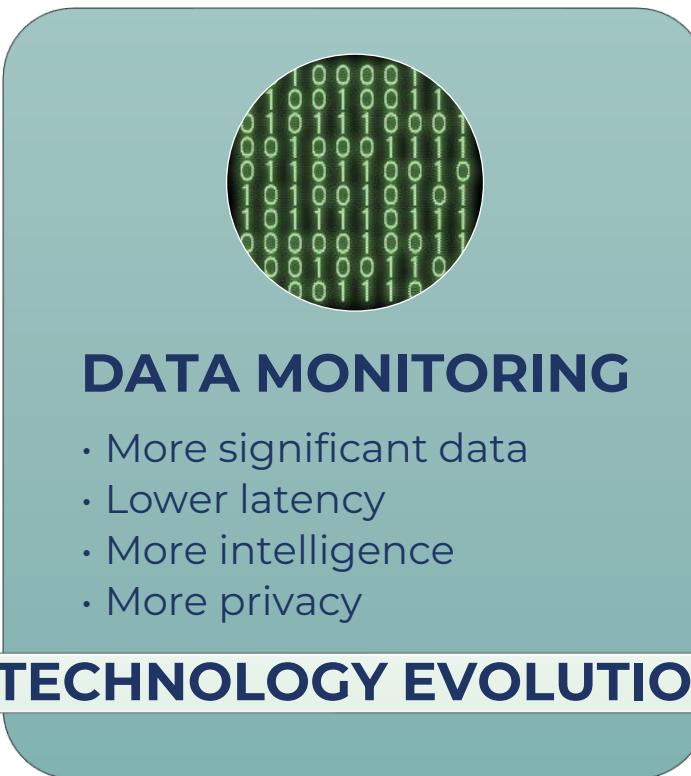
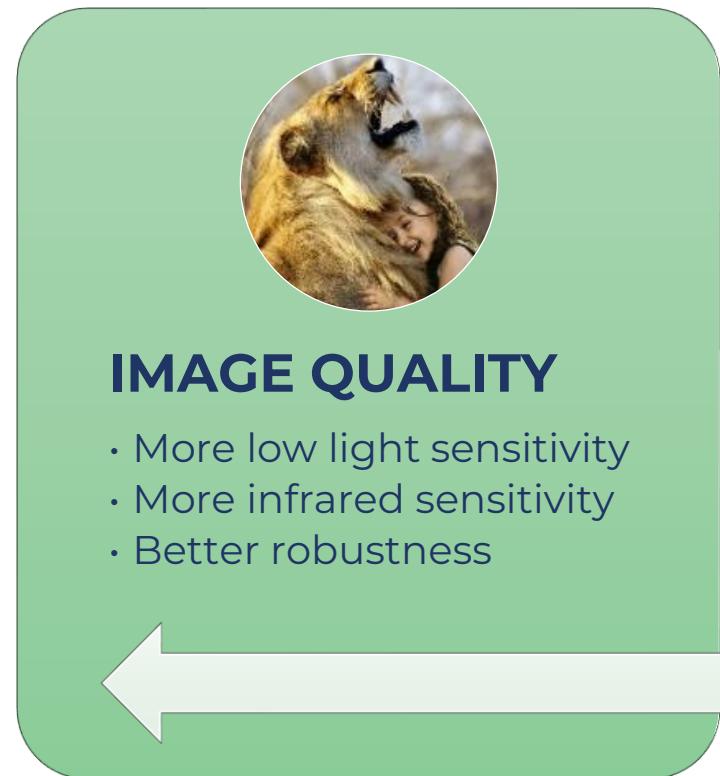


Electro-Mechanics



TECHNOLOGY TRENDS

Improving image and data quality, compactness...



TECHNOLOGY EVOLUTION

Stacked sensor

Hybrid lens

Liquid lens

Curved sensor

Metalens

Stacked sensor

SMA actuator

SMA actuator

Metalens

Stacked sensor

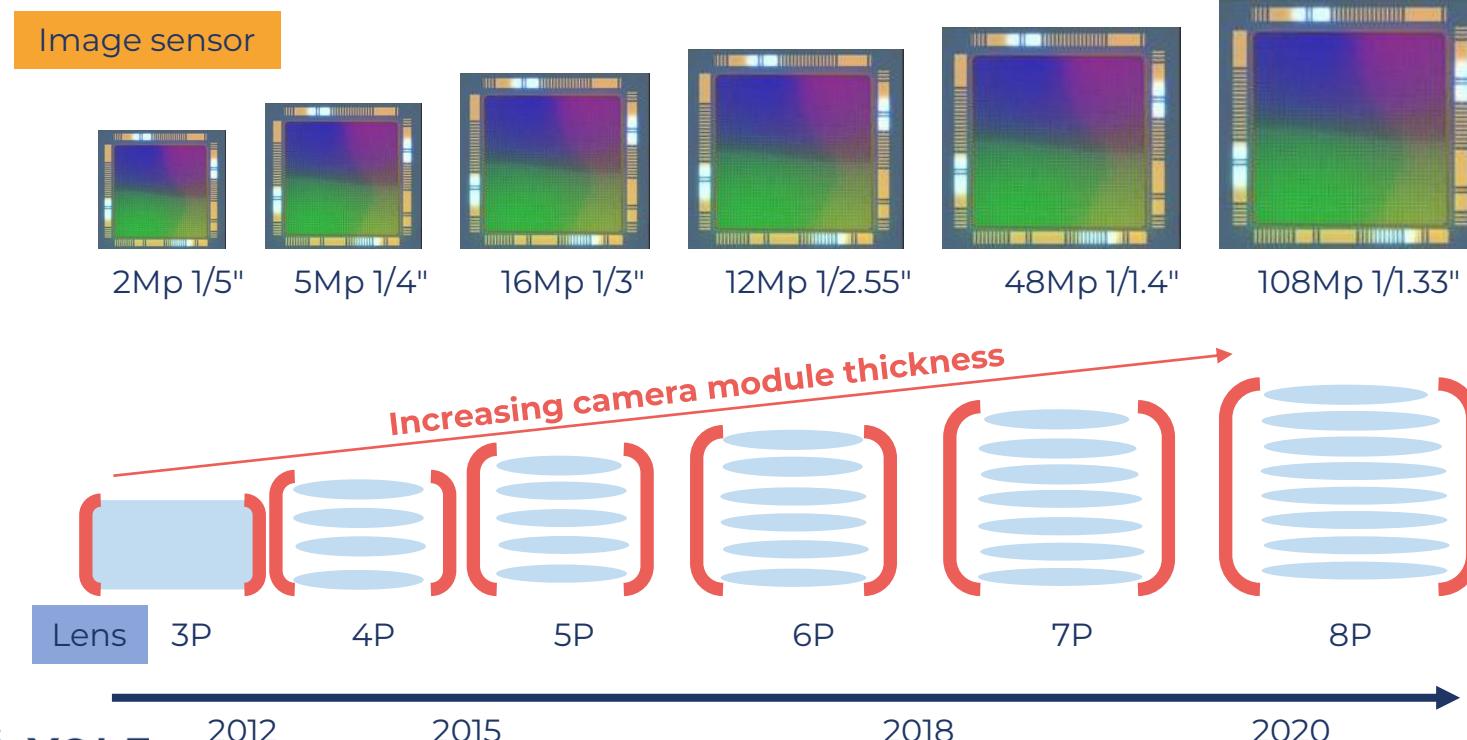
Curved sensor



TECHNOLOGY TRENDS

Consequences of image quality pressure (Mobile rear applications)

- Higher image quality requires not only higher sensor resolution but also larger pixel size, to increase light collection. This implies more accurate optical corrections in front of the sensor, which is currently done by increasing the number of stacked lenses.
- As this number increases, the cost and size of the lens module rises. Integrators are now looking for solutions to limit these increases.
- One objective is to replace one or several refractive lenses.



Higher image quality



Higher resolution image sensors



Increasing number of stacked lenses

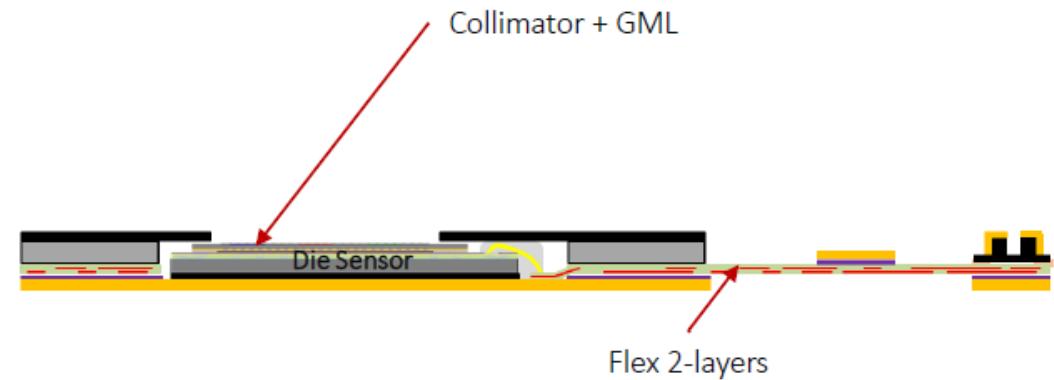
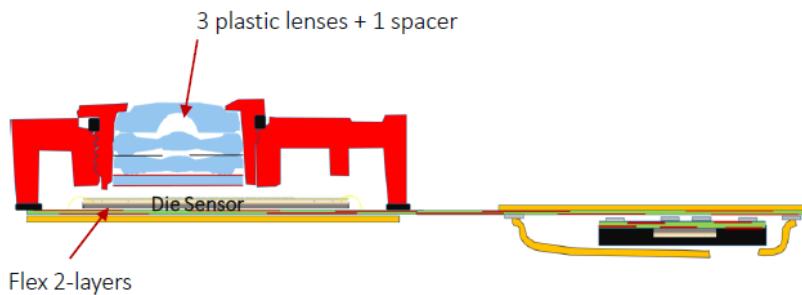
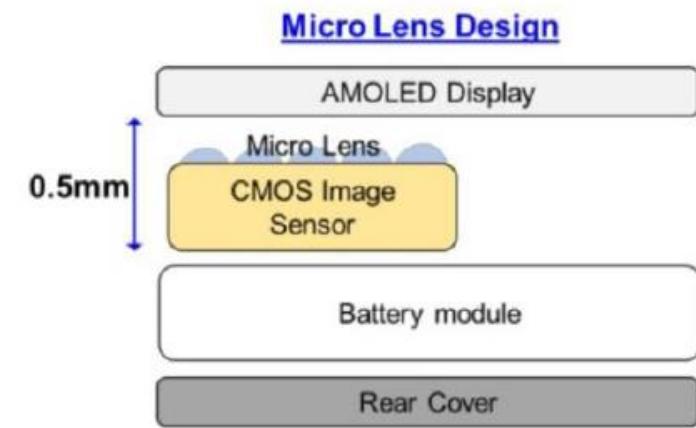
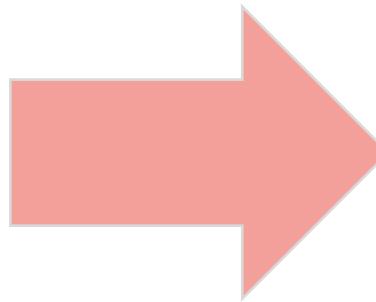
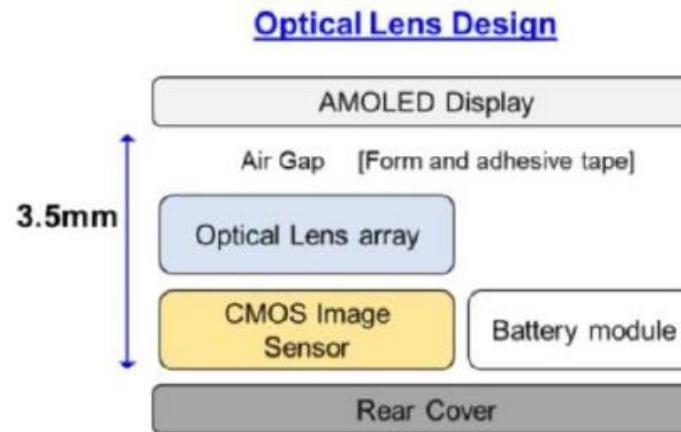


Increasing cost



Increasing size

Need to simplify and reduce size of optical module



GOODIX
GOODIX

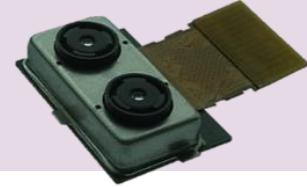
Version	Metal Plate	FPC	Sensor Technology	Sensor Marking	ASIC Marking	Glass Substrate	Filter
Goodix 2020	YES	Flex 2-layers	4M	RC2603TA7_25	-	-	Deposition on Die
Goodix 2019	YES	Flex 2-layers	4M	TC2403G0	GM185	YES	Deposition on glass substrate



TECHNOLOGY TRENDS

3D imaging and sensing technologies in Mobile and Consumer

Depth-sensing technologies in mobile and consumer devices

	Active stereo vision	Structured light	Time-of-flight
Image resolution	Several Mp	Max. 1-3 Mp	Max. 1Mp
Hardware	Simple cameras Complex system	Demanding illumination Complex system	Simple illumination Complex sensors
Computational power	High	Medium	Low
Limitations	May require illumination in low light, good for outdoor	Best indoors Need power	Best indoors Low resolution
Picture (example)		 <small>Courtesy of Apple</small>	 <small>Courtesy of LGIT</small>
Best suited for	Robotic & drone navigation	Short-range face recognition	3D mapping
Depth range	Limited (up to 20m for drone)	Shorter (<1-2m)	Higher (up to 8m)

Some historical players
(non-exhaustive)

   
  
SMARTSENS

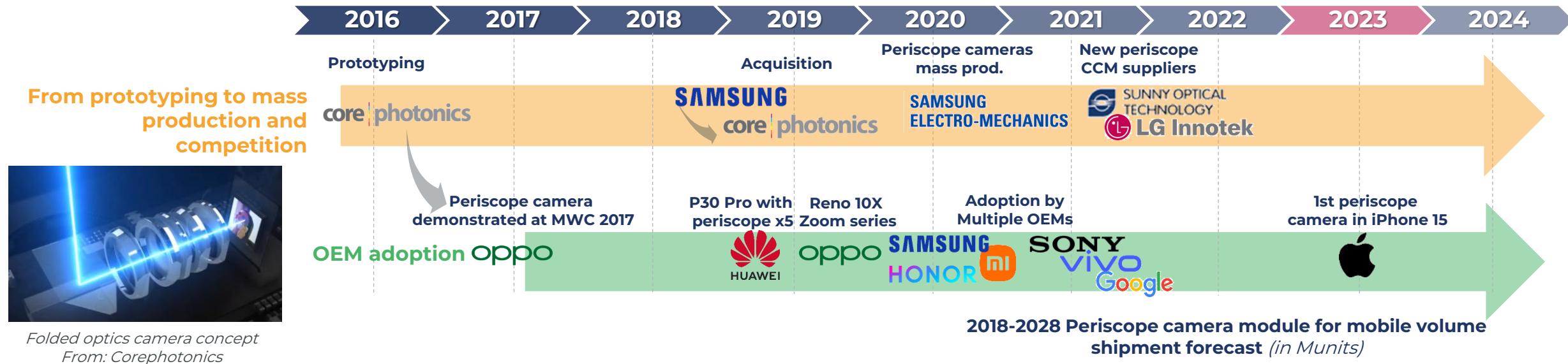
  
   

   
   
AHEAD OF WHAT'S POSSIBLE™

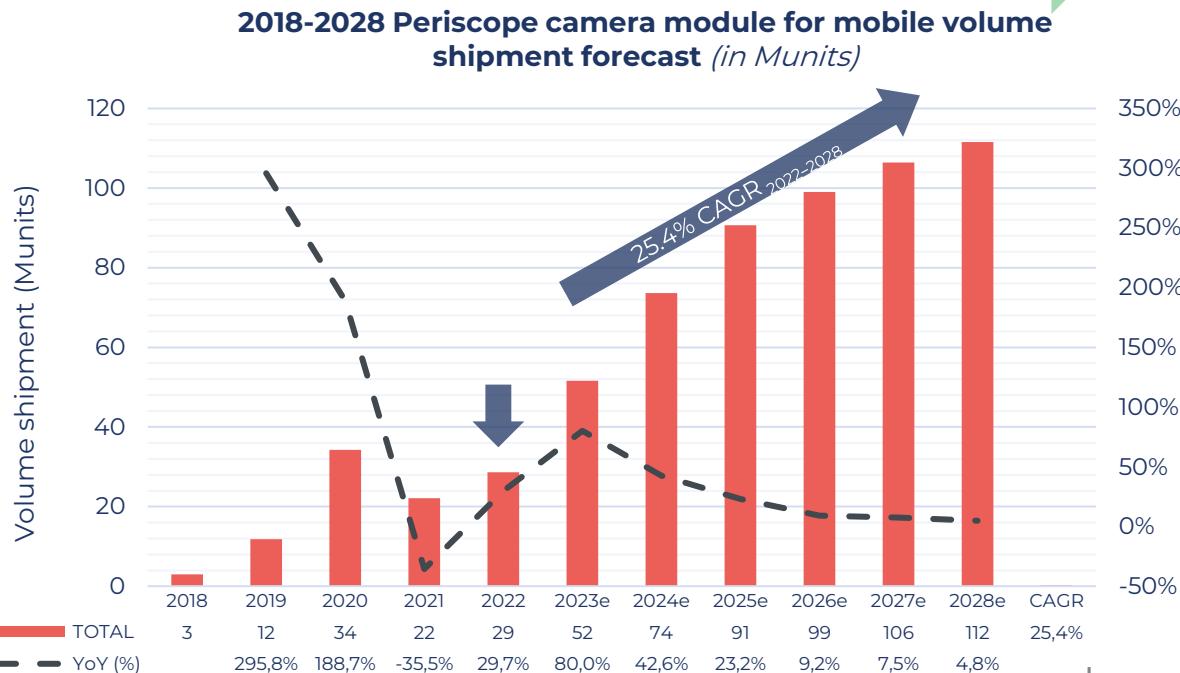


TECHNOLOGY TRENDS

History of periscope cameras in Mobile



- Zoom has always been a key differentiator for high-quality imaging and, consequently, smartphone OEM competition. In 2018, moving from dual to triple cameras at the rear opened new possibilities to improve optical zoom performance.
- Modern periscopic cameras, also named « folded optics » cameras, have been unveiled in MWC 2017 by Oppo from Corephonics technology. Samsung rushed to acquire Corephotonic in 2019 and initiated mass production. Huawei could successfully introduce periscope cameras to the market thanks to significant volumes (> 10M units) that allowed a return on investment.
- From the first commercial cameras in 2019 released by Huawei and Oppo, there has been a folded optics camera adoption wave from Android OEMs from 2020 to 2021. Lastly, in 2023, Apple introduced for the first time a periscope « folded optics » camera in its iPhone 15 Pro Max series, which has given additional momentum to the expected growth. It should get adopted not only in flagships but also in mid to high-end phones in the future thanks to module cost reduction.
- We consider 29M units of cameras to have been shipped in 2022, and it should increase to 112M units of cameras by 2028, with an associated 25.4% CAGR.





TECHNOLOGY TRENDS

Overview of new CCM innovations comparison table

Sub-component	Innovation path	Performance			Module compactness		Cost	Active companies*
		Sensitivity	Optical perf.	Reliability	XY footprint	Z-height		
Image sensor	Triple stack sensor	Green	Orange	Orange	Green	Orange	Red	SONY OMNIVISION™
Image sensor	Curved sensor	Orange	Green	Orange	Orange	Green	Yellow	CURVE-ONE REVOLUTION FOR IMAGING SYSTEMS
Optics	Liquid lens/tunable polymer	Orange	Green	Green	Orange	Green	Red	Varioptic® Lenses
Optics	Metalens (passive metasurface)	Green	Green	Orange	Orange	Green	Yellow	
Optics	Hybrid lenses (moving from plastic to glass) Mobile & Consumer	Orange	Green	Green	Orange	Orange	Red	
Optics	Hybrid lenses (moving from glass to plastic) Automotive	Orange	Red	Red	Green	Green	Green	
Actuators	SMA actuator	Orange	Green	Green	Orange	Green	Red	

Brings a significant progress

Neutral or compensated impact

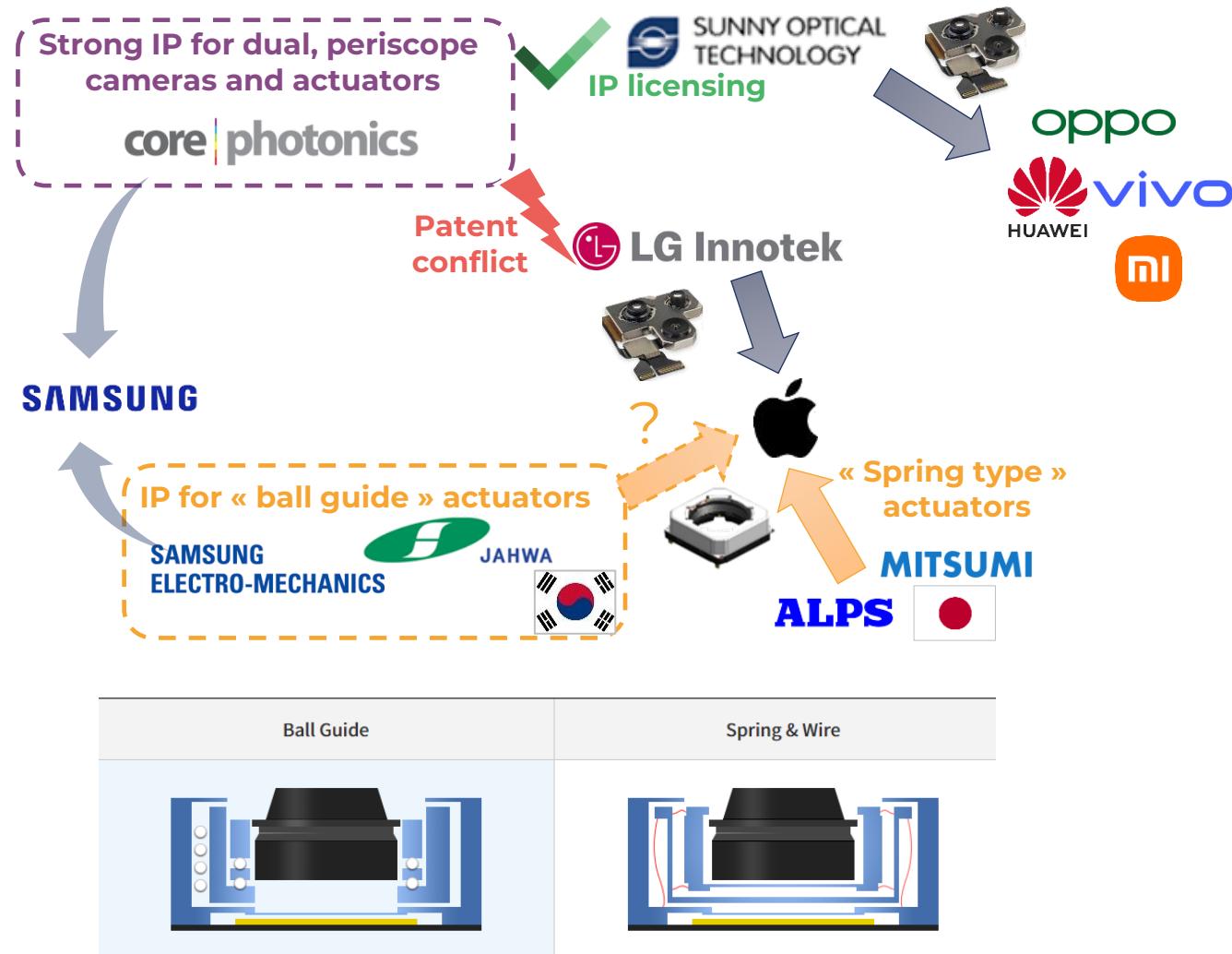
Degradation

*non-exhaustive list



TECHNOLOGY TRENDS

IP battles around camera module technology



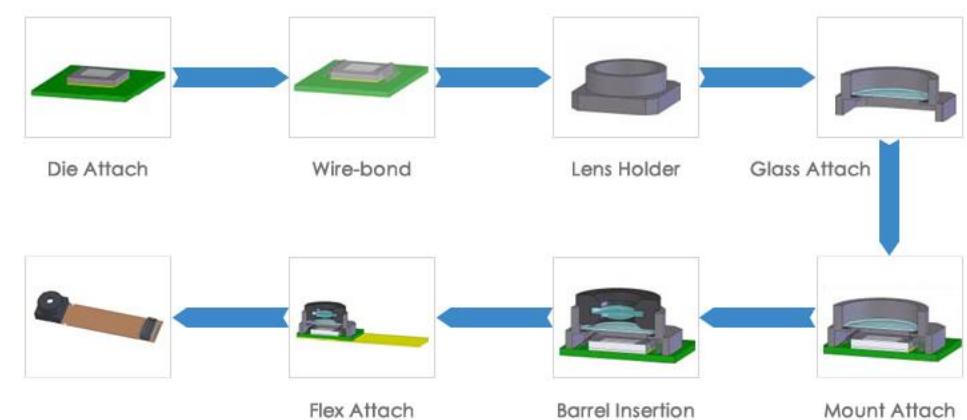
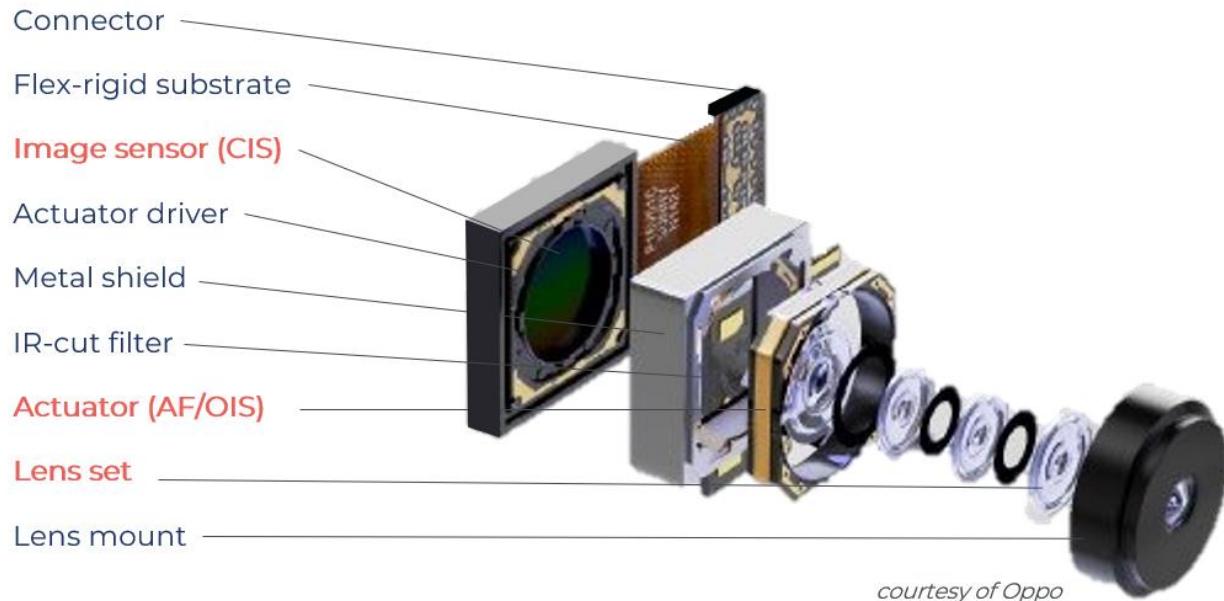
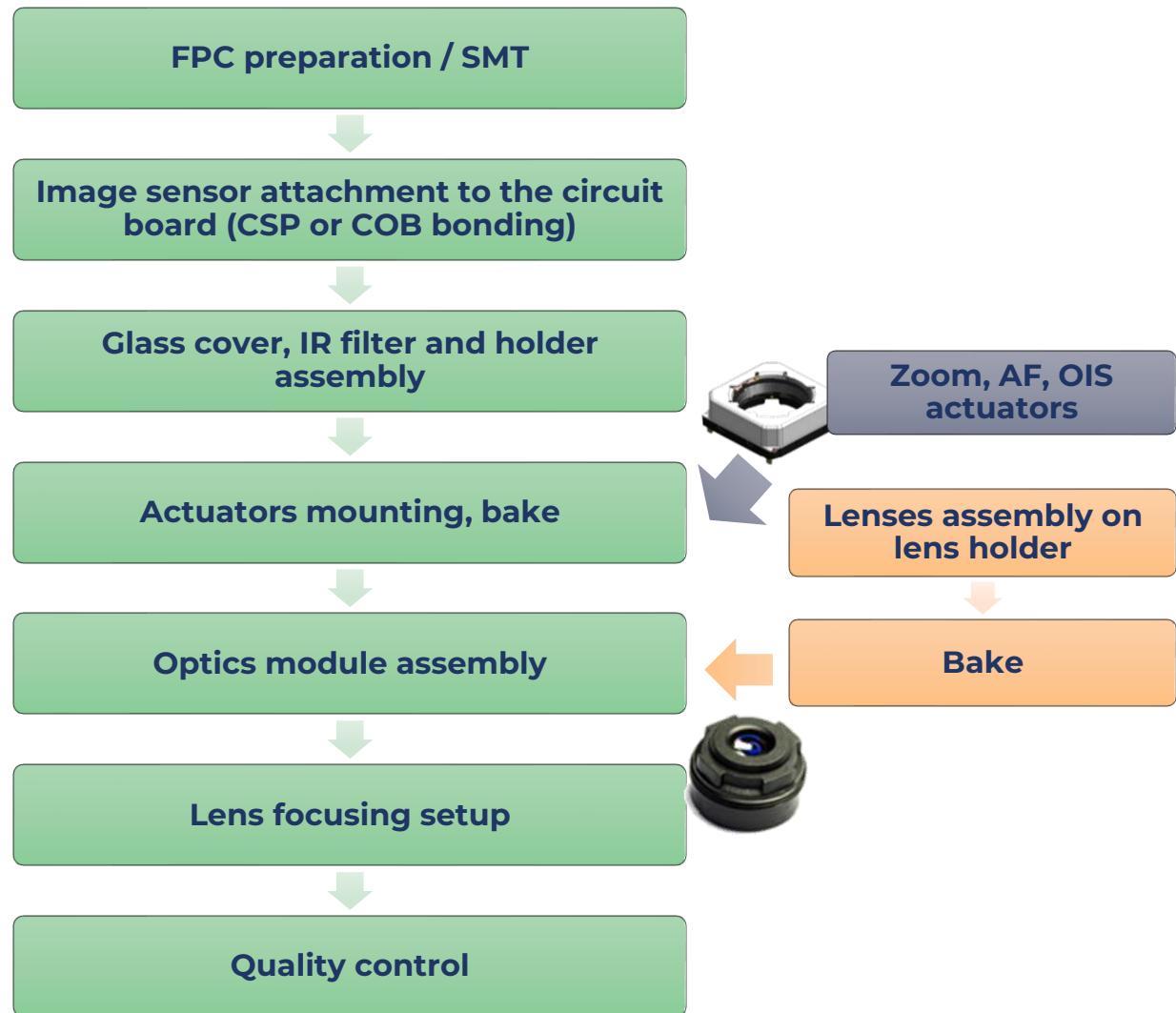
- Jahwa collaborated with Semco to develop ball-guide actuators, a highly desired actuating technology for larger cameras, including periscopes, to bring further speed, reliability and accuracy over spring-type actuators. However, some critical patents cover these ball-type actuators and their associated OIS system. For new cameras such as the periscope, Apple could not use TDK and Mitsumi, that can only provide spring-type actuators. Therefore it should use suppliers such as Jahwa or Semco.
- Nevertheless, patent infringements oppose Corephotonics, the historical innovation company in multi-camera, periscope and actuators solutions, that was acquired by Samsung, to LG Innotek, Apple and certainly other China-based CCM suppliers, while as an example, Sunny Optical had patented its IP to serve its OEM customers.
- Apple is then evolving in a constrained space in terms of camera module technological innovation and supply chain. First, Samsung is a clear competitor in smartphone suppliers. In addition, through its Semco and Corephotonic activities, it is conflicting with LG Innotek and Apple.

Camera module assembly



TECHNOLOGY TRENDS

Manufacturing: convergence of semiconductor packaging and electro-optical assembly

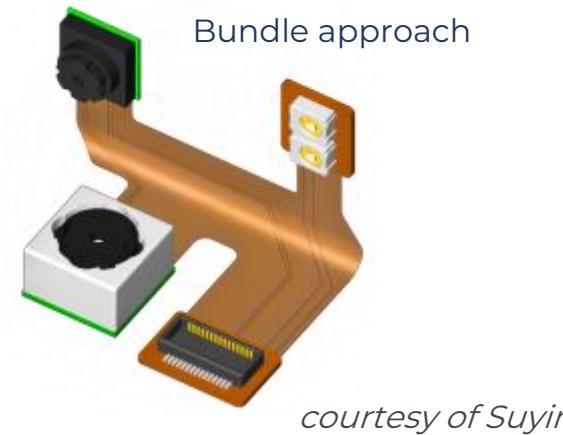


TECHNOLOGY TRENDS

Connectors

- Mobile CCM connection is primarily through flex and connectors of different types:
 - Board-to-board connectors
 - Zero Insertion Force connectors
- While the number of connections increases and the main board space becomes critical, the connection's pitch is reduced from 0.5mm to 0.35mm.
- For low-end smartphones, the approach is to bundle cameras and LED on one flexible circuit.

One 2 x 12 connector

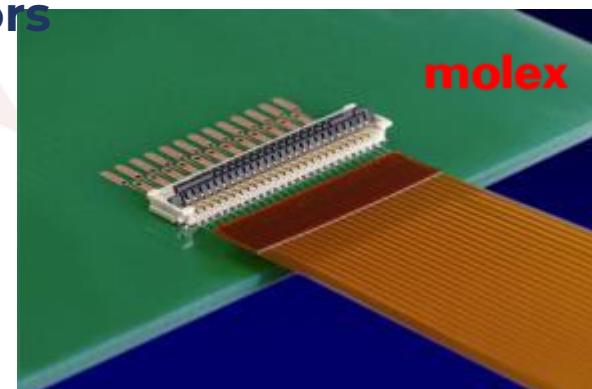


Multiple 2 x 19 connectors

Board to Board connector



Zero Insertion Force connector





TECHNOLOGY TRENDS

Active alignment is a key technology

Equipment manufacturers have developed specific platforms.

Active alignment:



Active alignment is probably the one of the most talked-about process for CCM



TECHNOLOGY TRENDS

Specific manufacturing equipments

Testing of components and end-products is critical.



Automatic testing

Testing of CCM image quality



Automatic testing

Testing of CCM image quality



Automatic testing

Testing of automotive CCM image quality



3D illumination testing

Testing of DOEs

TECHNOLOGY TRENDS

Inside an Automotive DMS camera: camera from Continental in DS car



Type	Tier 1	OEM	Image sensor supplier	Image sensor name	Description CIS	Computing supplier	Lens module*	Estimated Cost
DMS	Continental	DS	Onsemi	MT9V024	0.36 Mp / 6 µm	Texas Instruments	4G	~\$73

*G: Glass

- DMS cameras currently have a low resolution with a large pixel pitch.
- Pure RGB or IR monochrome image sensors will probably be good enough to get the job done, with the advantage of low cost.
- 3D image sensors can be more accurate but will add a higher cost, which is avoided by Tier 1s and OEMs.
- Hybrid lens sets, including glass and plastic lenses, are used to reduce the cost of the camera module.

Visible 2D cameras are the cheapest solution for in-cabin DMS, mainly driven by cost.



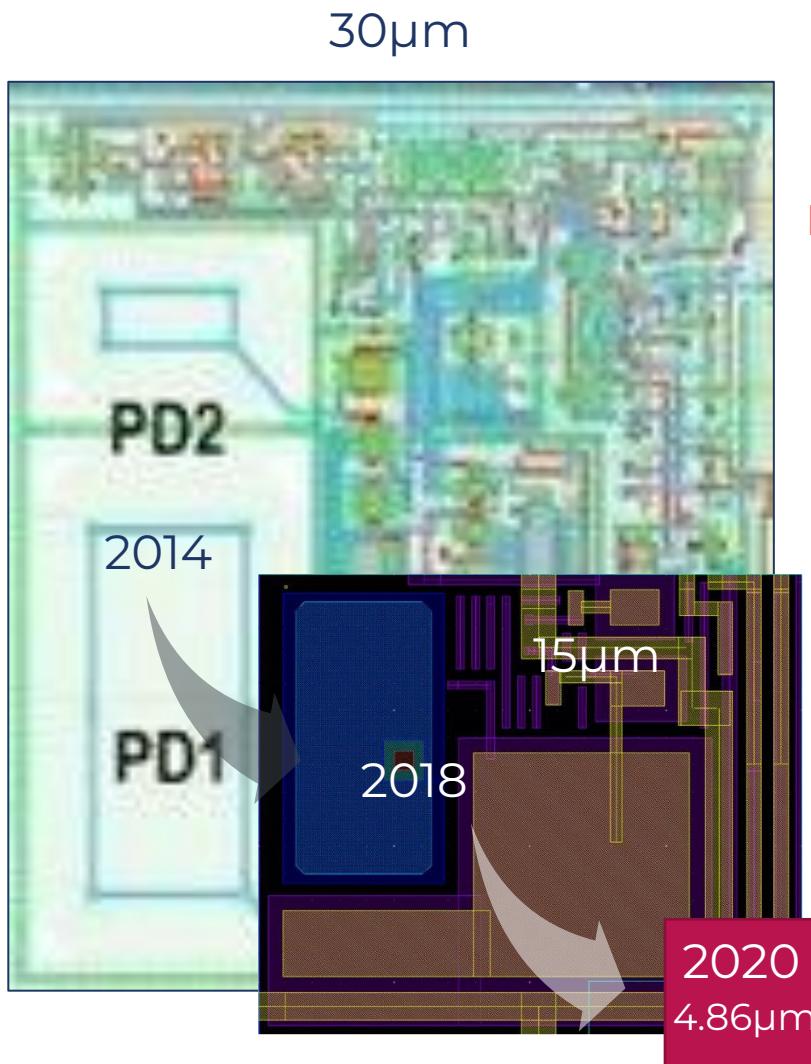


CMOS image sensor

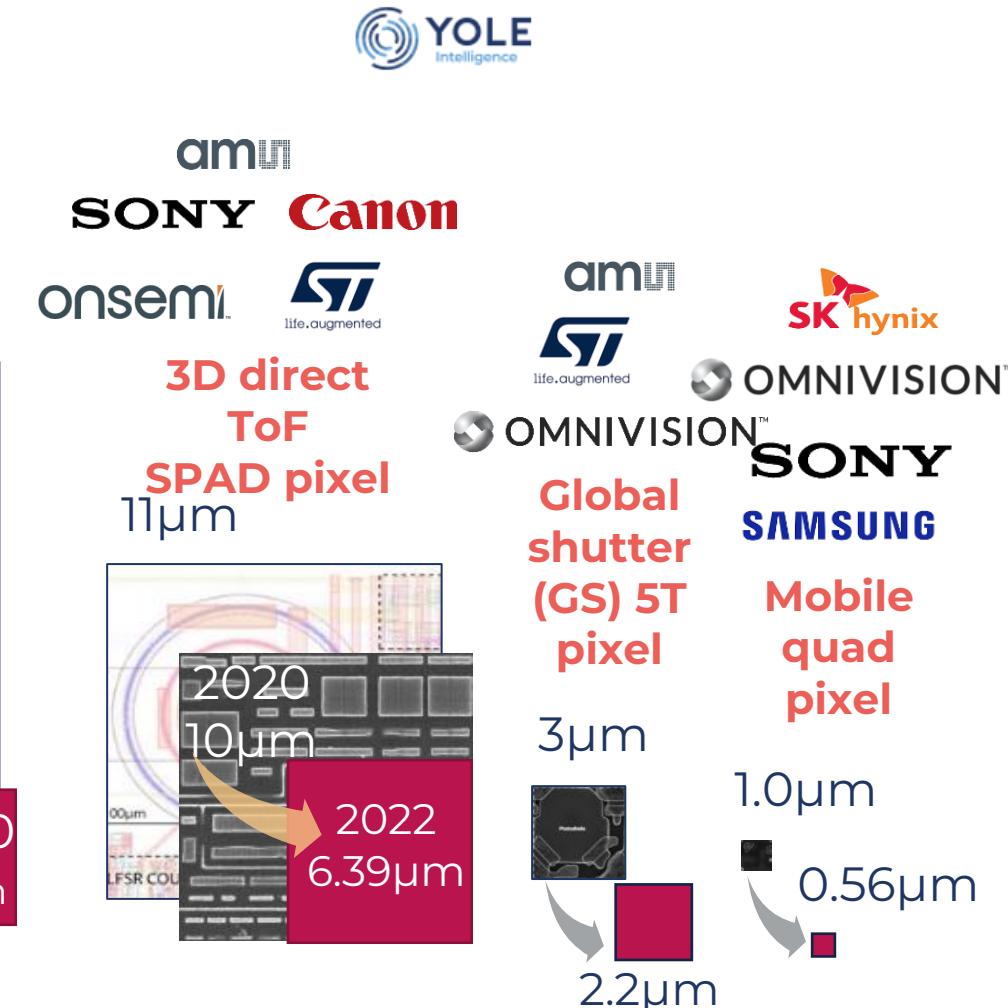


TECHNOLOGY TRENDS

Pixel size shrinkage



SONY
SAMSUNG
PROPHESEE
METAVISION FOR MACHINES
Event-based pixel
Panasonic
ANALOG DEVICES AHEAD OF WHAT'S POSSIBLE™
SONY
pmd
infineon





TECHNOLOGY TRENDS

Image sensors: optical format is directly linked to resolution and pixel size

Popular choices are at the intersection of specific resolution, pixel size, and optical format.

Increasing the resolution is a key marketing pitch for smartphone manufacturers, even though it does not always translate to better images.

As a rule of thumb, the sensor's diagonal is the achievable F/2.0 module Z-height.

A larger aperture will help reduce the height.

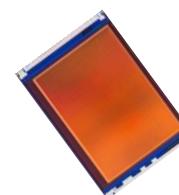


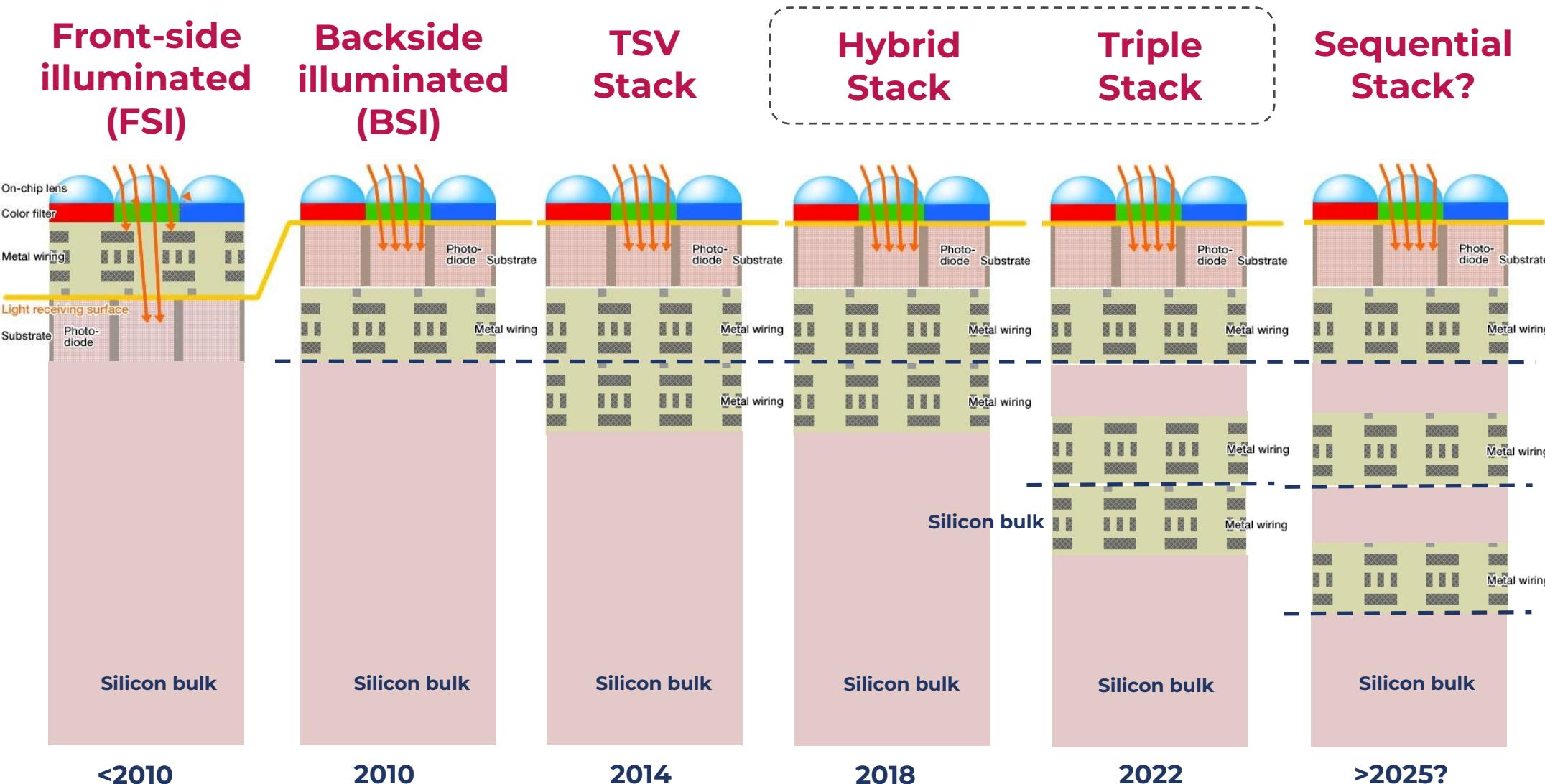
Image size	Format	Sensitive area	Surface	~Diag.	~Camera module cost	Resolution
■	1/5"	2.55 x 1.91mm ²	4.9mm ²	3.2mm	\$2.9	2MP
■	1/4"	3.20 x 2.40mm ²	7.7mm ²	4.0mm	\$4.3	5MP
■	1/3.2"	4.48 x 3.36mm ²	15.1mm ²	5.0mm	\$6.3	8MP
■	1/3"	4.80 x 3.60mm ²	17.3mm ²	5.3mm	\$7.3	12MP
■	1/2.55"	5.68 x 4.26mm ²	24.2mm ²	6.3mm	\$9.0	16MP
■	1/2.3"	6.24 x 4.68mm ²	29.2mm ²	7.0mm	\$9.7	20MP
■	1/1.7"	7.52 x 5.64mm ²	42.4mm ²	9.1mm	\$18.00	40MP
■	1/1.4"	9.12 x 6.84mm ²	62.4mm ²	11.4mm	\$19.8	48MP
■	1/1.33"	9.60 x 7.20mm ²	69.1mm ²	12.0mm	\$21.0	108MP
■	1/1.28"	10.0 x 7.50mm ²	75.0mm ²	12.5mm	\$22.0	162MP
■	1/1.22"	10.5 x 8.00mm ²	84.0mm ²	13.1mm	\$25.0	200MP
■	1"	13.15 x 10.15mm ²	166.1mm ²	16.61mm	>\$40	50MP

2022



TECHNOLOGY TRENDS

CIS led the way for 3D integration in semiconductors



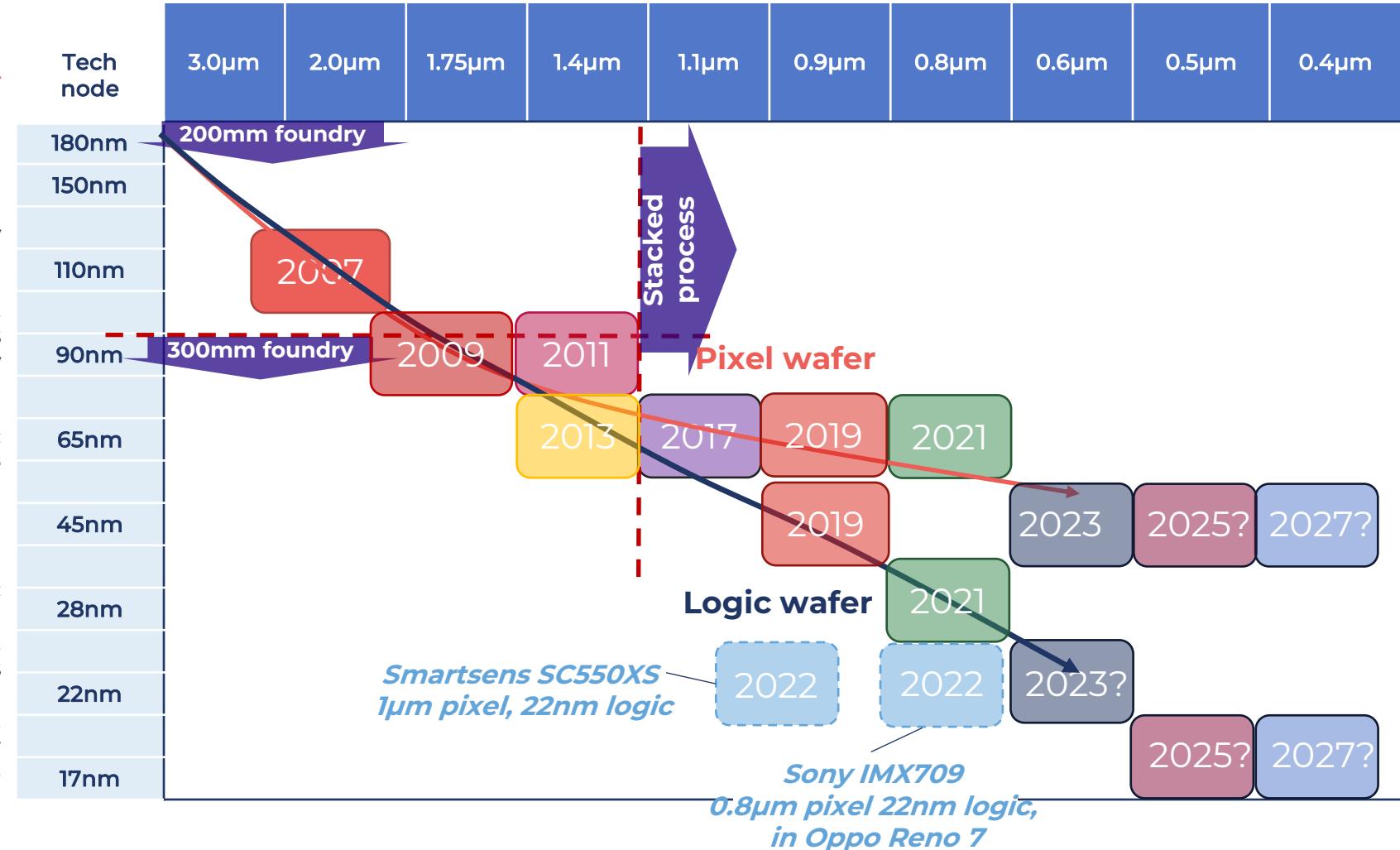


TECHNOLOGY TRENDS

Pixel size and technology node roadmap

With the demand for smaller pixels, the technology race has been reignited.

- Resolution, pixel size, and technology-node reduction are closely related.
- Sony has been using a 90nm node for 0.8µm pixels and down to a 45nm - 65nm technology node for the logic wafer.
- In stacked processes, only the logic wafer gets the latest technology node.
- Next-generation logic wafers will have the option to use FDSOI.
- In 2022, Sony and Smartsens released 22nm stacked logic products with 0.8µm and 1.0µm pixel sizes, respectively. Sony's product is in the Oppo Reno 7 smartphone. Samsung has already announced a roadmap for 17nm FinFET.

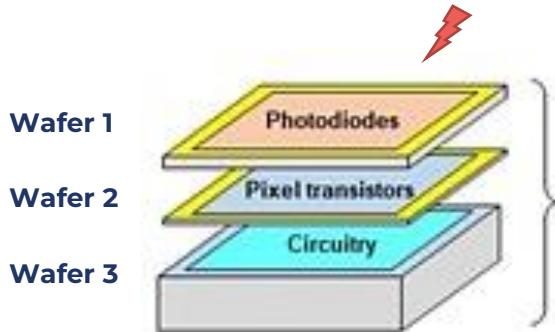




TECHNOLOGY TRENDS

Newly introduced triple-stack architecture

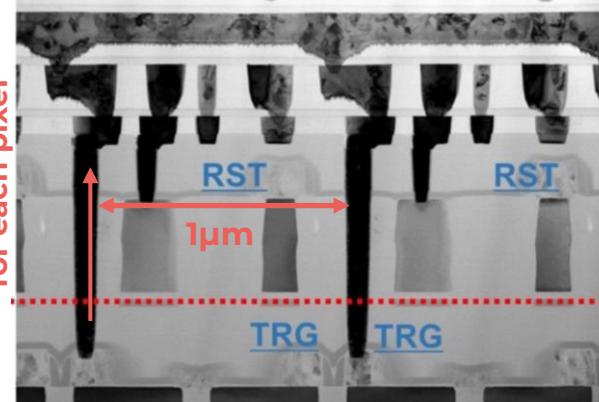
New generations of 2-layer transistor pixel allow 1µm pixels.



This new generation of in-pixel stack is a key CIS technology evolution:

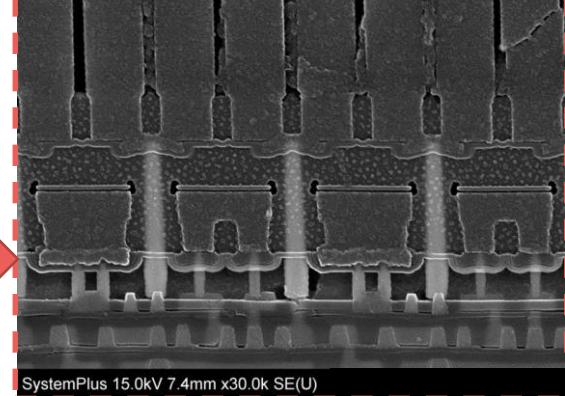
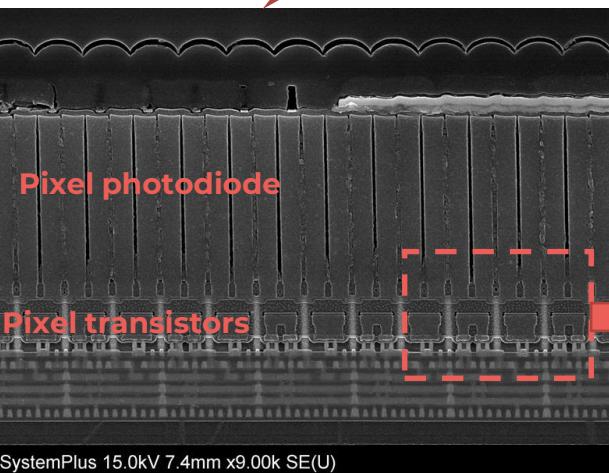
- Performance improvements: fill factor, full well capacity, dynamic range, signal-to-noise ratio.
- Fabrication: three wafers are used, two for CIS and one for logic CMOS.
- Deep contact by tungsten plug connects the two transistor layers. Cu-Cu hybrid bonding connects the pixels to the logic.

From Sony (pixel top photodiode is at the bottom on this picture)



Pixel transistors wafer

Pixel photodiode wafer (incl. transfer gate transistors)



From Yole SystemPlus analysis, Sony Xperia 1 V CIS (with triple stack)



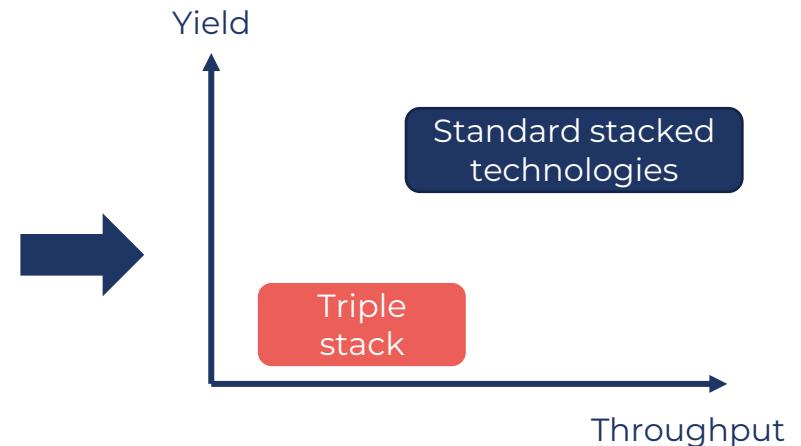
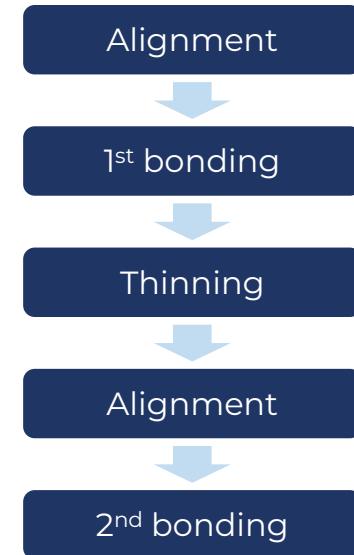
TECHNOLOGY TRENDS

Triple stack: a luxury image sensor?

Triple-stack architecture adds manufacturing challenges, reducing throughput and yield compared to standard stacked imagers.

- Triple stack architecture is still challenging to manufacture with additional alignment, thinning, and bonding steps.
- This complexity tends to decrease throughput and yield, eventually affecting the imager's cost.
- As a result, this type of sensor will most likely enter flagship smartphones initially.
- In 2022, Sony has integrated its own triple-stack new generation sensor in its flagship Xperia 1 V phone. We believe this architecture could also be found in the next iPhone smartphone generation.
- Omnivision and STMicroelectronics have also announced R&D activity on triple stack image sensors.

Adding critical steps in the process flow:



June 2023:
Sony Xperia 1 V



Sept 2023:
iPhone 15 Pro?



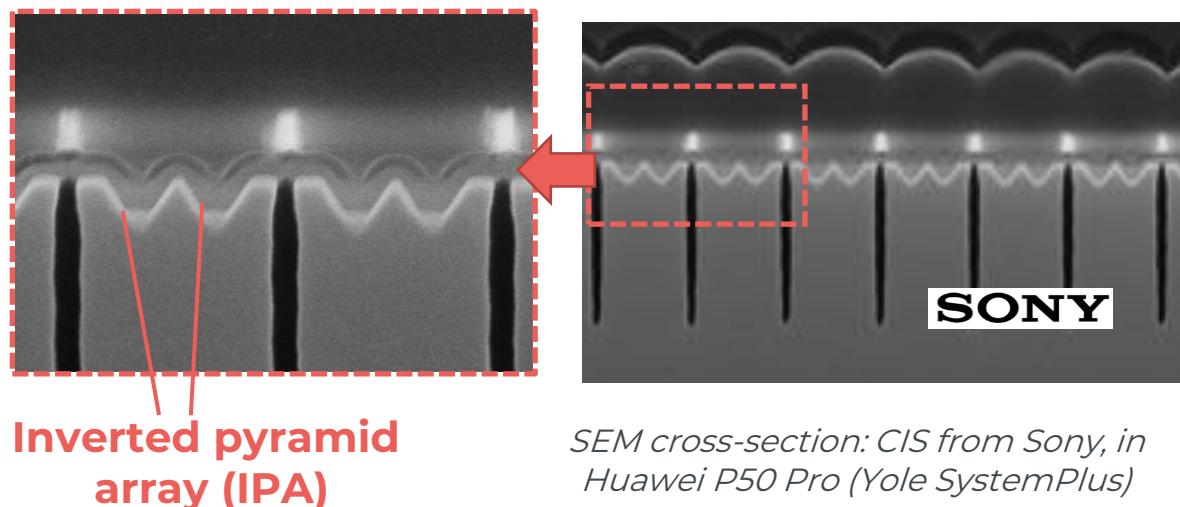


TECHNOLOGY TRENDS

Sensor performance: near-infrared sensitivity

- Silicon backside diffractive patterns, such as inverted pyramids, reduce reflectivity and enhance light diffraction into silicon pixels. This has been demonstrated by Sony on a 1.1 μm pixel pitch. Samsung, Omnivision, Onsemi, SmartSens, and ams have also introduced this innovation in some of their latest products to boost QE in the NIR domain.

Diffractive patterns such as inverted pyramids increase QE in NIR.



CIS suppliers using backside diffractive patterns



SMARTSENS

SONY

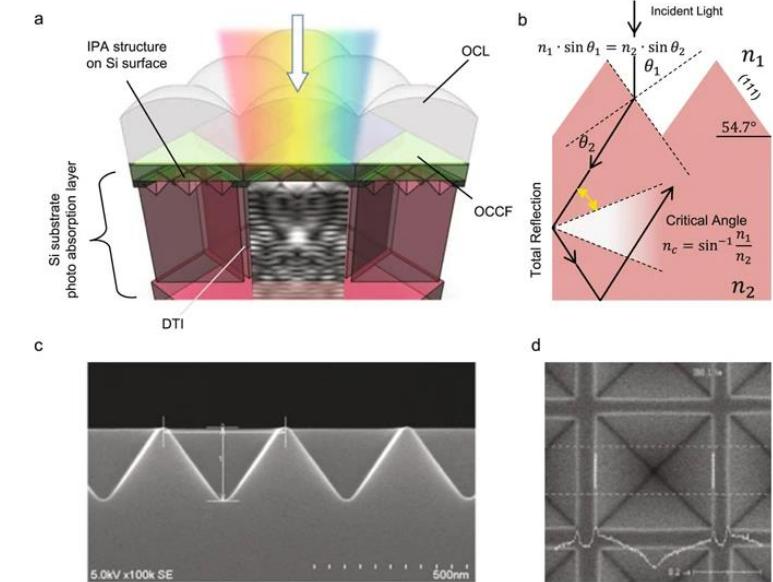
SAMSUNG

ams

onsemi

OMNIVISION™

Figure 1



Yokogawa et al., IR sensitivity enhancement of CMOS image sensor with diffractive light-trapping pixels. Sci Rep 7, 3832 (2017)



TECHNOLOGY TRENDS

Automotive DMS and OMS sensor fusion

In-cabin camera to monitor the driver and passengers simultaneously with one sensor.

Sensor fusion between DMS and OMS in one camera module is on the horizon.

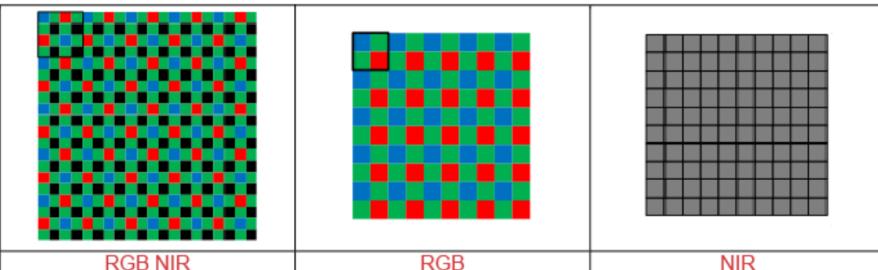
In this context, STMicroelectronics has developed a new hybrid sensor (VD1940) that goes beyond evaluating driver alertness in driver-monitoring systems (DMS). It now enables full monitoring of the driver and all passengers inside the vehicle.

The VD1940 combines the sensitivity and high resolution of infrared sensing with high dynamic range (HDR) color imaging in a single device. It can capture frames in both rolling-shutter and global-shutter modes.

The middle of the car is the best position for a single DMS/OMS camera



VD1940



VD1940 output formats

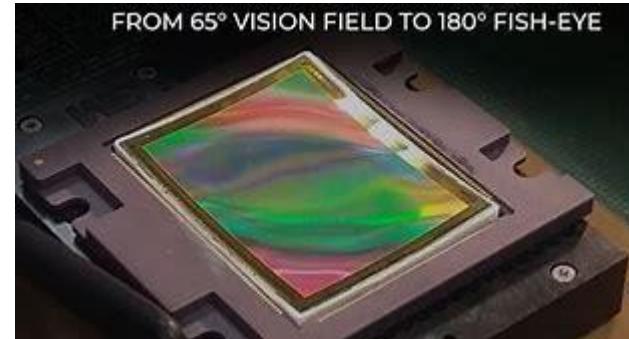
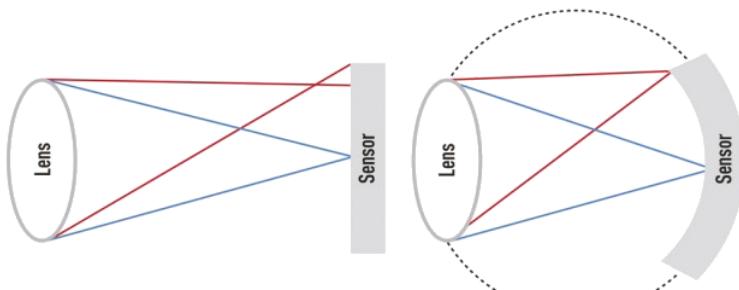
Product	Shutter	Pixel size/architect- ture	Resolution	Packaging	Color filter	Dynamic range	QE
VD1940	RS/GS	2.25 μ m BSI	5.1MP	Bare die	RGB-IR	100 dB (in RS)	25% at 940nm



TECHNOLOGY TRENDS

Curved image sensor technology

- Curving the image sensor is an innovative approach to reducing lens system complexity.
- This approach was initially tested for large chips, mainly in high-end photography and astronomy.
- This could be later applied to consumer camera modules as the first start-ups, such as Curve-one and Silina, entered the space.

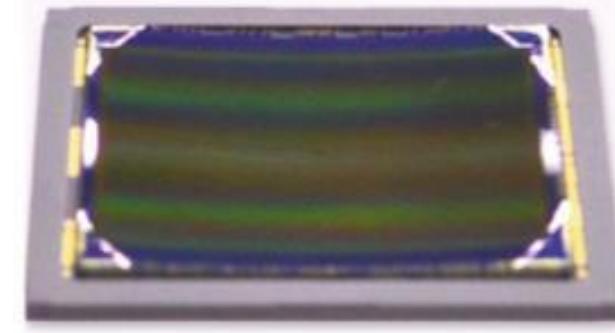


courtesy of Leti

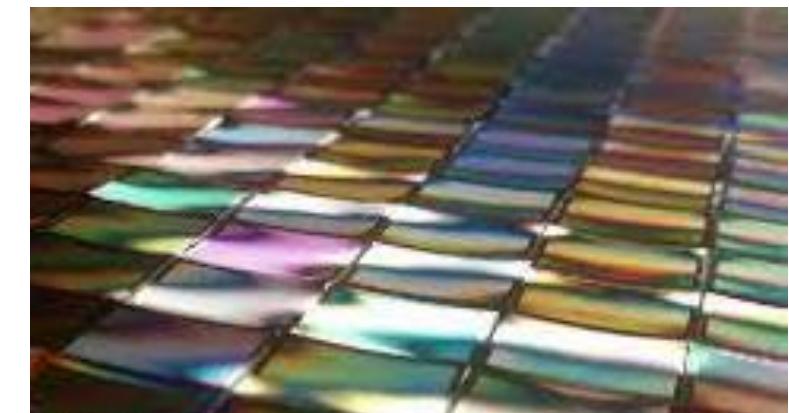
CURVE-ONE
REVOLUTION FOR IMAGING SYSTEMS



SONY



courtesy of Sony



courtesy of Silina



TECHNOLOGY TRENDS

Event-based is coming to commercial products

- Event-based sensors use a neuromorphic and asynchronous structure: speed not limited by frame rate, minimal data loading, lower power, better latency, speed, sensitivity, and intra-scene dynamics.
- The goal is to improve the speed at which a critical situation can be understood by a machine or vehicle. Further applications are being demonstrated, such as 3D structured light sensing.

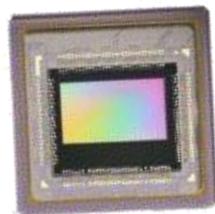
Changing the
image sensor
paradigm.



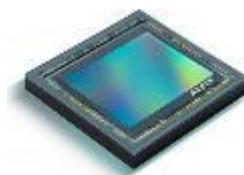
SAMSUNG

PROPHESEE
METAVISION FOR MACHINES

OMNIVISION™



IMX636ES sensor
from: Prophesee



ALPIX hybrid sensor product
from: AlpsenTek



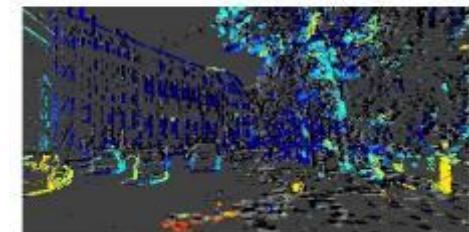
SONY

Particle-
size
monitoring

Security
detection
& tracking



Live
deblurring



Source: Prophesee

Application examples:

Spatter
monitoring

Hand
tracking,
SLAM

Vibration
monitoring

Eye
tracking





TECHNOLOGY TRENDS

CIS based SWIR imagers: applications

- SWIR imaging may experience a paradigm shift in the coming years with the emergence of low-cost technology developed from a CIS base.
- SWIR wavelengths are attractive to replace NIR for 3D sensing applications as they are less impacted by ambient light, and a higher illumination power can be used. This would increase the detection range and reliability of 3D systems and even allow the integration of new functionalities like an **under-display biometrics camera in smartphones**.
- Many chemical elements have identifiable spectral signatures in SWIR and not at other wavelengths. **SWIR could provide a fresh impetus for multispectral imaging.**
- SWIR technologies are not yet commercialized for these applications.

See SWIR Imaging 2023 report for more information:



Under-display
biometrics
2D/3D camera

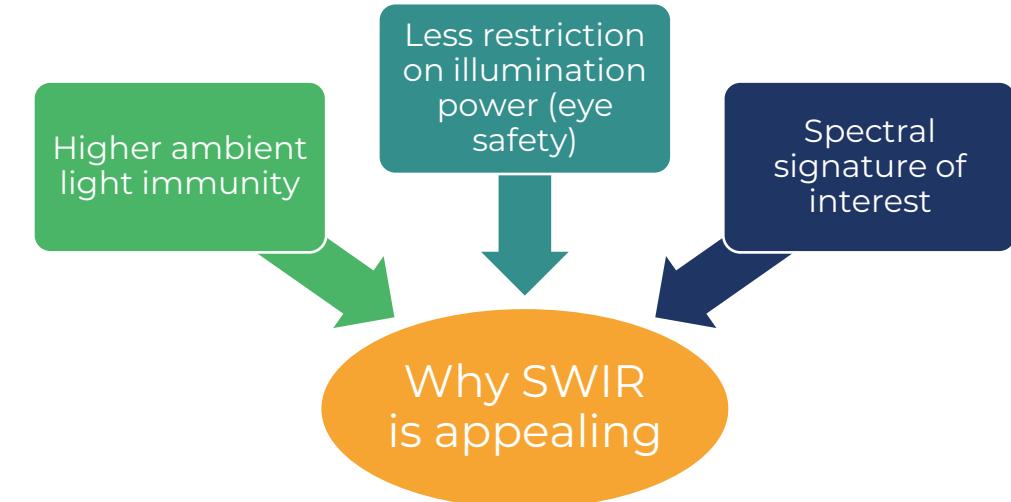
Longer
range 3D
rear camera



Tracking camera which
can operate in outdoor
environment



ADAS camera operating at
night, bad weather,
performing 2D/3D fusion

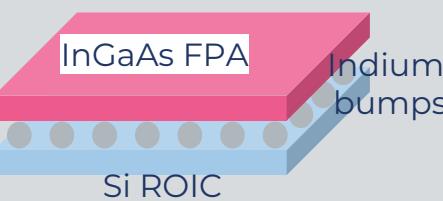
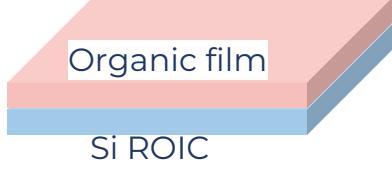




TECHNOLOGY TRENDS

CIS based SWIR imagers: technologies

CIS basis

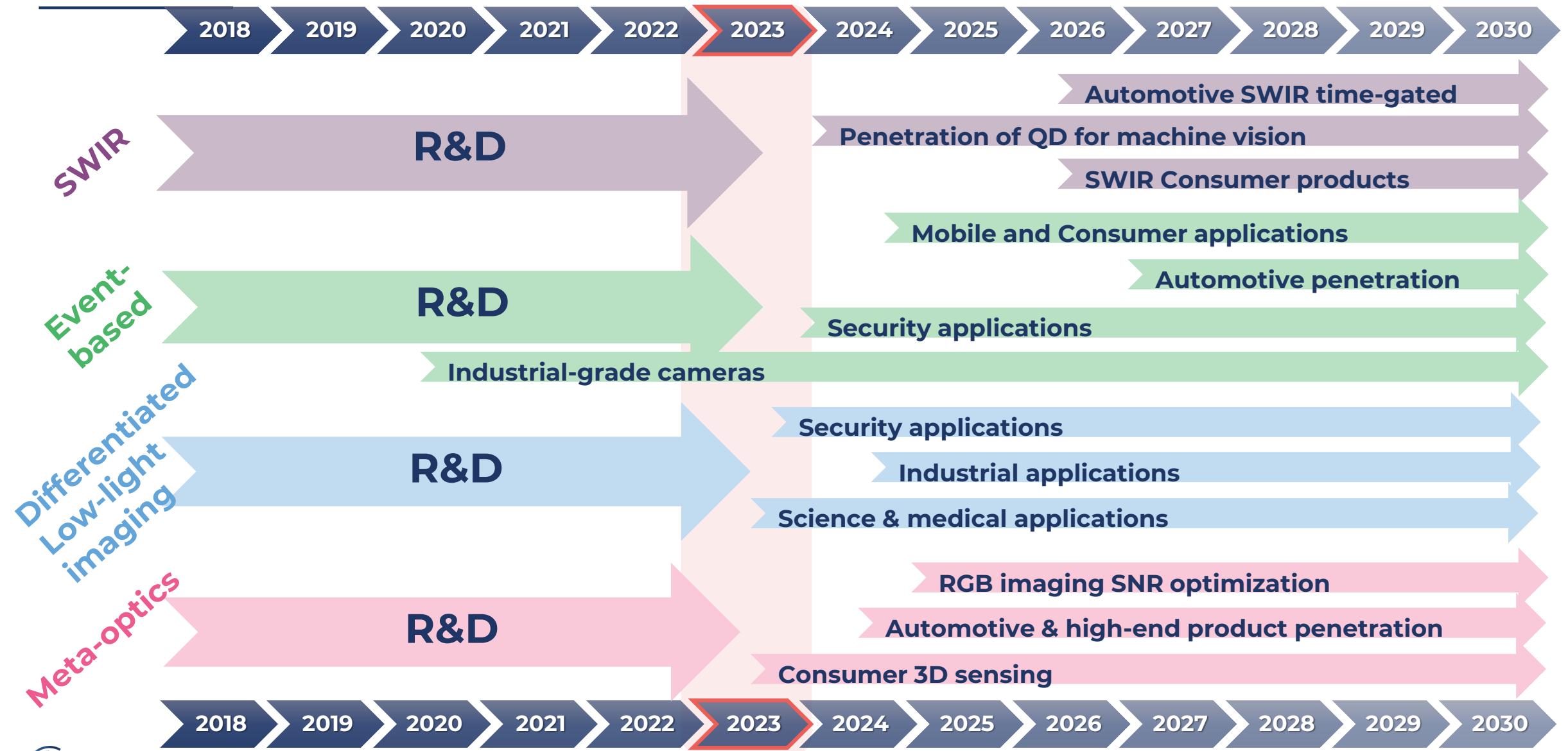
Technology	InGaAs	Ge-on-Si	Quantum dots	Organic photodiodes
Visual				
Maturity	++++	++	++	+
Weaknesses	Price (\$5,000-\$15,000 per chip)	Image quality (elevated dark current)	Robustness, response time of the material	Robustness, response time of the material
Manufacturing	<ul style="list-style-type: none"> Flip chip bonding at die level Cu-Cu bonding (Sony) 	Stacking of Ge-on-Si photodiodes on CIS ROIC on 8 or 12-inch wafers (CIS fabs)	Spin coating or evaporation of the thin film over the CIS readout.	
Main players	 SONY  GHOPTON & many others	  	  	 SAMSUNG R&D

- Ge-on-Si will be made in standard CIS fabs. There are still challenges with dark current, which limits image quality. **This technology is expected to be used first in robotics and automotive.**
- Quantum dots cameras are already used in industrial applications. The main challenges are around the robustness and response time of the photodiode. We expect this technology to be used first in consumer devices for biometrics and tracking applications. An organic SWIR imager is still to be demonstrated.
- Both types of technologies could come to the market by 2026.



TECHNOLOGY TRENDS

A tentative roadmap for emerging imaging technologies





Optics lens set



TECHNOLOGY TRENDS

Lens technologies

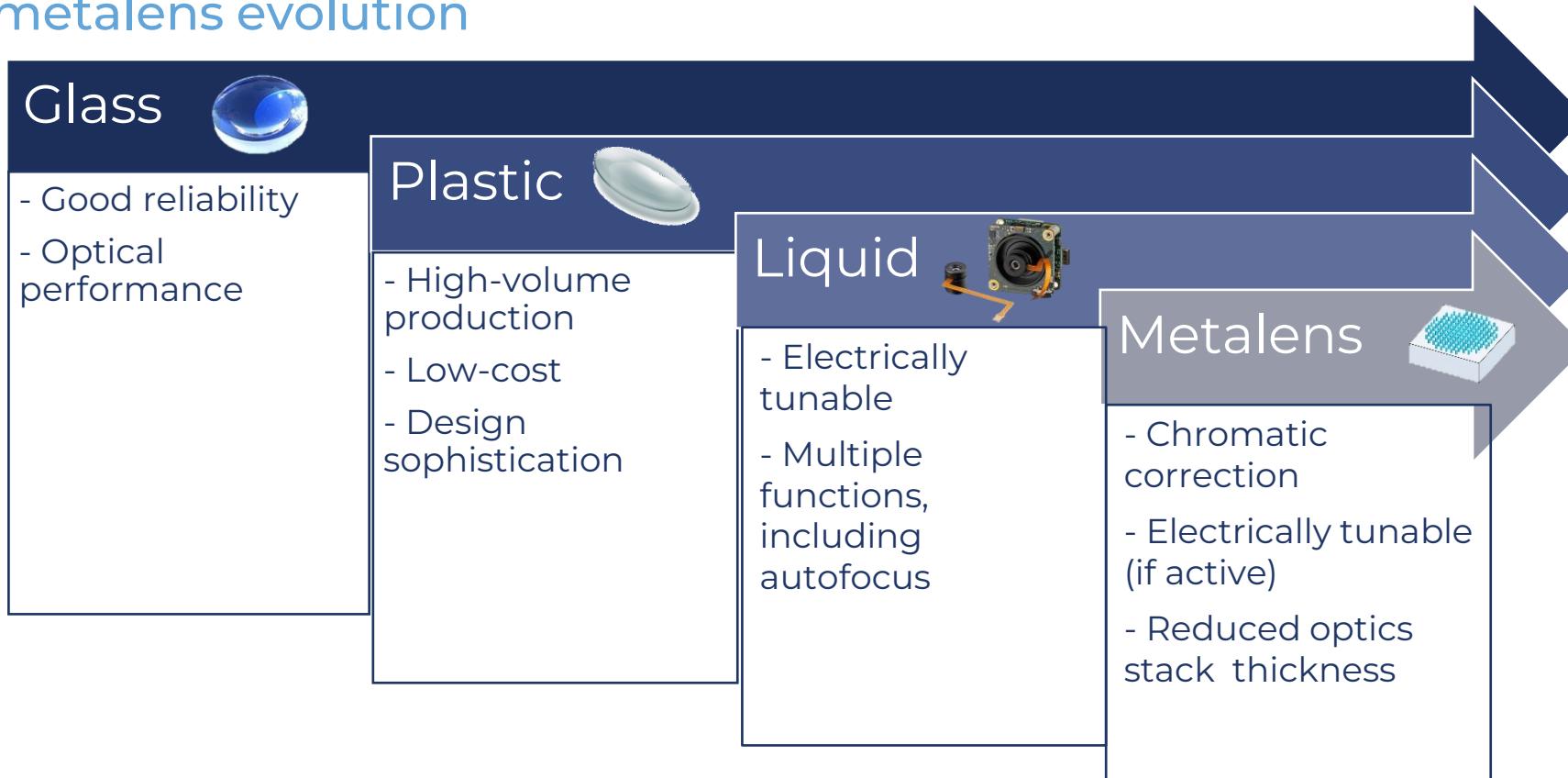
Technology	Mature			Emerging		
	Glass	Plastic	Glass+Plastic	Liquid	WLO	Metalens
Definition	Lens element made with glass. Most common lens technology.	Lens element made with transparent polymer. Particularly suitable for miniaturization.	Lens module containing a combination of plastic and glass lens elements.	Contains a soft lens element (liquid or gelatin) whose shape can be electrically controlled.	Optics made with a similar approach to semiconductor industry. Several optical pieces are processed at the same time, sometimes using a glass wafer as a handler.	Exploits the interactions of light and matter at the nanometer scale to achieve unprecedented control of the behavior of light.
Applications	<ul style="list-style-type: none"> Automotive ADAS, in-cabin and viewing Surveillance (all) High-end consumer cameras Industrial machine vision 	<ul style="list-style-type: none"> Mobile and consumer 	<ul style="list-style-type: none"> Automotive ADAS, in-cabin and viewing Surveillance Few smartphones (replacing one or several plastic lenses) 	<ul style="list-style-type: none"> Machine vision Few smartphones 	<ul style="list-style-type: none"> Few smartphones Medical (endoscopy) Lighting solutions 	<ul style="list-style-type: none"> Mobile and consumer Industrial (robotics navigation) More to come?



TECHNOLOGY TRENDS

From glass to metalens evolution

Over time, lens materials have evolved into glass, plastics, and liquids, and are now moving into metamaterials.



- Metalenses have made some progress with the first products being brought to the market for imaging applications (dToF ranger autofocus in smartphones, active metaoptics for LiDAR robotics navigation...). They are usually made with high refractive index polymers, semiconductors, or metal oxides.
- These materials (beyond metalenses) have their own characteristics; they cover the same or different functions and compete with each other. They continue to be optimized through technology and process.
- Liquid lens is emerging and has just started to be commercialized, proven in smartphone camera module; it can only be a lens element at its current stage, the primary function being to replace autofocus.

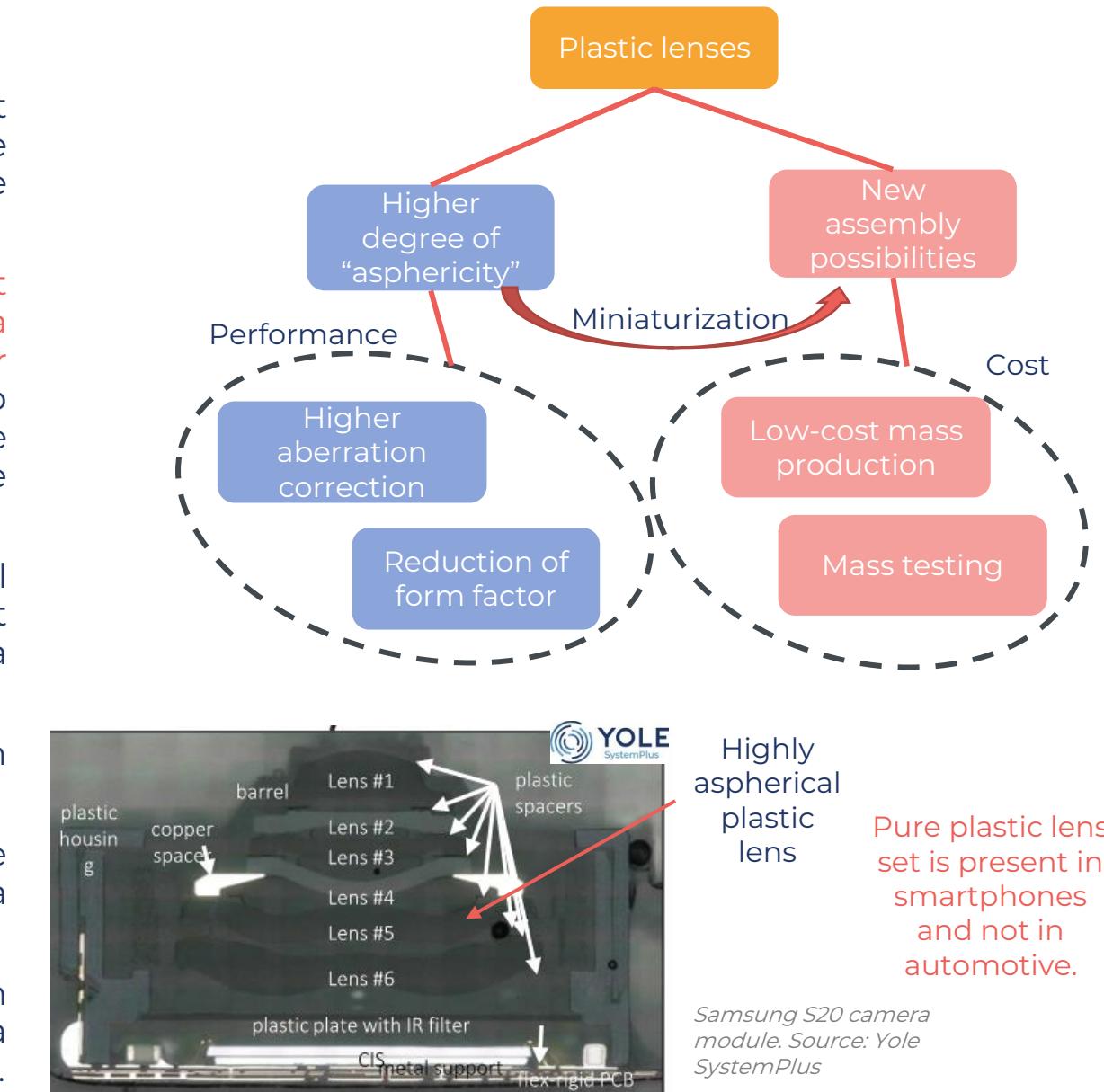


TECHNOLOGY TRENDS

Plastic lenses

Plastic lenses have been the solution for miniaturization. It is now a very widespread low-cost technology.

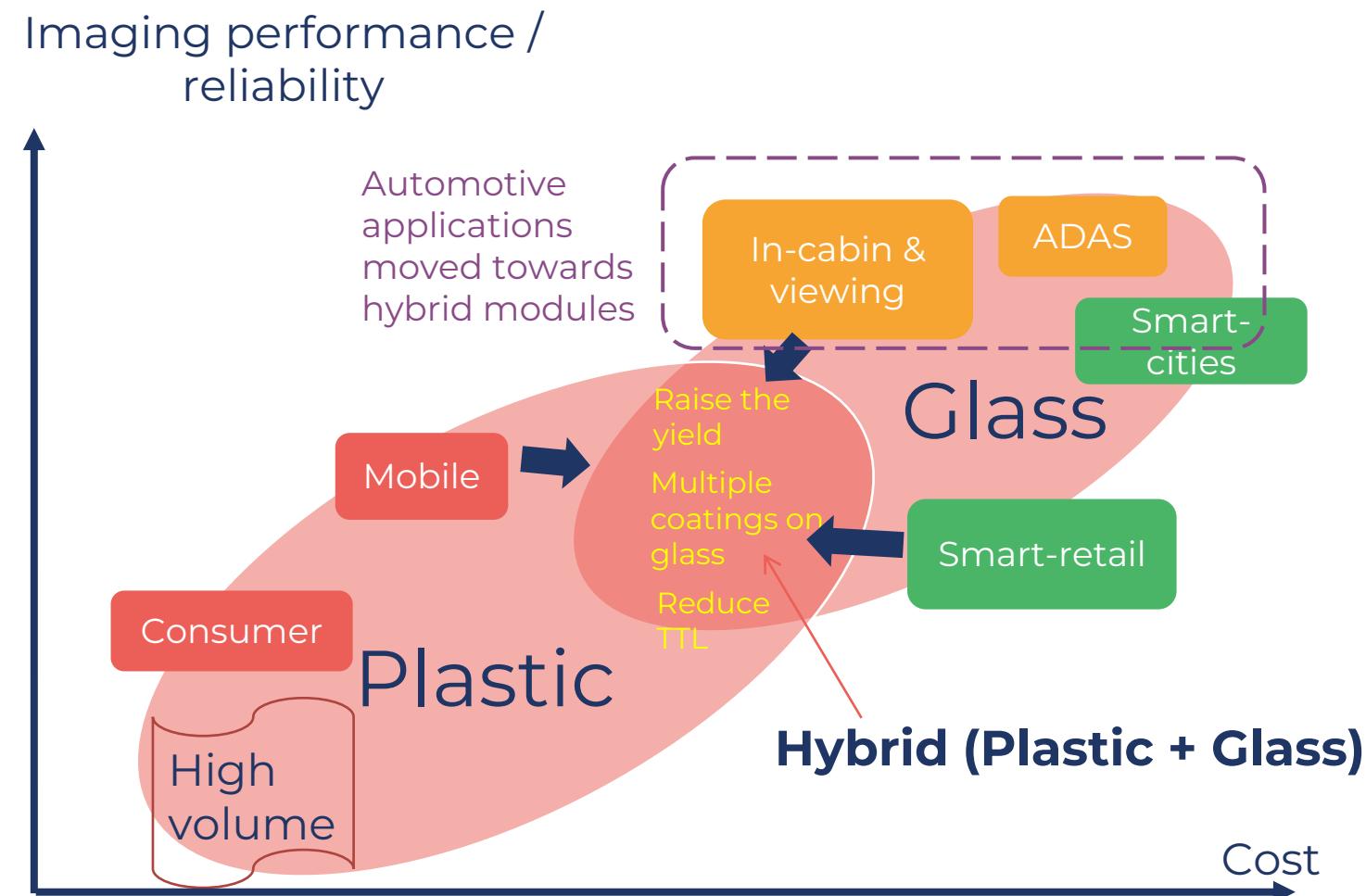
- Plastic lenses have existed for decades, but this technology really took off with the rise of mobile phone photography and the need for optics miniaturization.
- Despite lower optical quality than glass, it allows the designing of lens shapes with a higher degree of asphericity than other technologies. These complex designs help in solving problems while miniaturizing the optical modules, which is a priority while addressing the mobile phone market.
- Due to mass, volume, and technical considerations, the plastic lens is the most cost-efficient technology for small camera modules.
- Most lenses are made with an injection molding process.
- Due to their small footprint, most of these lenses are integrated into mobile camera modules and consumer goods.
- Plastic lenses started to be implemented in automotive camera modules, bringing a lower cost and more freedom in the design.



TECHNOLOGY TRENDS

Glass, plastic, or both? Comparing mature technologies

- Most lens modules contain plastic lenses, glass lenses, and sometimes both.
- Plastic lenses are low-cost and perfectly aligned with the mass market, like consumer and mobile phone markets.
- Glass is preferred in high-end segments such as automotive ADAS or smart-city imaging solutions. Both applications require high optical quality and robustness since systems could be exposed to humidity, high temperature, or mechanical strain.
- Mixing plastic and glass in a hybrid module is becoming attractive for several reasons:
 - Automotive and surveillance applications: plastic allows a cost reduction.
 - Smartphone: glass allows higher optical quality and a reduced TTL (Total Track Length).





TECHNOLOGY TRENDS

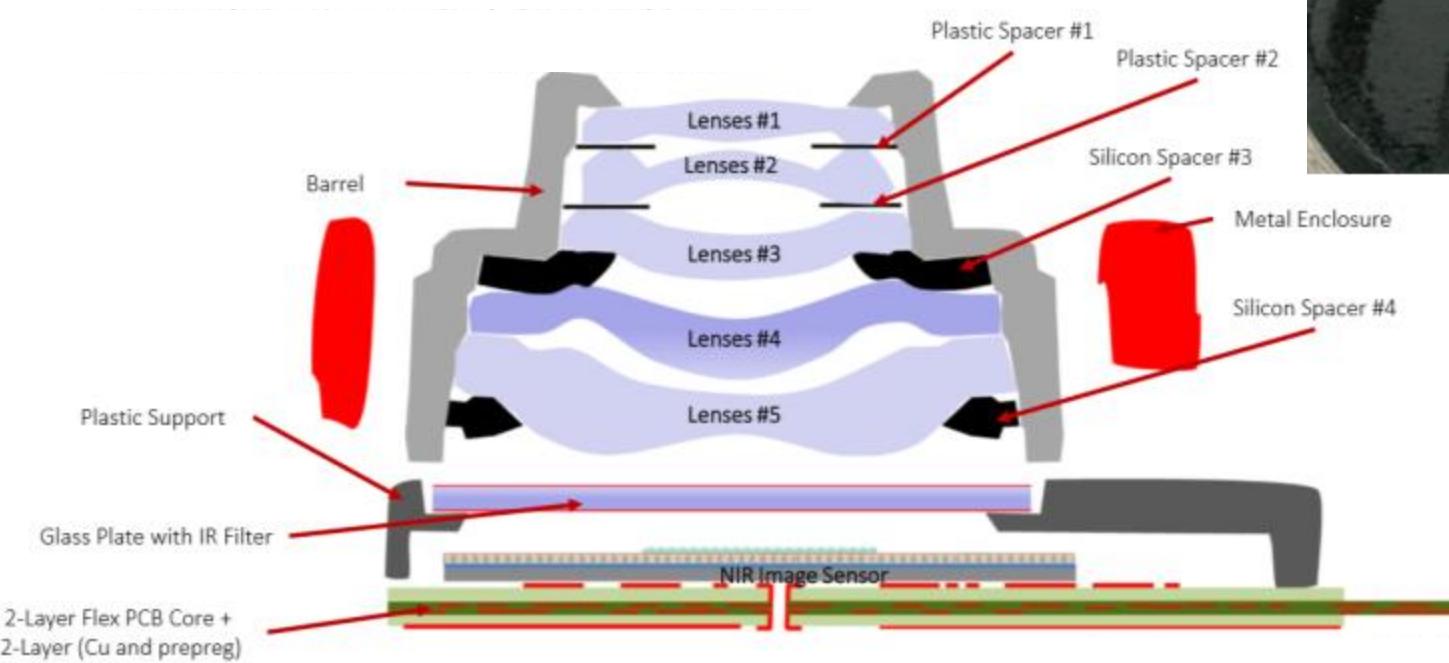
Glass lens (Mobile)

Glass remains a sure thing when tackling difficult optical problems.

Glass lenses using high index material **help** in developing 7 - 8 lens sets.

- High index material
- High transparency

This approach signals the end of the current technological approach



2G-3P optics
in Xiaomi's
Mi 8 Explorer Edition

Hybrid lens set in Automotive camera modules



The first lenses used in automotive cameras were made of glass because their optical properties give a better image with the smallest amount of distortion.

Thus, the price of a lens set depends more on the material used than the number of lenses used. Some lenses include rare earth materials and are expensive.

Implementing plastic lenses has three major advantages:

- Reduce the cost
- Reduce the size
- Give more freedom in the design: with injection molding, the lenses can be given a spherical shape, which enables the lens to control the light passing through with fewer aberrations.

Challenges:

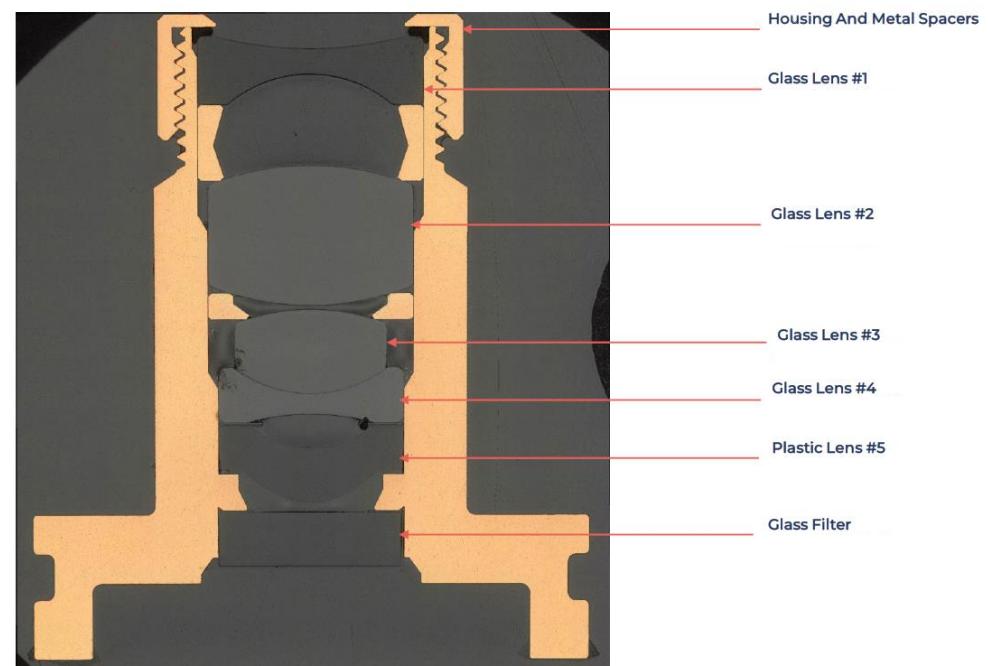
- Cost
- Size constraints
- Thermal stability over a long period (~ 15 years)
- Depth of field related to the positioning of the camera (variable from one car to another).

As the trend of increasing the image sensor resolution continues, major player Sunny Optical has completed the R&D of 17MP front-view vehicle lens sets.

The transition from full glass to hybrid glass-plastic lens sets has happened and is expected to stay with the cost pressure applied.



Continental 



Lens module

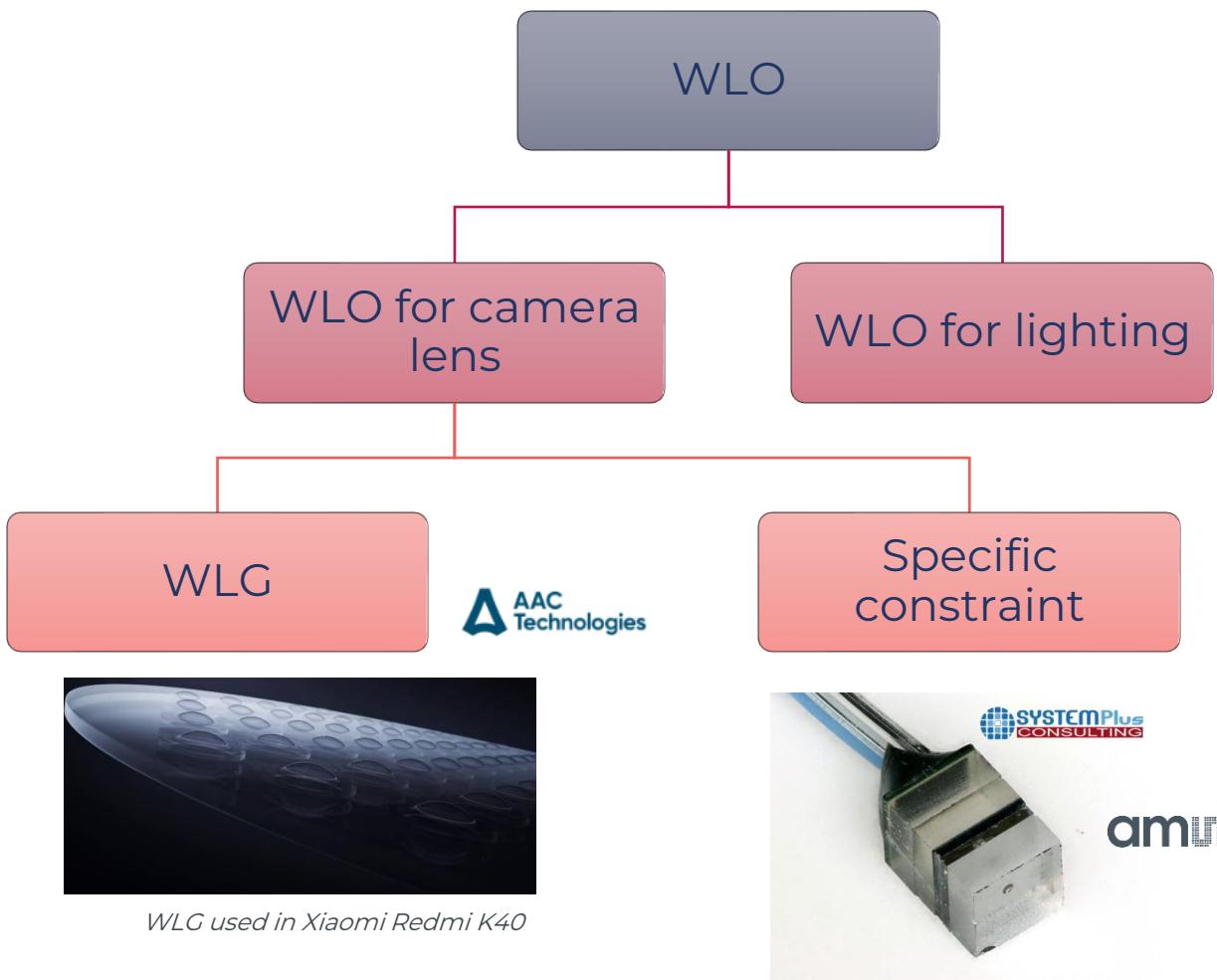
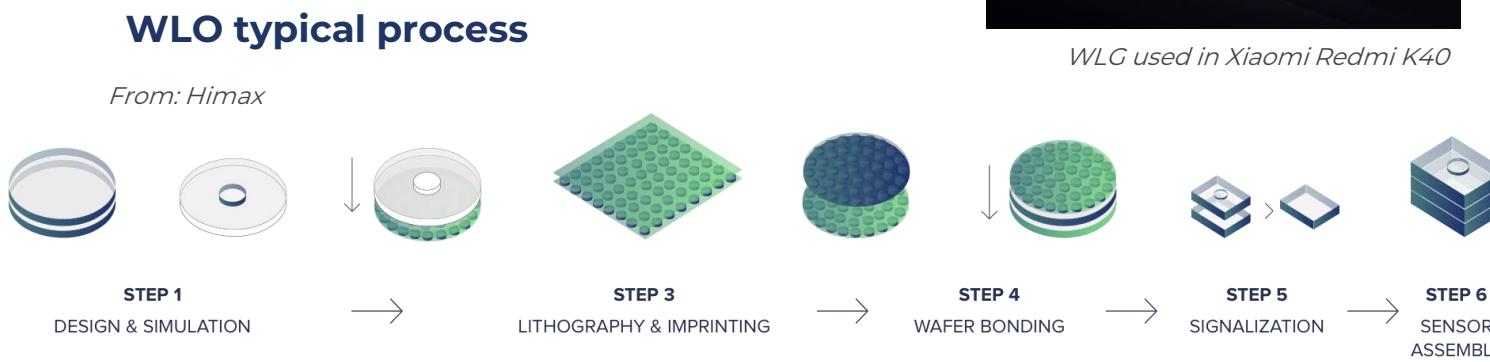


TECHNOLOGY TRENDS

The use of Wafer Level Optics (WLO)

Wafer-level optics (WLO) are mainly used for light-shaping, but WLG could reduce the cost of glass lenses in modules.

- Classical WLO techniques are particularly adapted to small optical structures (microlens array). Thus, it is mainly used in light-shaping components (dot projectors, diffusers, ...)
- For a camera lens this technology has been used in the NanEye endoscope camera, which needed to be extremely small. However, WLO does not compete with injection molding in plastic lens manufacturing for smartphones.
- AAC developed a parallel process to make glass lenses, called “wafer level glass” (WLG), to decrease the cost of the glass element compared to classical manufacturing.

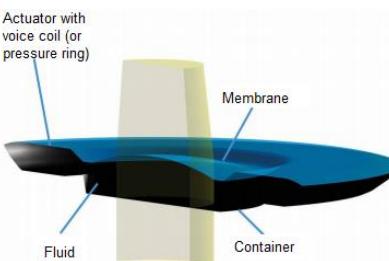


TECHNOLOGY TRENDS

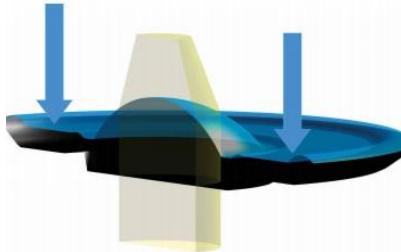
Liquid lenses

A liquid lens is mainly used to fine-tune the focus. There are several possible technologies.

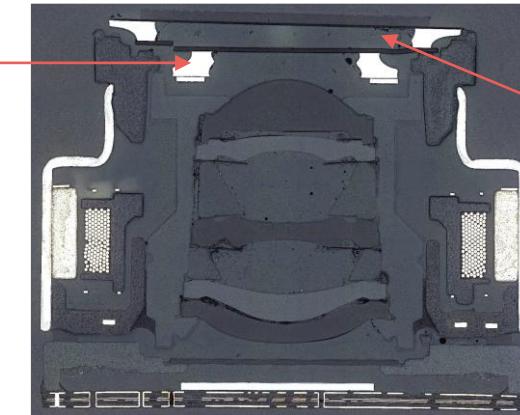
- Liquid lenses are optical elements that have a shape that can be electronically tuned. They are mostly used on top of classical lens modules (with fixed plastic or glass lenses) to replace mechanical autofocus.
- Two main technologies are competing in this field:
 - An Optotune lens contains an oil between one flexible membrane and one glass plate. A mechanical ring presses one of the membranes to change the shape of the lens.
 - A Corning lens contains two non-miscible liquids. The shape of the interface between the liquids changes when an electrical current is applied. It does not contain any mechanical actuator.
- There is only one liquid lens per module at the time, because of the current technological limitation of these devices.



Courtesy of Nextlens (Optotune)



Pressure
ring

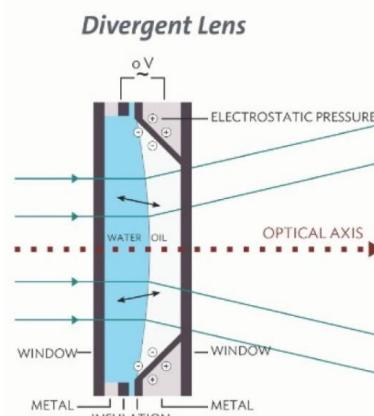


Tunable lens
poly-
dimethylsiloxane,
PDMS

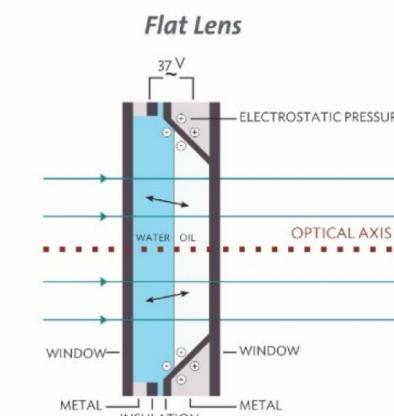
Voice coil motor



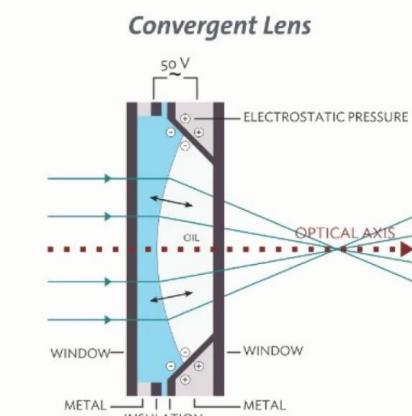
Liquid lens camera module in Xiaomi Mi Mix Fold (from Yole SystemPlus)



Divergent Lens



Flat Lens



Convergent Lens

Courtesy of Corning Varioptic

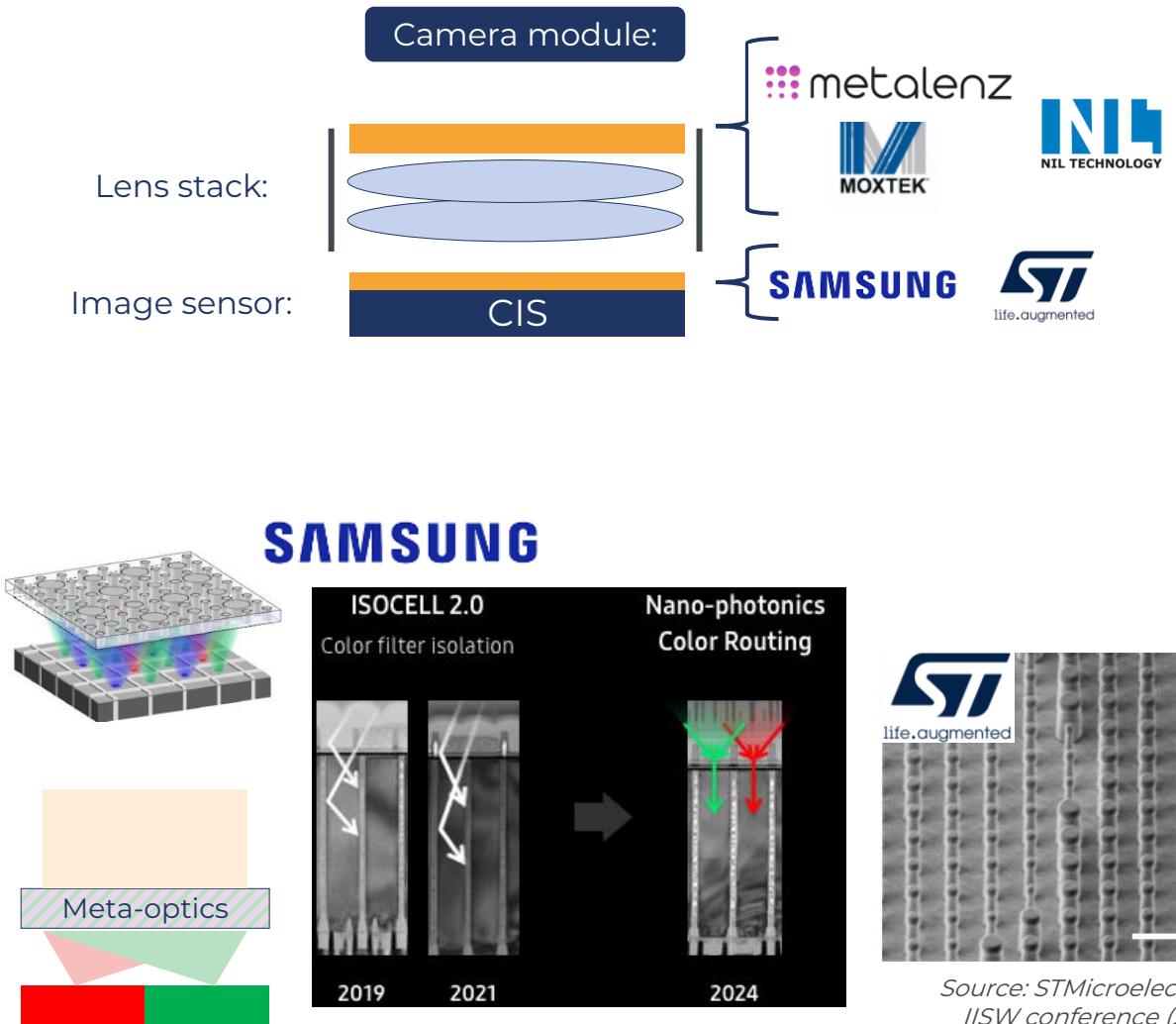


TECHNOLOGY TRENDS

Meta-optics: the ultimate evolution of flat optics (1/2)

Meta-optics can be integrated directly in CIS instead of microlenses to increase SNR.

- Meta-optics are investigated to replace optical elements in camera modules (refractive lenses, diffusers, dot projectors, etc.). These metasurfaces cumulate several optical functions, which help reduce the number of optical components in the camera or lighting modules. **Meta-optics** can also be integrated into CIS for SNR optimization, replacing microlenses.
- Samsung plans to introduce its **color routing** technology. We expect it will consist of a meta-optics structure that deflects light depending on the wavelength. This would replace microlens arrays and eventually increase SNR for color image sensors.
- STMicroelectronics is working on integrated meta-optics that act as microlenses for SPAD arrays. At the module level, the company uses Metalenz designs for optical elements in dToF multizone modules.



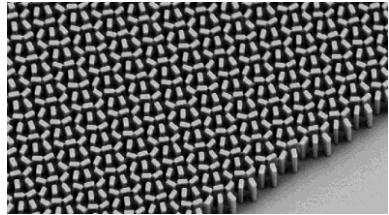
Source: Samsung

Source: STMicroelectronics,
IISW conference (2020)

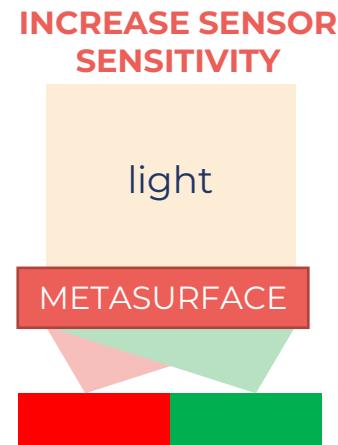


TECHNOLOGY TRENDS

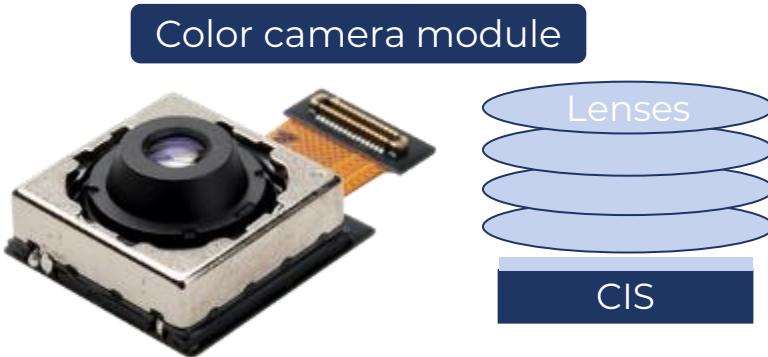
Metasurfaces: the ultimate evolution of flat optics (2/2)



Source: Capasso group,
Harvard university



BEAM STEERING
Source: Lumotive

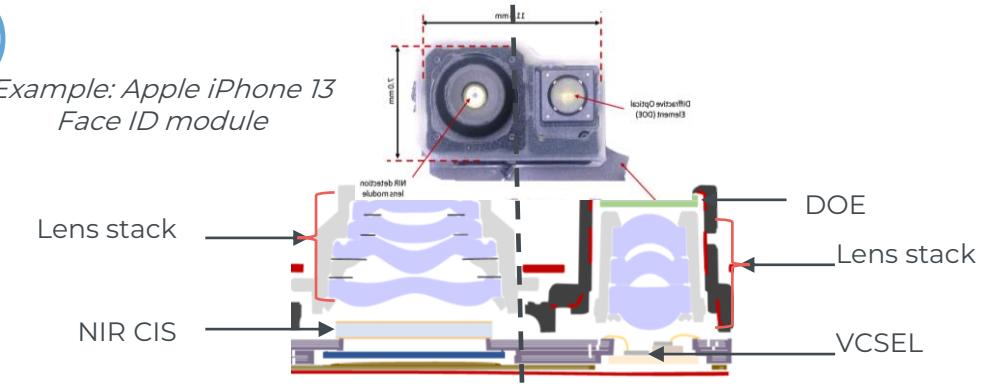


Source: LG Innotek

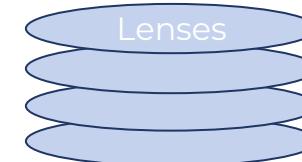
THINNER, CHEAPER MODULE

METASURFACE
CIS

Example: Apple iPhone 13
Face ID module

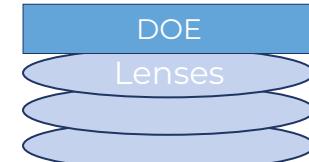


2021



NIR CIS

Dot projector



VCSEL

>2024



METASURFACE



METASURFACE

>2027



METASURFACE



TECHNOLOGY TRENDS

Wide-angle optics for Automotive in-cabin imaging

Wide-angle vision solutions to cover the whole cabin for DMS and OMS with higher pixel density in specific regions.

Inspired by the human eye, Immervision's new type of wide-angle optics can monitor the entire in-cabin using Smart Pixel Management, Immervision's patented technology, to monitor – in very great detail – the driver's face. **Smart Pixel Management allows the magnification of a region of interest in the field of view** at the optical level, providing more precision where it matters. Immervision also offers an image processing library with de-warping functionality to render rectified images for computer vision applications (e.g., gaze tracking, hands-on wheel) and end-user applications (e.g., video calls, selfie pictures).



Magnification of the driver's face with smart pixel management technology

IMMERVISION



In-cabin 360° image with wide-angle optics

Wide-angle optics present an opportunity to improve the performance of DMS and OMS applications and cut system costs by combining cameras or reducing the sensor resolution. It also enables features such as high-resolution selfie pictures and video calling in a single system.



Actuator

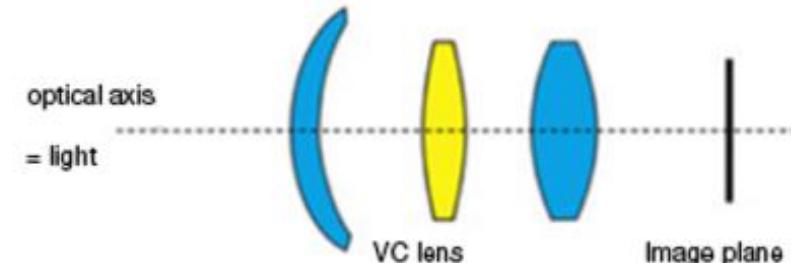


TECHNOLOGY TRENDS

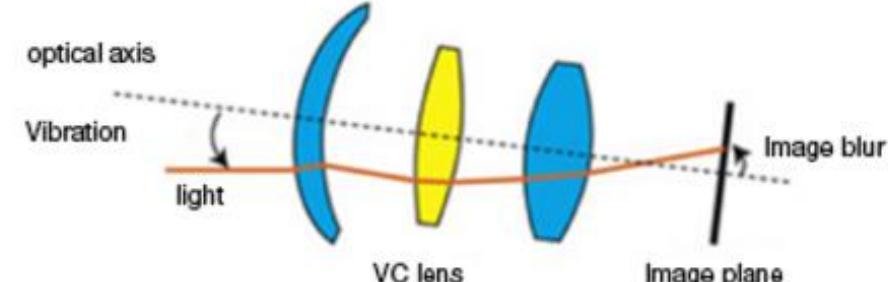
The beginning of OIS story in smartphones

- OIS is no longer a premium phone-only feature.
- Initially, Nokia released a mobile camera with OIS, but they could not translate this innovation into smartphone sales.
- Apple then controlled the pace of innovation in CCM and introduced the OIS in the iPhone.
- In 2015, the OIS feature significantly penetrated the CCM industry.

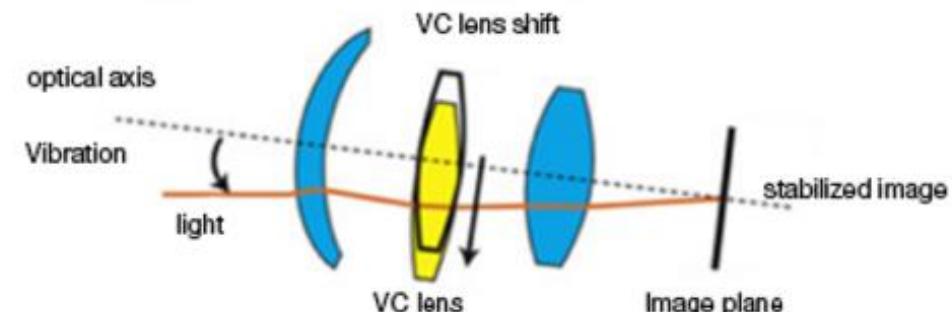
1. Static condition



2. Hand shake VC = off



3. Vibration VC = on

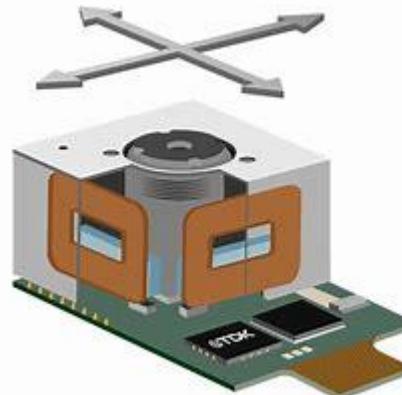




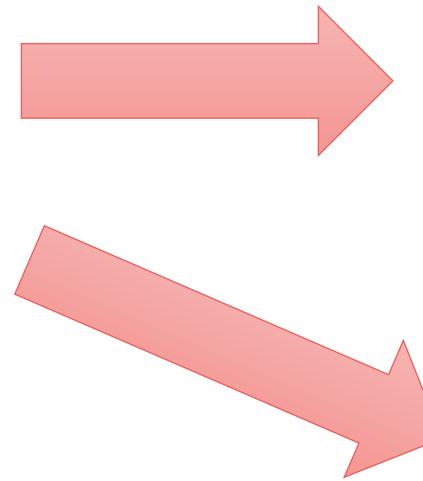
TECHNOLOGY TRENDS

Opportunity for the sensor-shift and module-shift OIS in mobile phones

LENS-SHIFT TYPE



X, Y SHIFT + Pitch, Yaw



- The lens-based OIS system effectively moves the camera's lens in relation to the phone's movement. While doing this, it can shift the lens. This is more commonly found in smartphone cameras.
- The module-shift OIS is based on a gimbal; it has wide X-axis and Y-axis tilt angles and enables rotation correction.
- On the other hand, the sensor-shift OIS shifts the sensor, not the lens. It also has rotation correction.
- Both module-shift and sensor-shift OIS technologies were introduced in smartphones.

Module shift



X, Y SHIFT + Pitch, Yaw

onsemi

SAMSUNG
ELECTRO-MECHANICS

vivo

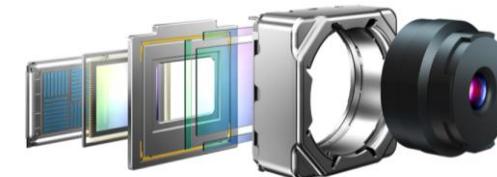
ALPS

CIRRUS LOGIC

LG Innotek



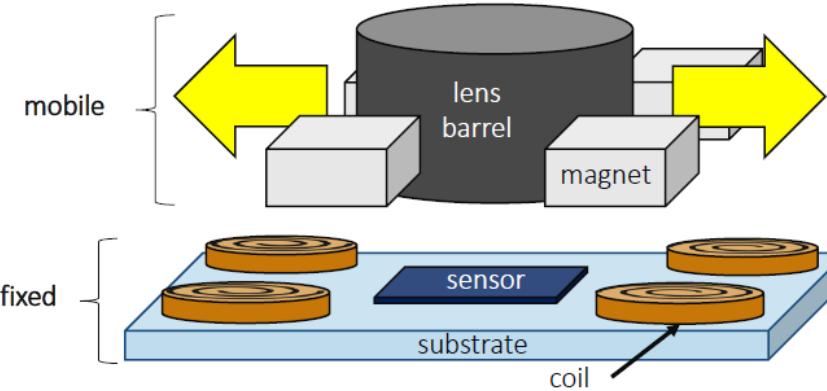
Sensor shift



X, Y SHIFT + Pitch, Yaw + Roll

TECHNOLOGY TRENDS

OIS innovation – from lens-shift to sensor-shift

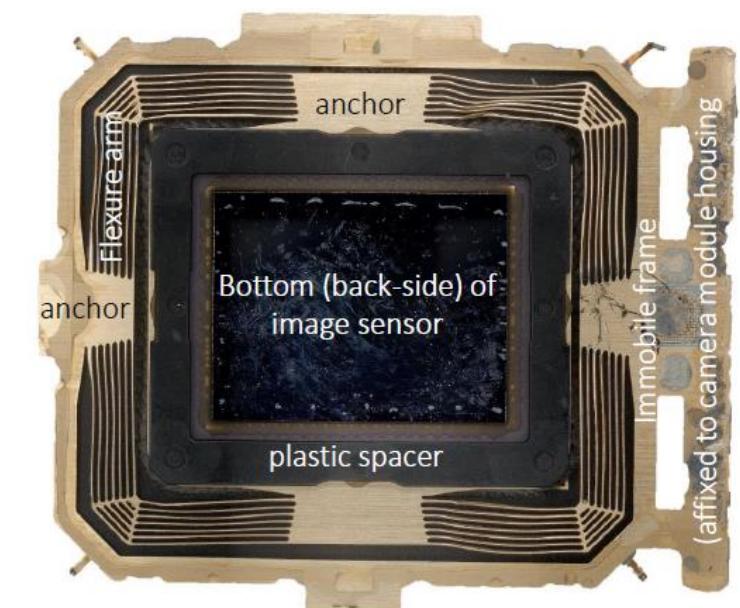
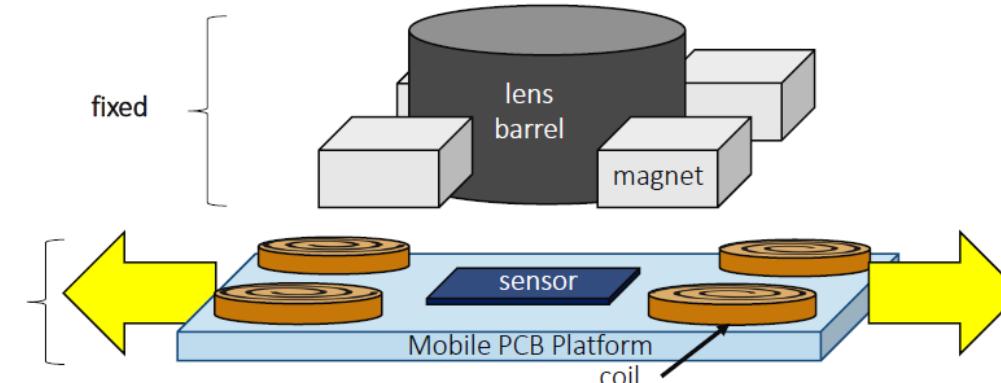


Traditional Optical Image Stabilization

In traditional OIS, coils are used to apply forces to magnets affixed to the lens barrel, which causes the lens barrel–magnet assembly to move. This allows the optics to correct for hand-shaking during long exposures.

Sensor-shift Optical Image Stabilization

In Apple's sensor-shift OIS, the lens barrel–magnet assembly is fixed, and these same forces move the image sensor.



Back side of Flexible Printed Circuit with substrate still connected
©2021 by System Plus Consulting



TECHNOLOGY TRENDS

Going beyond VCM with SMA actuators

- High-end OIS remains in the hands of the leading historical players, and innovation is critical for new entrants to differentiate themselves and achieve new design wins. While emerging technologies such as piezo motors, MEMS actuators, and liquid lenses have been brought to market, their use remains somewhat niche, while most products are based on more conventional VCM technology.
- SMA actuation leverages specific materials that change their crystal phase as a function of temperature: the expansion or contraction of the crystal lattice can produce a change in wire length. Temperature is controlled through the applied current into the wires, and a suspension assembly allows to perform the camera module actuation features.
- Thanks to SMA, there are potential benefits over VCM:
 - **Higher power efficiency:** move heavier lenses that have started to spread into CCM applications with large format CIS
 - **Higher compactness potential:** no metal shielding (not sensitive to electromagnetic interferences) and no position sensors required (resistance monitoring)
 - **Reliability might be improved:** as immune to electromagnetic interference, a benefit for its use in foldable phones
- Cambridge Mechatronics' 8-wire system, which is used in the Huawei Mate 50 Pro, uses a configuration of 8 independently-controlled SMA wires to achieve actuation along the X, Y, and Z axes as well as pitch and yaw, resulting in both autofocus and OIS features in a single actuator.
- SMA has the potential to increase penetration of advanced optical correction features, especially beyond the premium range of smartphones. Going to mass production, it should allow to bring its cost down to the level of VCM technology. With its superior power efficiency and compactness we also expect SMA to penetrate into XR headsets imaging applications.



SMA actuator
From: Cambridge Mechatronics



Alps and Cambridge Mechatronics potential partnership / licensing?

ALPS

Mass production capability

+ Performance
SMA design



- Bring more design flexibility for high-end and premium phones
- Allow the technology entering into mid-tier smartphones

SMA actuator found in some smartphones:



**Huawei
Mate 50 Pro**



**Oppo
Find X5 Pro**

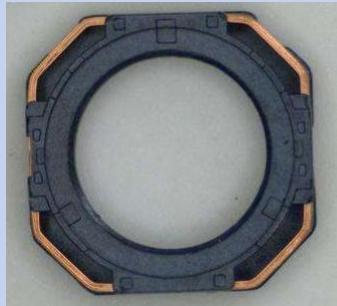


**Xiaomi
Mix Fold 2**



TECHNOLOGY TRENDS

“Liquid pistons” – the next mobile and consumer camera revolution?



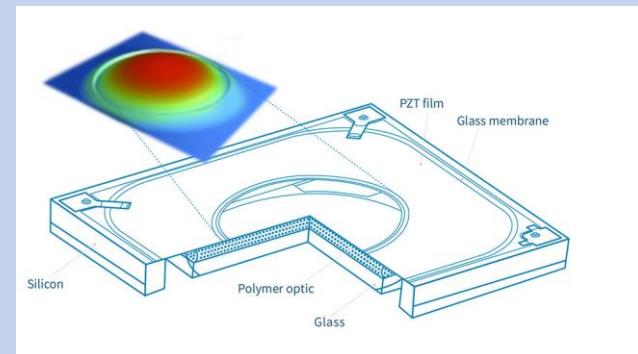
- **Voice Coil Actuator**



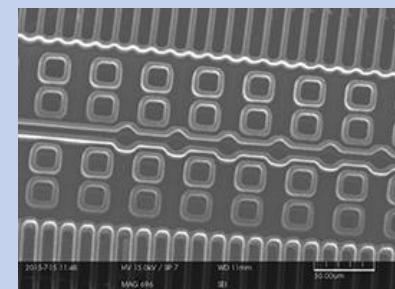
- **Shape Memory Alloy Actuator**



2020



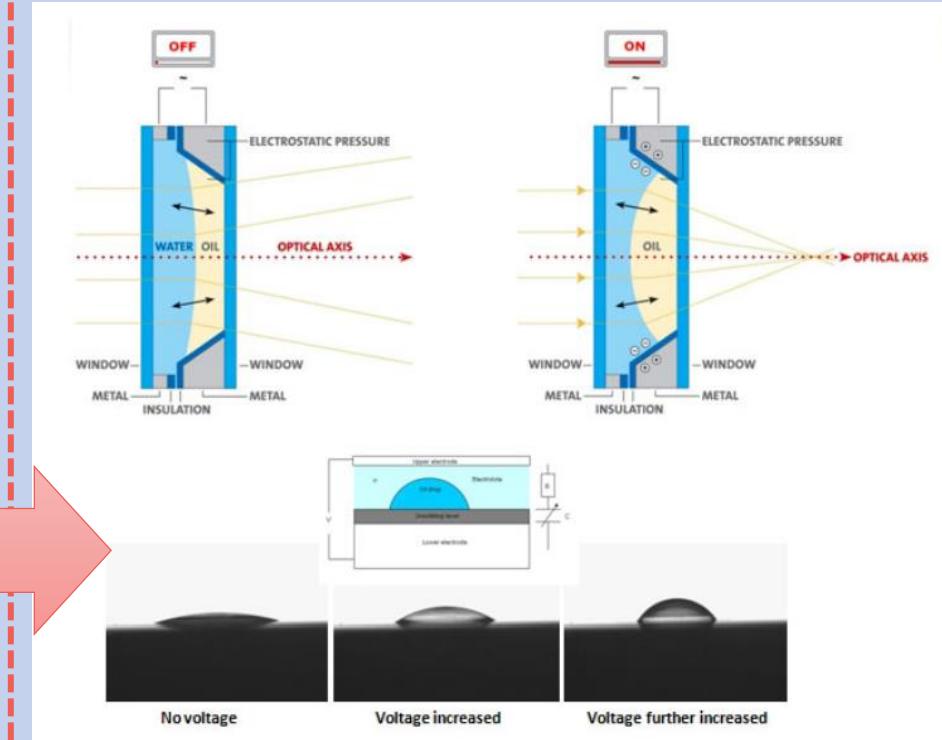
- **Tunable Optical Lens**



- **MEMS Actuator**



2023



- **Liquid (Crystal) Lens**

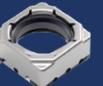
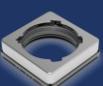
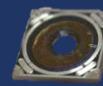
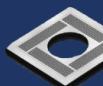


2025



TECHNOLOGY TRENDS

From VCM to other emerging technologies

Actuator type	Voice Coil Motor VCM 	Shape Memory Alloy SMA 	Tunable polymer 	Liquid lens 	MEMS 
Physical effect	Electromagnetic	Electromechanic	Piezoelectric	Electrostatic (electrowetting)	Electrostatic
Cost assumption	+	++	++	+++	+++
AF			Demonstrated in Xiaomi Mitu 4 Pro smartwatch (Polight)	Demonstrated in Xiaomi Mix Fold phone (Nextlens)	
OIS					
Wafer level					
Mass production					
Main players					
Challenging the leaders on VCM market shares					

Non-exhaustive list of technologies and companies

Other potential technologies not mentioned (piezo motors, liquid crystals...)

Techno. proven/mature

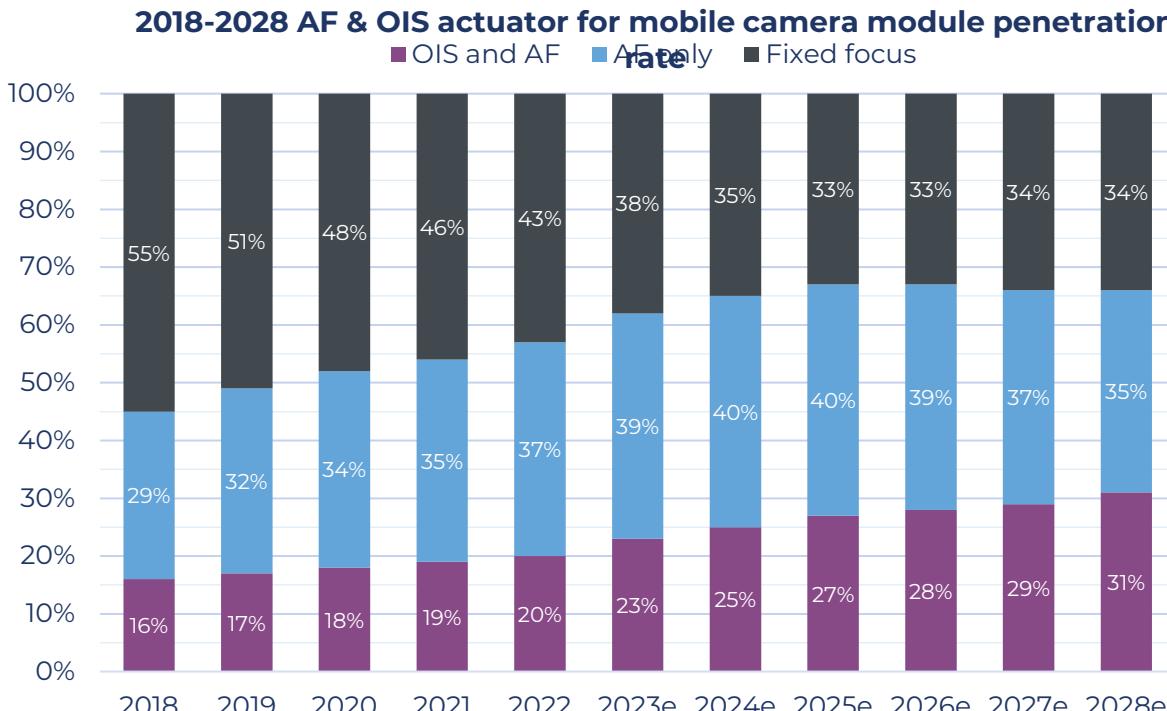
Potential/getting mature

Not available

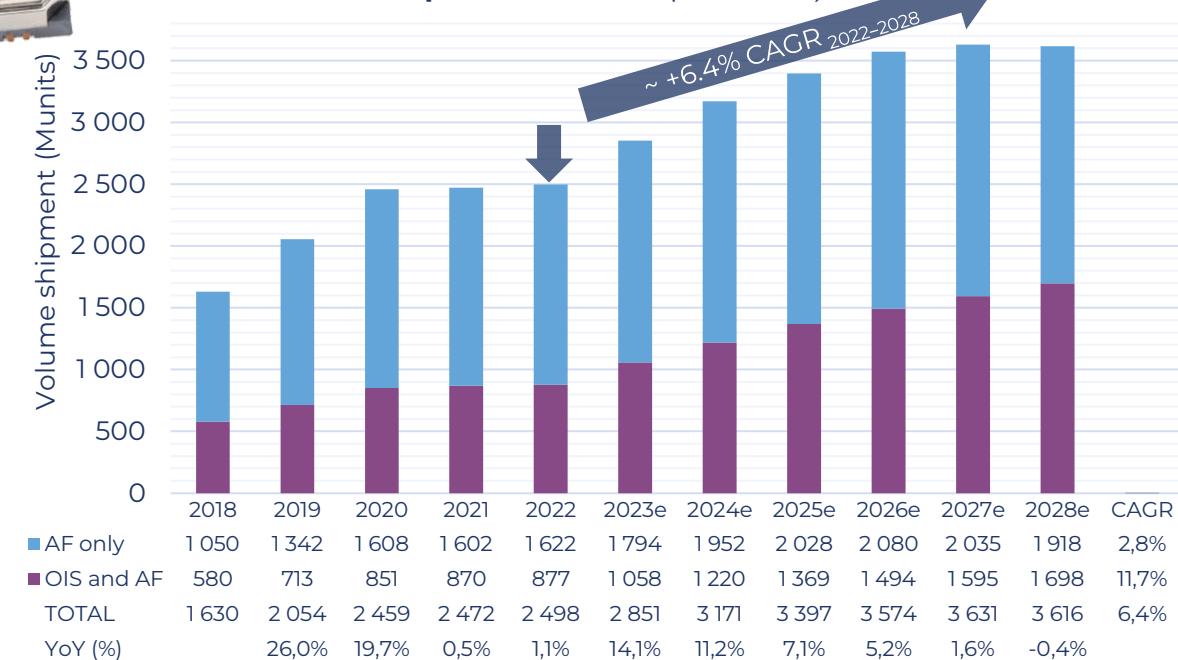


TECHNOLOGY TRENDS

AF & OIS technology penetration in smartphone cameras



2018-2028 AF & OIS actuator for mobile camera module shipment forecast (in Munits)



- The multi-camera approach adds complexity, adding a fixed focus module in middle-end phones and a periscope camera that requests OIS in high-end and flagship smartphones.
- Overall, with technological maturity and more reasonable cost, OEMs have increasingly implemented OIS to improve image performance.

- AF actuators are necessary for 8Mp+, and they could increase their penetration into more CCM thanks to a significant cost decrease allowed by the emergence of solid competitors, particularly in China (ZET, Hozel, New Shicoh, BL....).
- OIS was introduced by Apple in 2015 and is now standard in high-end handsets. In 2020, OIS also started to benefit from the multiple-camera approach. Apple continued to innovate with OIS technology and worked with LG Innotek to introduce the first sensor-shift camera module. It might be adopted by more OEMs in the future.
- We had overestimated the combined OIS and AF mode actuators these past few years. From a new mobile market survey analysis, we had to consider 877M units for 2022, to almost double by 2028.



Conclusion



TECHNOLOGY TRENDS

Conclusion

- In the climate of Consumer market stagnation, most imaging leaders are working to increase their product value and performance, targeting new product developments. Zoom has always been a key differentiator for high-quality imaging and, consequently, smartphone OEM competition. From the first commercial cameras in 2019 released by Huawei and Oppo, there has been a folded optics camera adoption wave from Android OEMs from 2020 to 2021. **Lastly, in 2023, Apple introduced for the first time a periscope camera in its iPhone 15 Pro Max series, which has given additional momentum to the expected growth. It should get more adopted not only in flagships but also in mid to high-end phones in the future thanks to module cost reduction.** Jahwa collaborated with Semco to develop ball-guide actuators, a highly desired actuating technology for larger cameras, including periscopes, to bring further speed, reliability and accuracy over spring-type actuators. However, some critical patents cover these ball-type actuators and their associated OIS system.
- The CMOS image sensor industry is animated by a profusion of technological innovations that aim to continue improving sensor performance and integrability and unlock new sensing capabilities. In general, the industry is still seeking smaller pixels, higher signal-to-noise ratio, and higher dynamic range while decreasing power consumption and the physical footprint of the sensor. **Sony is introducing its first triple-stack sensor with pixel transistors on a separate layer** for its Xperia 1 V smartphone, while Omnivision and STMicroelectronics are also investigating such architectures. Not only are pixel architectures changing, but it is also the case for logic, with smaller technology nodes. Another critical challenge is to increase device sensitivity, especially for low-light or 3D sensing applications. A low-cost SWIR imaging segment is emerging, leveraging a CIS basis to address Consumer applications (tracking cameras, 3D sensing, multispectral imaging). Event-based imaging is emerging as a solution for high-speed, low-latency, and low-power imaging as it ensures a reasonable data load.
- The manufacturing of individual camera modules is becoming more mature, but **new types of modules, such as the periscope camera, require more effort because of their optical complexity.** Mobile phone imaging has given rise to the widespread use of plastic lenses, which were previously made of glass. The optics lens industry has largely moved from Germany and Japan to South Korea and China. However, as the height needs to be minimized, the increased number of lenses makes the assembly of the lens very complex. A high-resolution CIS requires a high-quality lens, that does not necessarily mean increasing the number of lenses; another approach is adding glass to the lens set, as the hybrid approach. A new paradigm, such as a free-form or liquid lens, has risen, and **metalenses are coming to the market as an ultimate evolution of flat optics to bring further the performance and improve the compactness of the camera modules.** WLO plastic lenses have made good progress, and their small size gives them an advantage in medical applications such as endoscopy. Another way to resolve the problem of CIS with a large number of pixels is not to increase the number of lenses but to use lenses with a high refractive index material. The quest for these materials with sufficient levels of quality and reliability is still ongoing.
- VCM technology has matured, while the SMA actuator is coming to bring progress in lightweight, energy, and power efficiency, allowing to move of the large, heavy lens modules necessary for large-format CIS. **While emerging technologies such as piezo motors, MEMS actuators, and liquid lenses have been brought to market, their use has remained somewhat niche, while most products are based on the more conventional VCM technology.** Recently, Alps Alpine announced the mass production of an SMA actuator for camera modules. **This SMA technology offers precise and rapid actuation with superior compactness and energy efficiency compared to traditional VCM technology.** Additionally, the immunity to magnetic interference makes SMA actuators an ideal solution for foldable smartphones. OIS technology has clearly moved on from lens shift to sensor shift and even module shift.

CONCLUSION AND OUTLOOK





CONCLUSION AND OUTLOOK

Camera module industry transitioning to new opportunities

A competitive landscape driven by industrial capacity, key innovations, and sensitive supply chains...

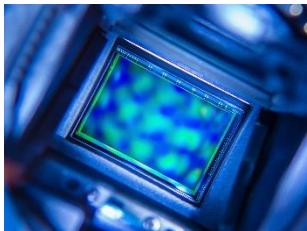
- Overall, the CMOS camera module industry faces challenges and opportunities driven by technological innovations, market dynamics, and emerging trends. The camera module industry has evolved offering more complex modules, bringing actuator, larger resolution, larger formats, etc., then transitioning to multi-camera trends and now opening the way for new multi-sensing modalities with even more intelligence brought closer to the sensing module.
- The CCM industry experienced growth until 2021, driven by mobile phones, new energy vehicle adoption, and high demand for PCs and tablets. However, in 2022, revenue slightly decreased to \$35.5 billion. Growth is expected to resume in 2023 but with a slower year-over-year rate from 2024 onwards, projecting a 4.8% CAGR from 2022 to 2028. In 2022, mobile and consumer applications have made up nearly 96% of shipments, and automotive represented 3%. 3D imaging and sensing camera modules accounted for 12% of the market in 2022 and are expected to increase to 14% by 2028.
- Mobile high-end photography is shifting towards larger resolution and size image sensors with higher average selling prices (ASPs). The automotive CCM price also increased in 2022 due to supply chain issues and higher-resolution solutions. The module assembly contribution is expected to increase from 2023 as modules become more complex. Despite a decline in smartphone shipments, higher-end products and new sensing opportunities will sustain the Mobile imaging market.
- Investments continue to secure capacity and new technologies development. CCM manufacturers and CIS giants dominate the market. CCM revenues have slightly decreased in 2022 as a soft landing after the largely inflated growth from the previous years. In this context, CCM manufacturers have experienced different fortunes, and previous revenue trends have been exacerbated in 2022: LG Innotek's continued on its tremendous growth, with 24% YoY, and could outperform its competitors: Foxconn, Sunny Optical, Semco, Ofilm, Q-Tech, Cowell, etc.
- The CIS industry experienced a transformation in 2022, with Sony leading, while Samsung reduced its footprint. The competitive landscape is affected by the economic conflict between the U.S. and China. Optics lens set and CCM actuator revenues slightly decreased in 2022, with China and Taiwan-based companies dominating the market. Japanese actuator companies have outperformed Korean ones, except for TDK, which declined due to its exposure to Huawei.
- Imaging leaders focus on increasing product value and performance. Zoom remains a key differentiator for high-quality imaging. The CMOS image sensor industry seeks smaller pixels, higher signal-to-noise ratio, and higher dynamic range. New technologies like SWIR imaging, event-based imaging, metalenses, liquid lenses,... are emerging. Complex lens assemblies are required for high-resolution CIS. VCM technology has matured, while SMA actuator technology is emerging as a more efficient solution. OIS technology has evolved from lens shift to sensor shift.



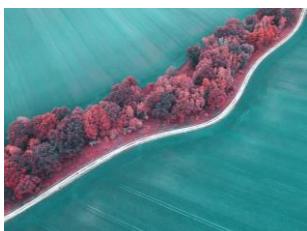
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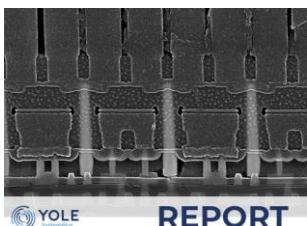
[Status of the CMOS Image Sensor Industry 2023](#)



[SWIR Imaging 2023](#)



[Imaging for Security 2022](#)



[Sony's 2-Layer Transistor Pixel in the IMX888 CIS](#)



[3D Imaging and Sensing 2023](#)



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[Smartphone Camera Module & CIS Comparison 2023 Vol.1: iPhone Evolution](#)



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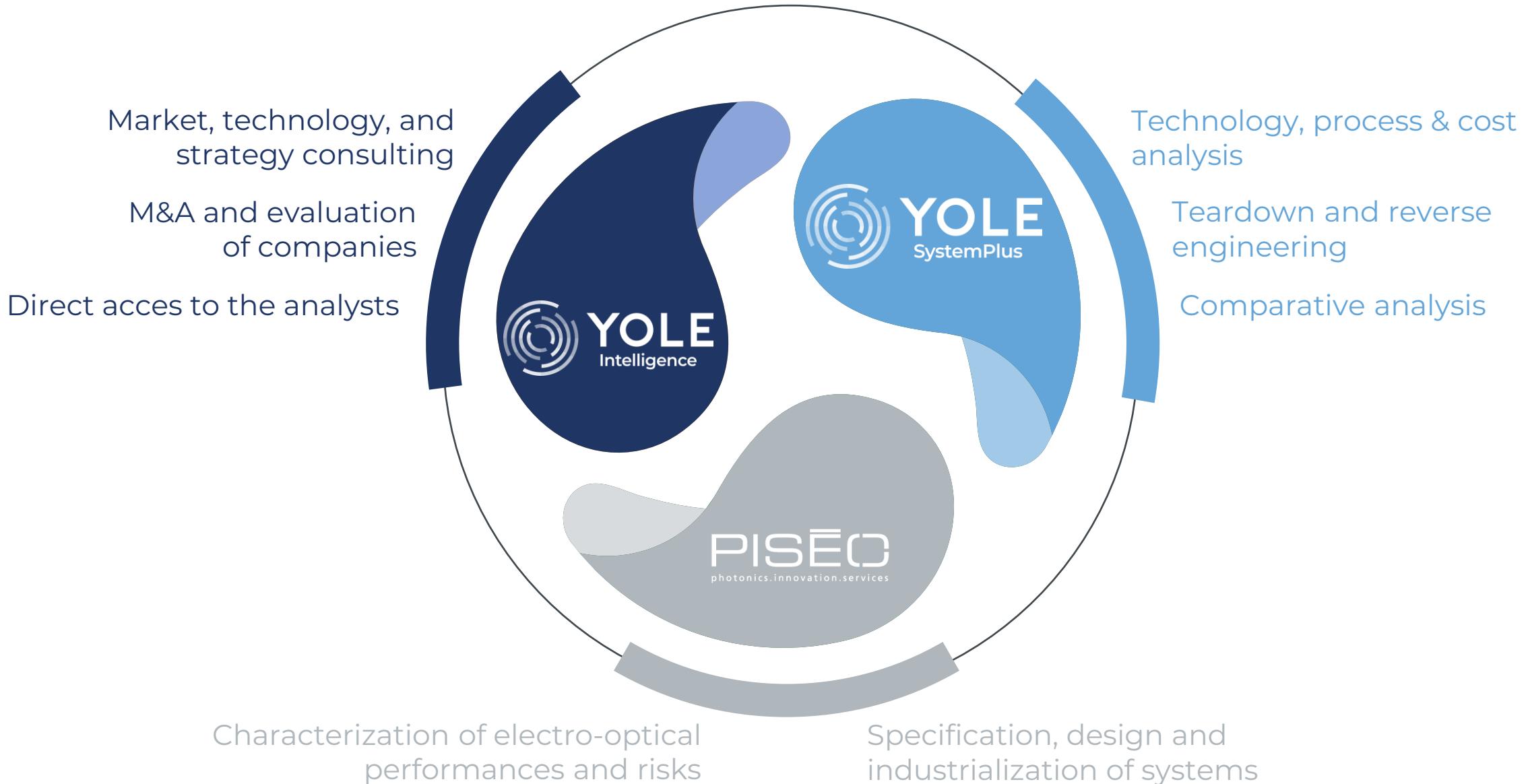
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Types of analysis

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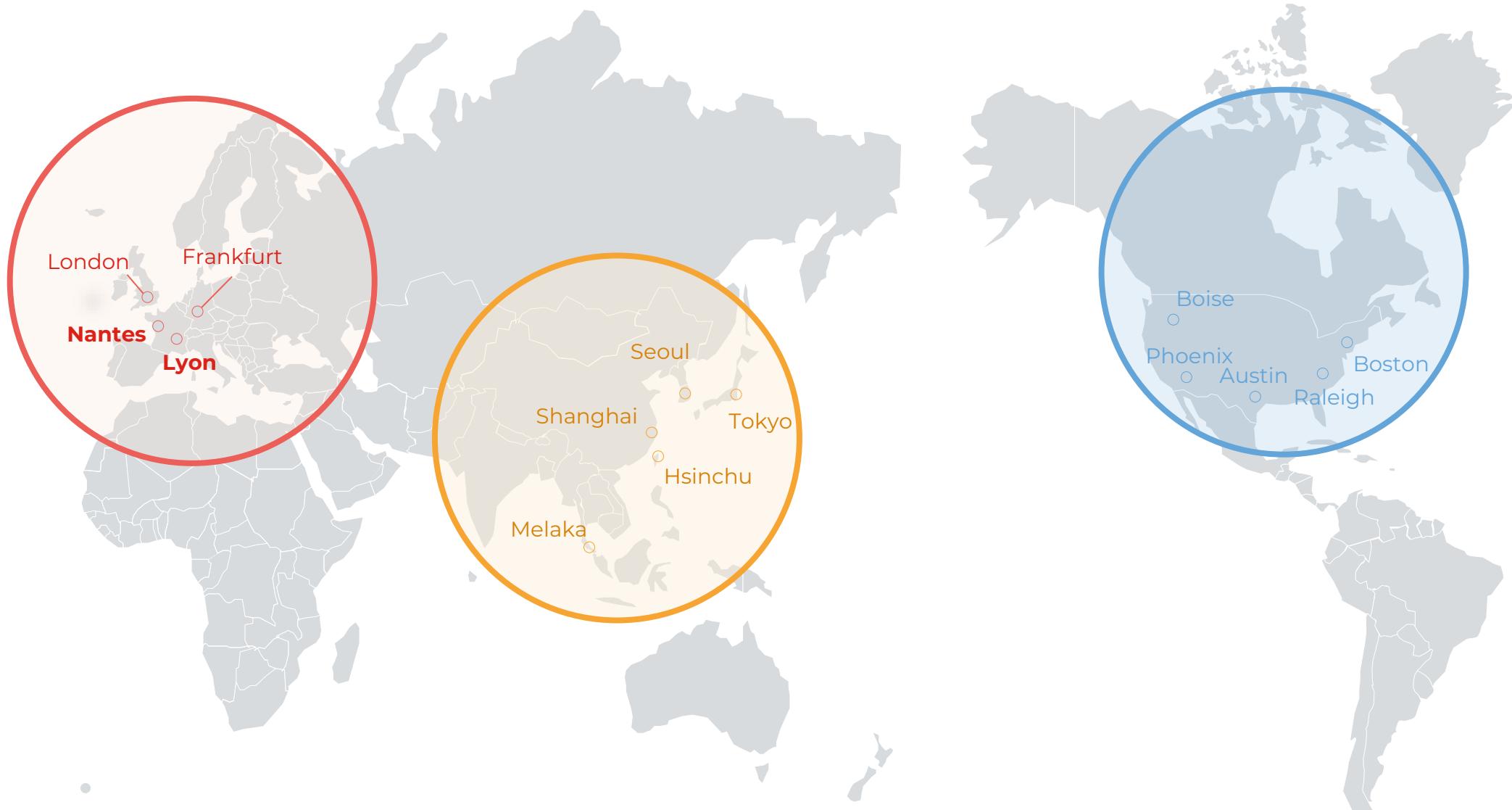
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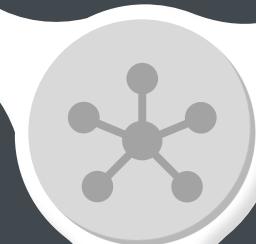




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 - Per application
 - Per technical needs
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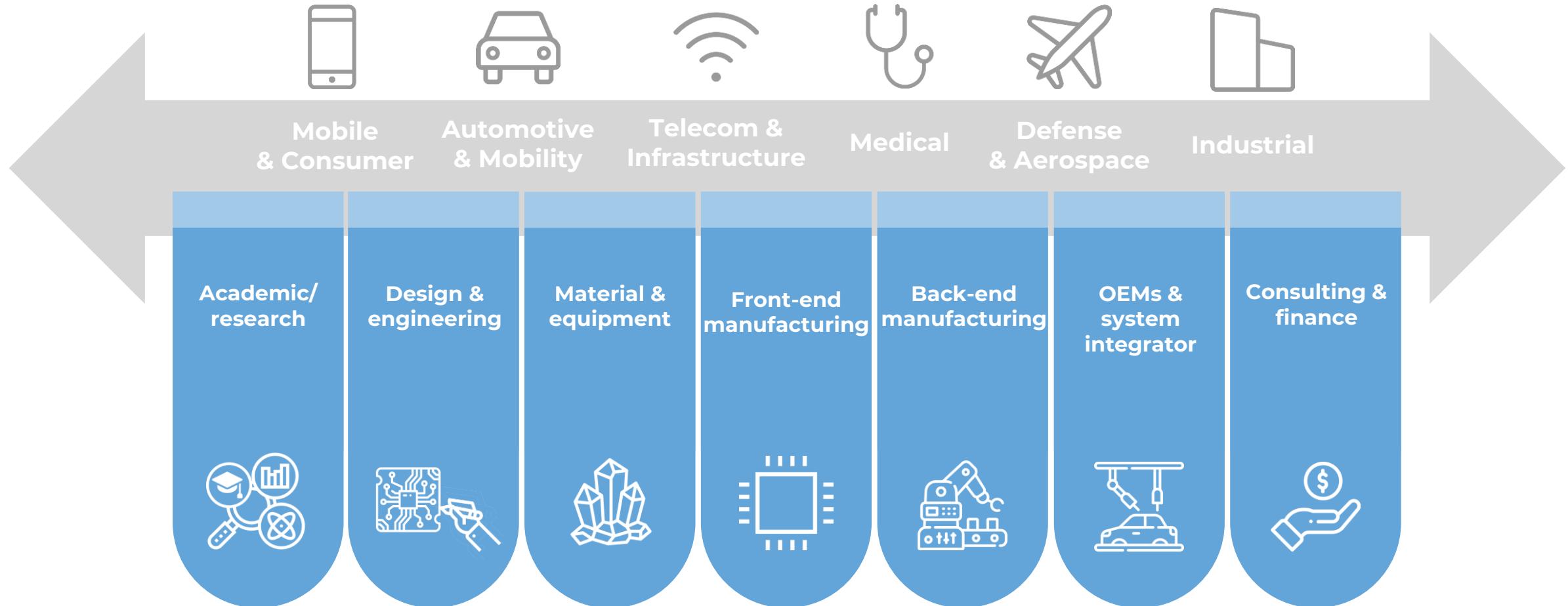
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6 KEY MARKETS





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NORTH AMERICA

sales.us@yolegroup.com
+1 833 338 4999

EMEA

sales.emea@yolegroup.com
+49 69 9621 7675

JAPAN, KOREA, REST OF ASIA

sales.japan@yolegroup.com
sales.korea@yolegroup.com
sales.restofasia@yolegroup.com
+81 3 4405 9204

GREATER CHINA

sales.gc@yolegroup.com
+886 979 336 809 +86 136 6156 6824

FINANCIAL SERVICES

Jean-Christophe Eloy
eloy@yolegroup.com | +33 4 72 83 01 80

CUSTOM PROJECT SERVICES

Yole Intelligence
custom.yint@yolegroup.com | +33 6 27 68 69 33

Yole SystemPlus
custom.ysp@yolegroup.com | +33 2 72 17 89 85

GLOBAL OPERATIONS

Marketing & Sales
marketing@yolegroup.com | +81 80 8131 7837

Public Relations & External Communications
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