Analysis of Automotive LiDAR Market

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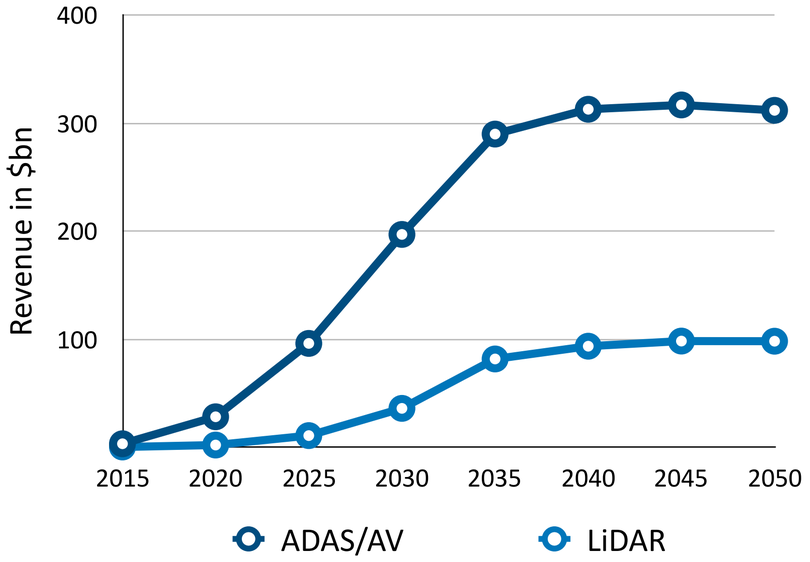
Market Overview

The self-driving race opens up vast investment opportunities.

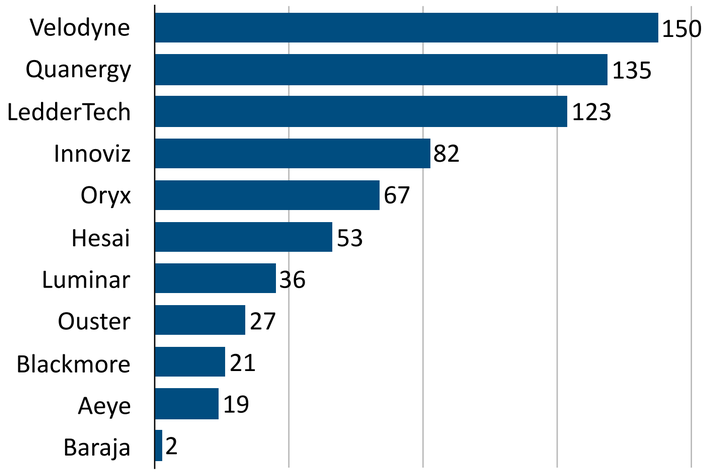
The Autonomous Vehicle(AV) market is estimated to reach $300 billion revenue by 2040, and LiDAR industry is estimated to account for 30% of the total revenue.

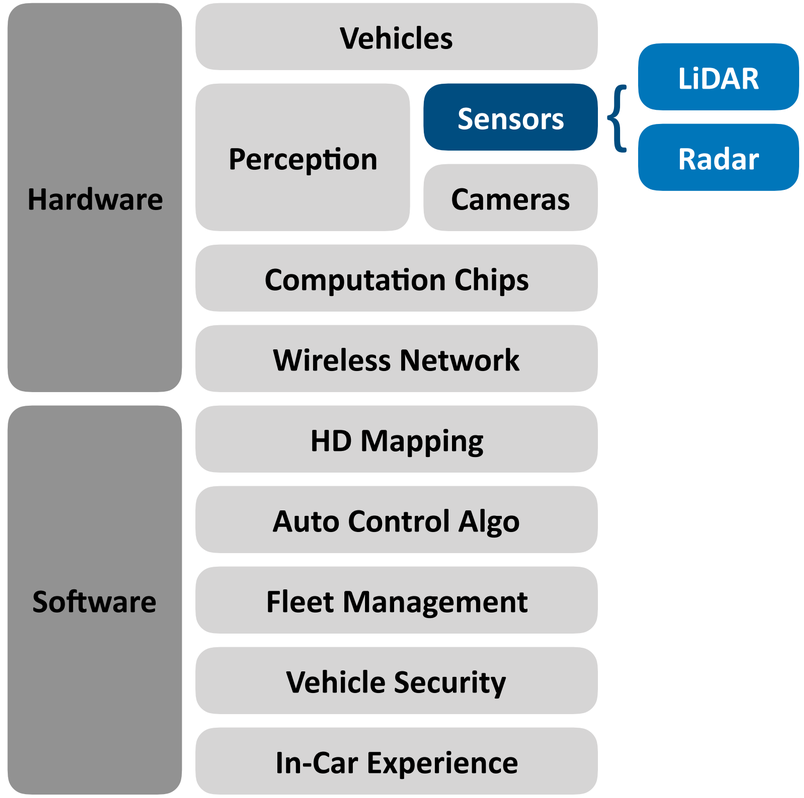
Forbes estimates at least $800m has been invested in LiDAR since 2016.

ADAS/AV & LiDAR Market Opportunity in $bn



Capital Raised in LiDAR Market in $mn





Source: Goldman Sachs, Crunchbase

Investment Thesis

- **LiDAR is essential in AV**: it's widely perceived that AV relies on a combination of LiDAR, camera and mmW Radar. Camera captures objects but no precise distance data, LiDAR provides high resolution distance data, and Radar covers a longer range with less accuracy.
- **Major AV players are actively acquiring LiDAR technology**: in 2016 Ford & Baidu invested $150m in Velodyne; in 2017, GM acquired Strobe, and Argo acquired Princeton Lightwave; in 2018, Blackmore raised $18m led by BMW.
- **LiDAR remains the most expensive piece of hardware in AV**, accounting for more than half of the hardware cost: Velodyne HDL-64E($75,000) + 4 x Velodyne PUCK(4 x $4,000 = $16,000), Radar($10,000), Cameras($6,000), IMU($4,000), other processing units($5,000), Vehicle($50,000).

	Velodyne HDL-64E	Velodyne HDL-32E	Velodyne PUCK	Robosense RS-32	OUSTER OS-I
Channels	64	32	16	32	64
Range/m	120	80-100	100	200	100
Price	$75,000	$30,000	$4,000	$16,800	$12,000

- **Solid-state LiDAR is more likely to be the mass production solution** in the long term due to lower cost, although mechanical(spinning) LiDAR dominates the current market of self driving car research, as producing a cheap and reliable system with moving parts is harder than without.

Therefore, there is tremendous investment opportunity in early-stage startups that manufacture **high-performance** and **cost-effective** solid-state automotive LiDAR.

Technology

How LiDAR works: LiDAR shoots laser onto objects and measures distance by measuring how long the light takes to bounce back.

Mechanical LiDAR spins its laser transmitter to cover 360° horizontal field of view(FoV), and stacks up multiple same units to cover vertical FoV. It requires high precision actuator and lots of calibration in assembly, which leads to its high cost, bulky size and lower robustness. The technology is mature and dominates current R&D market.

Other scanning methods besides spinning transmitter: MEMS(Microelectromechanical systems), OPA(optical phased array), Spectrum-scan.

- **MEMS**: instead of spinning transmitter, MEMS LiDAR shoots laser onto spinning micro mirror, which reflects light towards different directions. It still has moving parts so inherently susceptible to shock and vibration as mirrors may drift out of alignment. It's much cheaper and smaller compared to conventional mechanical LiDAR because with only one static laser source, the architecture is simpler.
- **OPA**: OPA LiDAR scans by adjusting laser phase passing an optical array. It's more reliable and lasts longer as there's no moving parts. The challenge is to manufacture an optical array with unit size smaller than half a wavelength, which is about 500nm.
- **Spectrum-scan**: Spectrum-scan LiDAR scans by adjusting laser wavelength passing a prism. Similar to OPA, it has high robustness and reliability.

Flash LiDAR doesn't scan its surroundings. Instead it works like a camera with light flooding entire FoV in one pulse. It has limited range compared to others because less light is shot onto each direction. The challenge is to design a highly sensitive detector that can pick up weaker reflected light.

Majority LiDARs use **pulsed laser** while a few use **FMCW(Frequency-modulated continuous-wave)**. FMCW measures wave interference instead of photon energy. Wave is less susceptible to environmental variance and contains velocity(doppler) data. FMCW puts more challenges on transmitter as the frequency and line width needs to be accurately controlled.

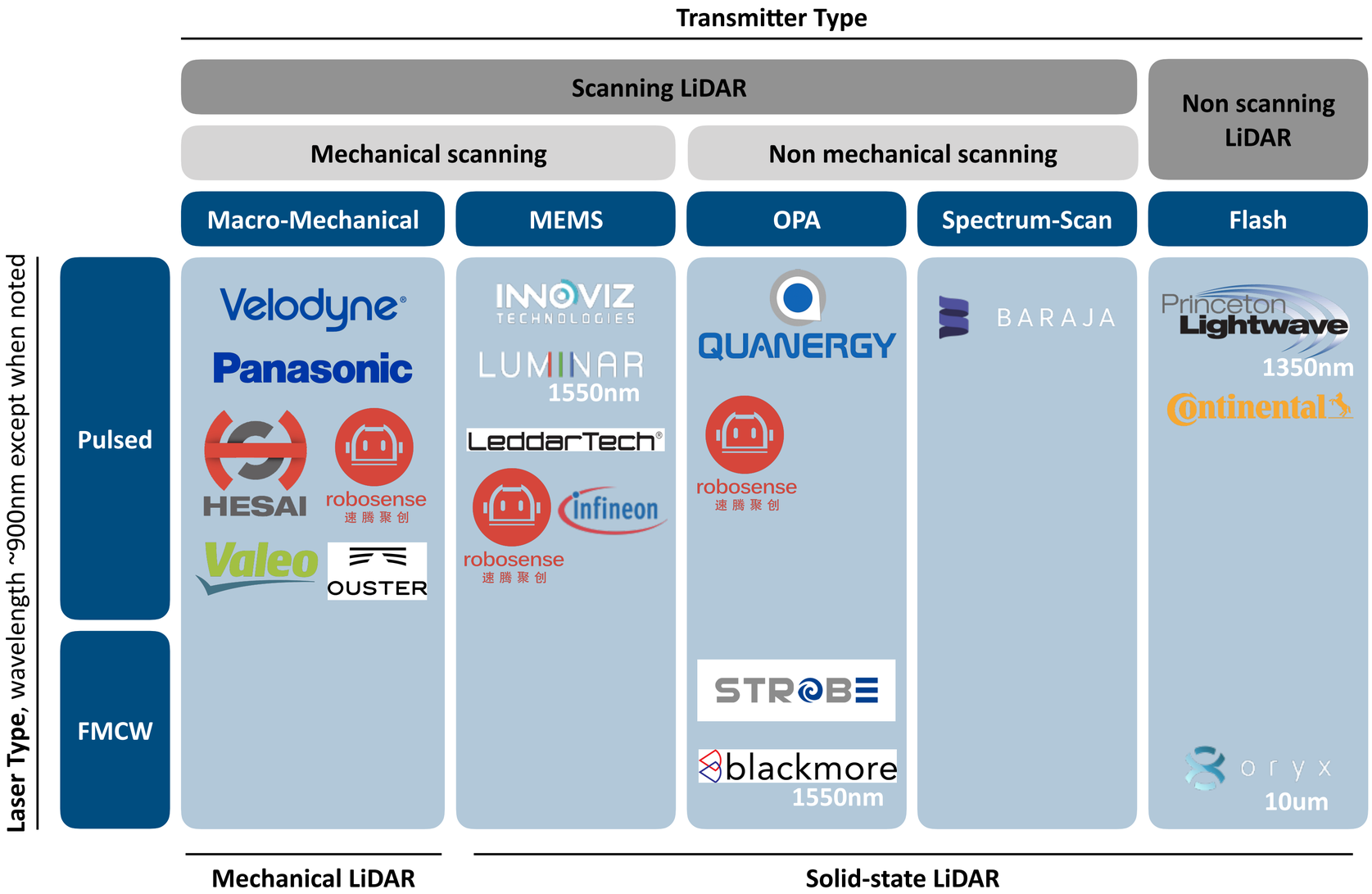
Majority LiDARs work at **900nm wavelength** while a few at **1550nm**. 1550nm covers longer range because of its higher dust robustness and a much higher power allowed by eye safety rules than 900nm.

Existing Players

Velodyne is still the leading player offering LiDARs with highest quality. But the high cost($75,000 for 64-channel) scares away many AV startups, who prefer LiDAR with okay performance but much lower cost.

That opens up opportunities for starts up like **Hesai, RoboSense and Ouster**(Ouster OS-I is $12,000 for 64-channel). More than 30% of AV startups with road test permits in CA used mechanical LiDARs from Hesai.

While solid-state LiDAR is hot, very few are commercially available yet. **MEMS is likely to be the next hit after mechanical LiDAR, followed by OPA and Spectrum-scan.**



Startups of Interest | Baraja

Overview

Founded in 2015, Baraja has been in stealth mode until July 2018 when it released its innovative spectrum scanning method. It has 60 employees and is based in Sydney, with offices in San Francisco and China. The company is expanding throughout Europe and Asia.

Financing

Seed round: $2.2m by Blackbird Ventures (Australia) and Sequoia China, announced on Feb 5, 2016

Grant: $1m Accelerating Commercialisation Grant from AusIndustry on Nov 14, 2016

Product & Technology

Baraja is the **1st LiDAR company that uses Spectrum-Scan**. Instead of using moving parts and multiple lasers, it uses a single multicolor laser and prism-like optics to split and scan its beam over a field ranging 30 degrees in the vertical and 92 in the horizontal.

Spectrum-Scan LiDAR is ready to market now. No buyers announced yet.

Founders

Federico Collarte(CEO), Cibby Pulikkaseril(CTO)

Startups of Interest | Blackmore

Overview

Founded in 2016, Blackmore is a leader in developing compact and robust FMCW LiDARs and supporting analytic tools and software. It is based in Bozeman, Montana.

Financing

Series A: $3.5m by NEXT Frontier Capital, Millennium Technology, announced on Dec 12, 2016

Series B: $18m by BMW i Ventures, NEXT Frontier Capital, Millennium Technology, Toyota AI Ventures, announced on Mar 20, 2018

Product & Technology

Blackmore uses **OPA** scanner and **FMCW** (same as Strobe, acquired by GM). It also uses **1550nm** laser instead of 900nm which enables it to achieve a higher range and robustness.

Founders

Randy Reibel(CEO), Stephen Crouch(CTO), Trenton Berg, Jim Curry

Startups of Interest | RoboSense

Overview

Founded in 2014 by a group of PhDs from Harbin Institute of Technology who have been working on LiDAR for 7+ years, RoboSense is the leading provider of autonomous driving LiDAR. It has 200+ employees and is based in Shenzhen with offices in Beijing and Silicon Valley.

Financing

Series A+: $?m by FOSUN Kinzon Capital on June 2016

Product & Technology

Mechanical: RS-LiDAR-16, RS-LiDAR-32, Multi-LiDAR coupling platform on market.

Solid-state: RS-LiDAR-M1(**MEMS**), RS-LiDAR-M1 Pre(**MEMS**, used in Alibaba's unmanned logistic vehicle), SEEKER(**OPA**) on market.

Software + Hardware solution (Prometheus) in development.

Founders

Chunxin Qiu(CEO), Chunchao Qiu(COO), Letian Liu(CTO), Xiaorui Zhu(Chief Scientist)

Startups of Interest | Hesai

Overview

Founded in 2013, Hesai started by designing laser-based Methane/Natural Gas leakage detectors, and pivoted its focus to LiDAR in 2016. More than 1/3 of the 54 companies with road-test permits in California are Hesai's customers. It has 200+ employees and is based in Shanghai.

Financing

Seed: $2m by LightHouse, on Oct, 2014.

Series A: $16m by Pagoda, LightHouse, GrainsValley, Jiangmen, announced on May 11, 2017

Series B: $37m by Baidu, Lightspeed China, Zhenfund, announced on May 3, 2018

Product & Technology

Mechanical: 40-channel mechanical LiDAR(PANDAR 40), sensing kit(LiDAR + cameras, PANDORA) on market.

Solid-state: PANDAR GT in development.

Founders

Yifan Li(CEO), Shaoqing Xiang(CTO), Kai Sun(Chief Scientist)