

高頻高壓半導之SiC

— 我是一粒响当当的銅豌豆

1. Silicon Carbide Device Technology

王不老說半導

元朝第一浪子关汉卿：响当当的铜豌豆

- 作为元曲四大家，关汉卿自评“普天下郎君领袖，盖世界浪子班头”，他在《不伏老》中写道：“我是个蒸不烂、煮不熟、捶不扁、炒不爆、响当当一粒铜豌豆！”
- 王国维评：“一无依傍，自铸伟词，而其言曲尽人情，字字本色，故为元人第一。”
- 在高頻高压半导体世界裡，我們竟可以戲稱，SiC是粒响当当铜豌豆**



試問：為何SiC是粒响当当铜豌豆？

解答：他其實比铜豌豆厲害多了

- 其化性穩定，不畏許多強酸，性格剛烈無比，硬度接近鑽石，可忍受極高溫($\sim 1900\text{C}$)，絕不軟化(melting)，只會氣化(sublimation)，熱傳導性(k)大，熱擴展係數(CTE)小，故能忍受極大的热冲击(thermal shock)
- 因此，它的用處非常廣泛(如右圖所示)，用它來做相關高頻高壓電子器件，更是適得其所

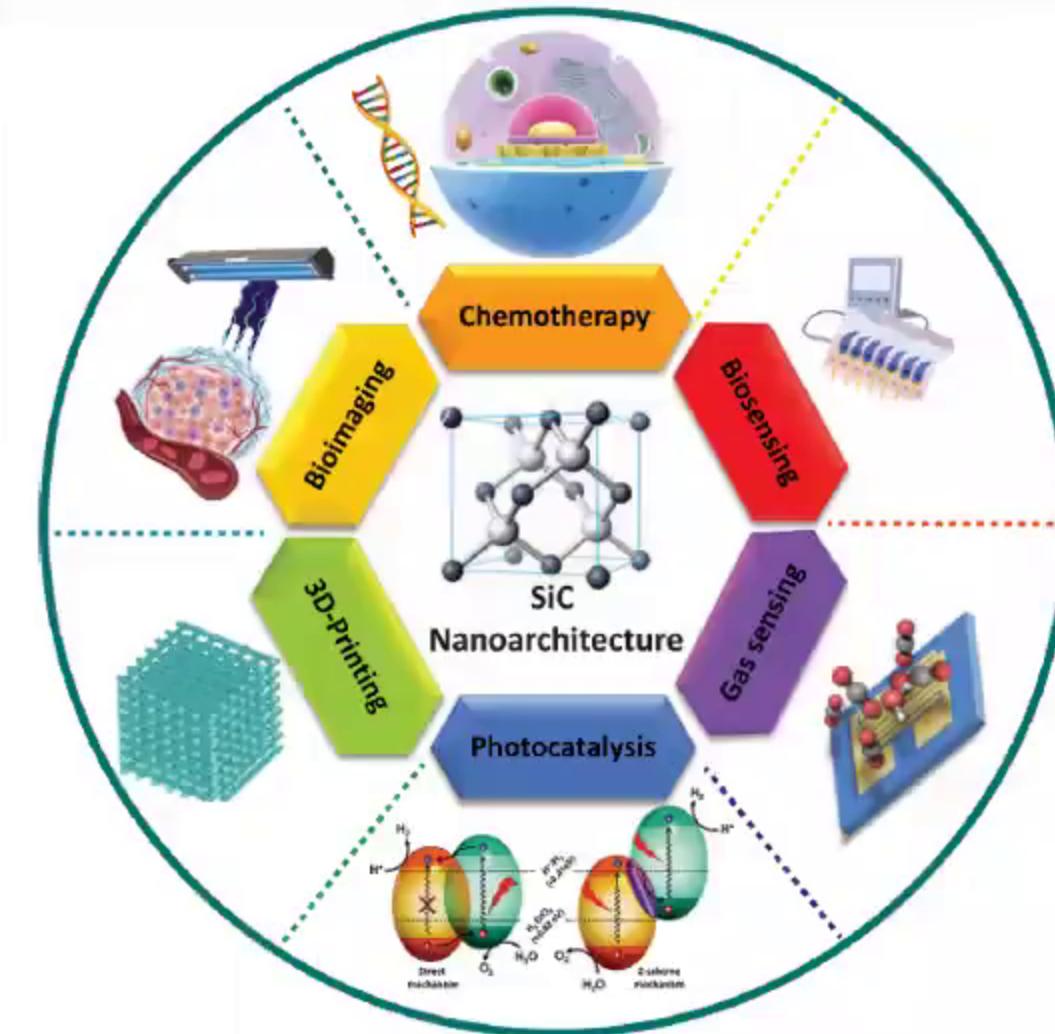


Fig. 1. SiC nanoarchitecture for diverse applications.

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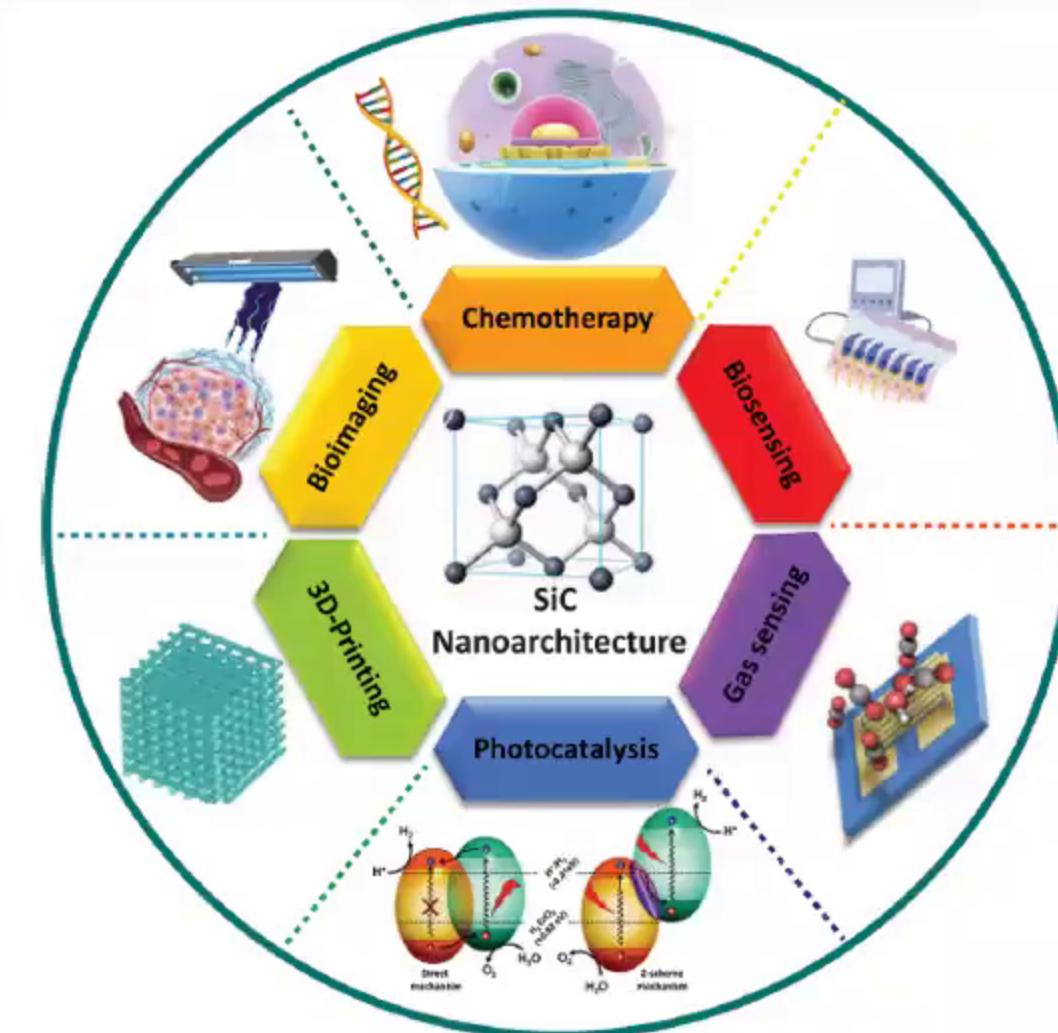


Fig. 1. SiC nanoarchitecture for diverse applications.

回味：高功率高頻半導江湖的四大金剛

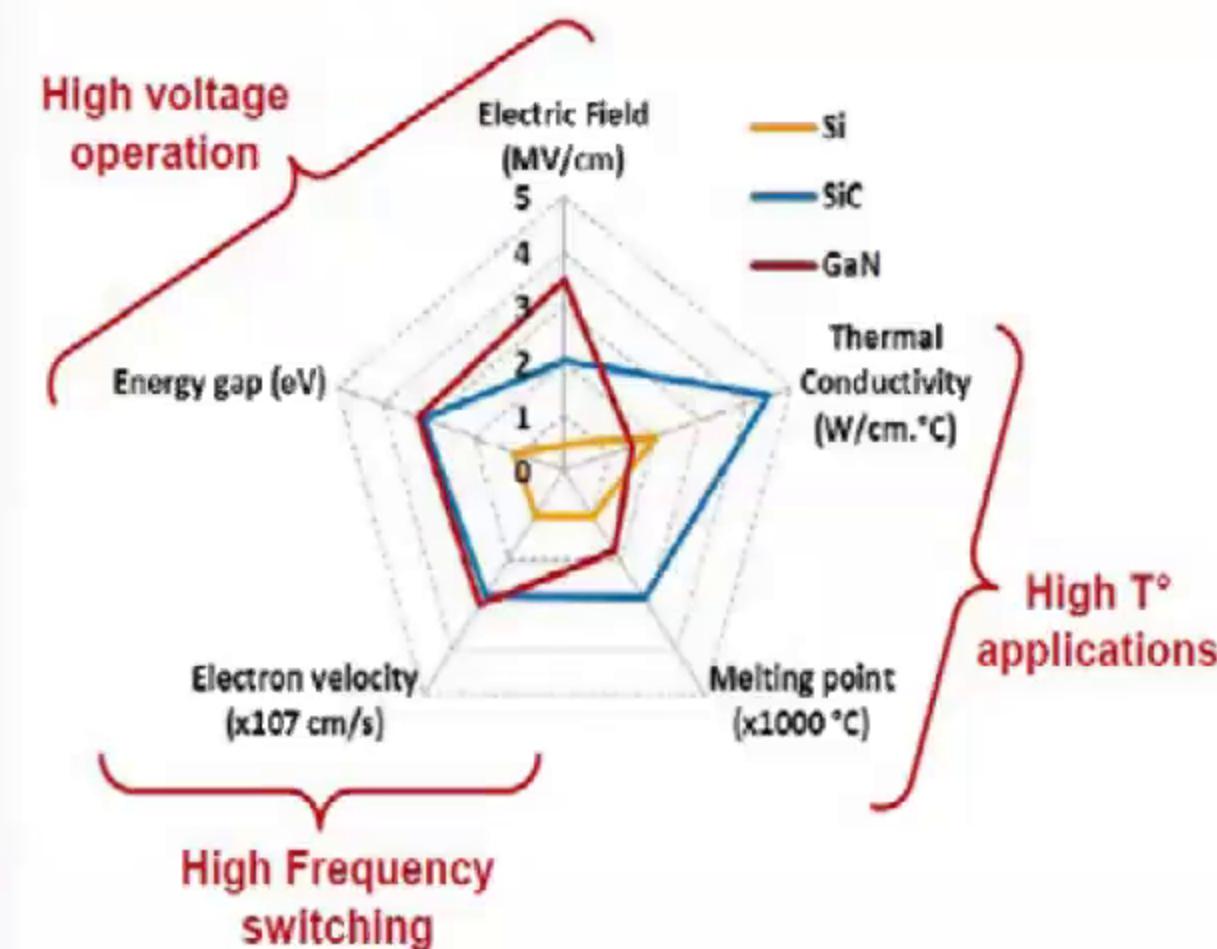
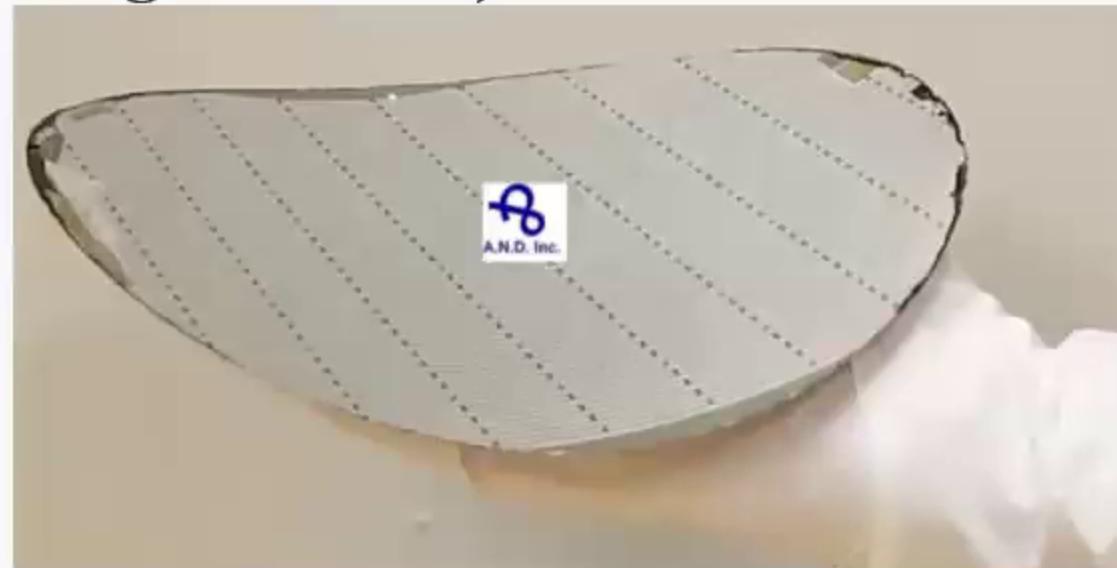
Properties	Si	4H-SiC	GaAs	GaN	Application
Crystal Structure	Diamond	Hexagonal	Zincblende	Hexagonal	
Energy Gap : E_G (eV)	1.12	3.26 3x	1.43	3.5	high temp. operation, emission wavelength
Electron Mobility: μ_n (cm^2/Vs)	1400	900	8500	1250	High frequency devices
Hole Mobility: μ_p (cm^2/Vs)	600	100	400	200	
Breakdown Field; E_B (V/cm) $\times 10^6$	0.3	3 10x	0.4	3	Power devices
Thermal Conductivity (W/cmK)	1.5	4.9 3x	0.5	1.3	High heat dissipation
Saturation Drift Velocity: v_s (cm/s) $\times 10^7$	1	2.7 3x	2	2.7	High frequency devices
Relative Dielectric Constant: ϵ_s	11.8	9.7	12.8	9.5	
p, n Control	Good	Good	Good	Average	
Thermal Oxide	Good	Good	Behind	Behind	MOS structure

回味：高功率高频半导体江湖的四大金刚

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回味: Si, SiC and GaN的蜘蛛擂台

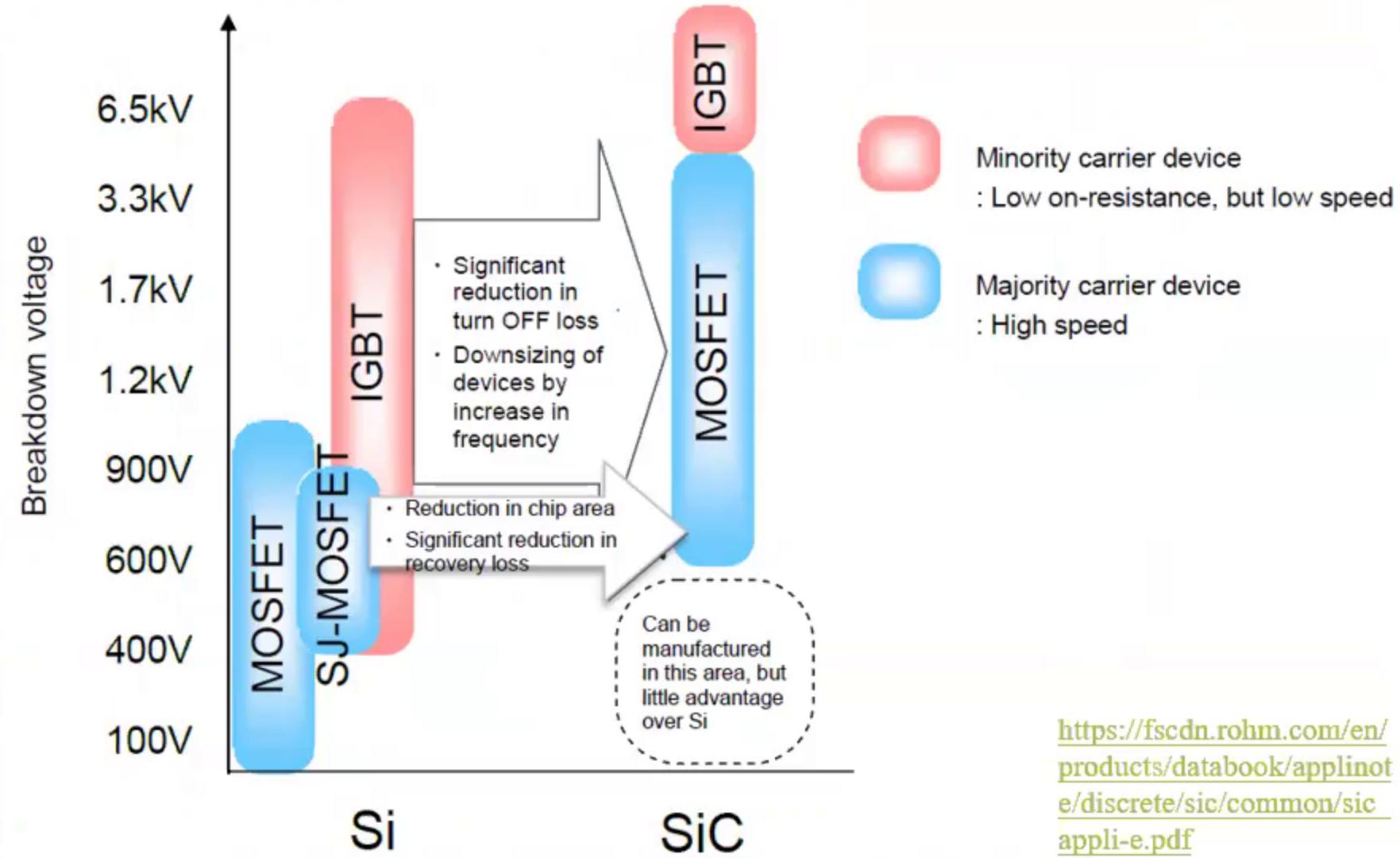
- SiC for high Temp application
- GaN ~ reach high voltage, but requires bulk GaN substrate
- Silicon may not compete at the high frequency range (but AND begs to differ)



Imbruglia et al (2019). WINSIC4AP: HIGH PERFORMANCE SiC POWER TECHNOLOGY FOR RELIABLE APPLICATIONS

SiC vs Si MOSFET & IGBT

- 天下沒有白吃的午餐，所以必須善用SiC的優劣(i.e., 又小又精幹)，不然有些划不來
- SiC器件制程到底還是貴了些



https://fscdn.rohm.com/en/products/databook/applinote/discrete/sic/common/sic_appli-e.pdf

碳化硅世界之無煙戰

- 第3代半导体的主要用途，就是用作控制高电流的功率半導器件
- 優良的碳化矽基板倚賴接近完美的晶種(天科合達的晶種發展已超過10年)



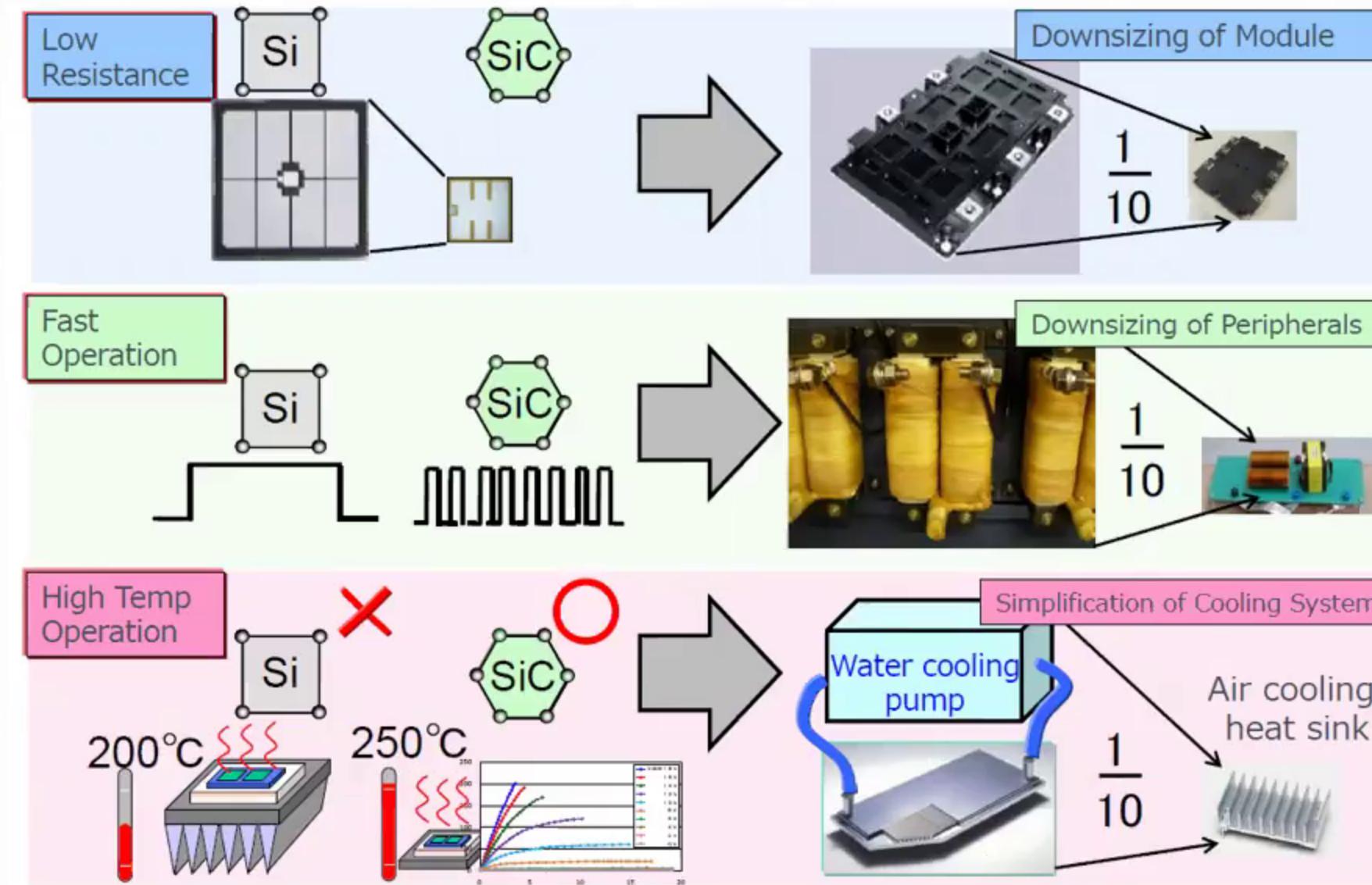
U.S. opens first major silicon carbide chip plant in New York

Wolfspeed's 200mm facility to supply American and Chinese EV makers



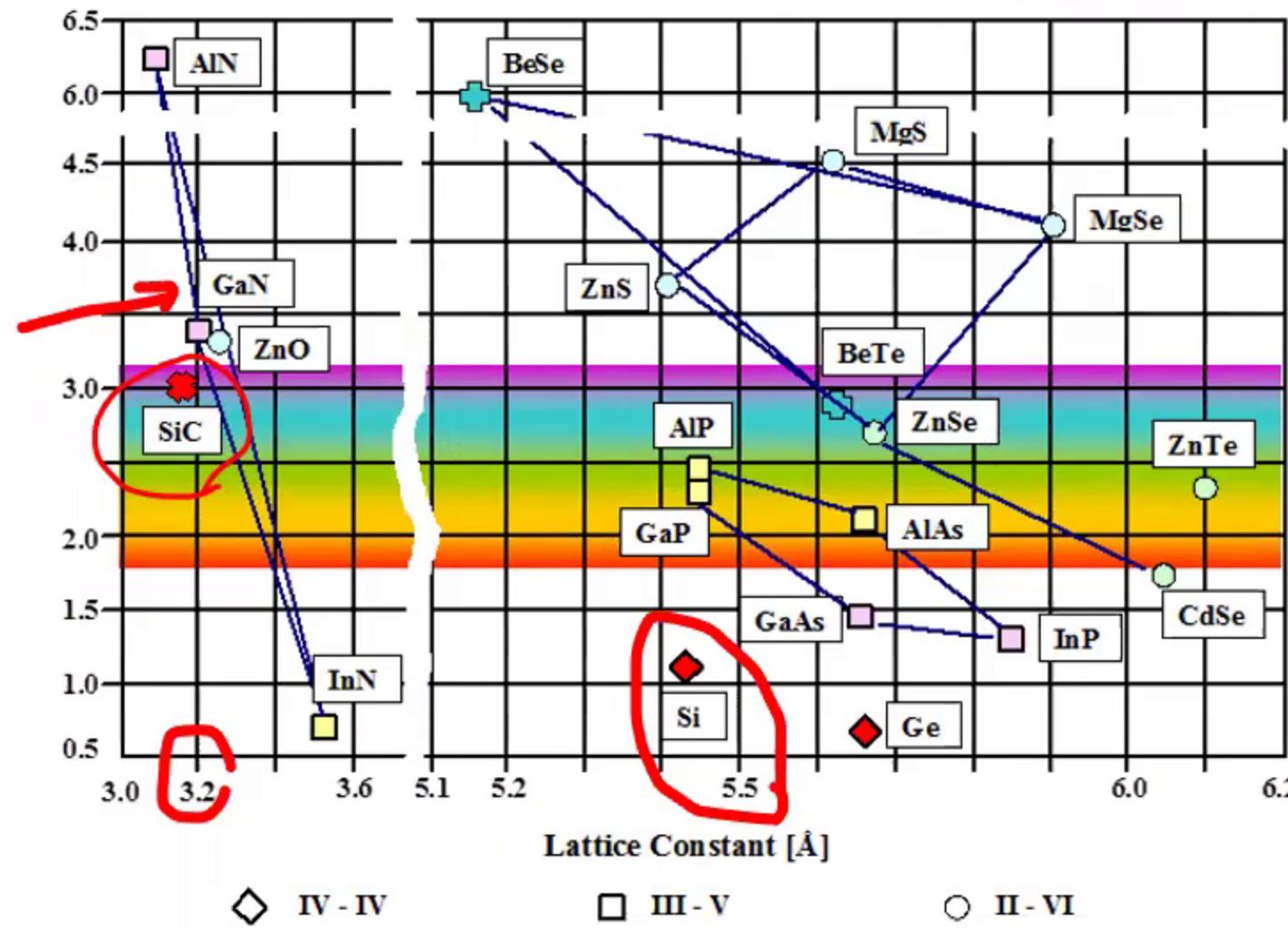
U.S. chipmaker Wolfspeed is aiming to expand its production of silicon carbide chips, which are used in electric vehicles. (Photo by Jack Stone Truitt)

SiC較Si器件应用領域的優勢



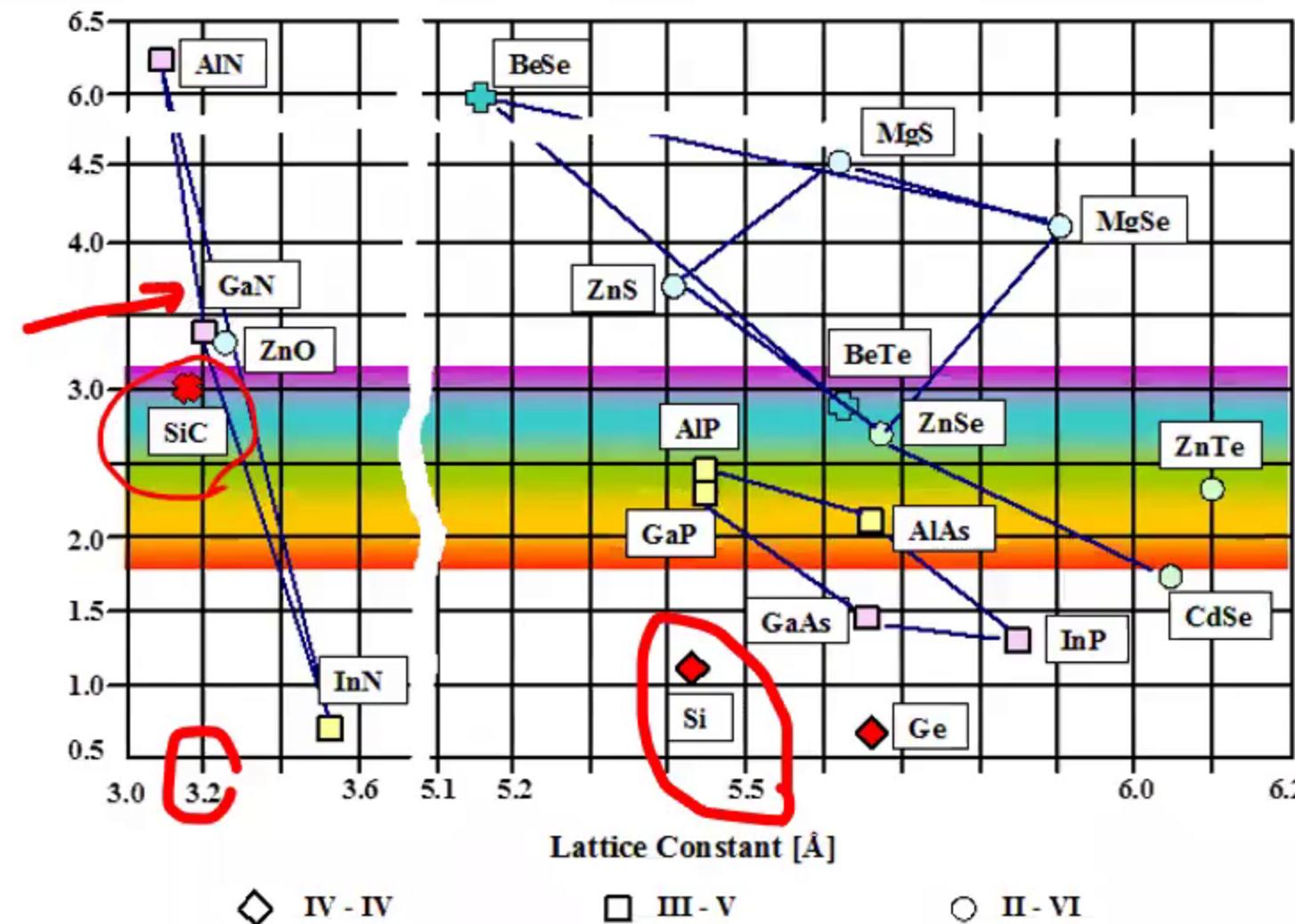
試問: GaN可以磊晶在SiC上嗎?

- 解答: 很不舒服, 也很難磊晶, 但晶圓便宜
- 与(111)平面相反, (100)硅平面不呈现6倍对称性, 而是更适合立方相外延生长的4倍对称性
- 然而, (β -GaN)立方相是亚稳定的, 热力学上稳定的六方GaN相勉强可以在(100)平面上生长



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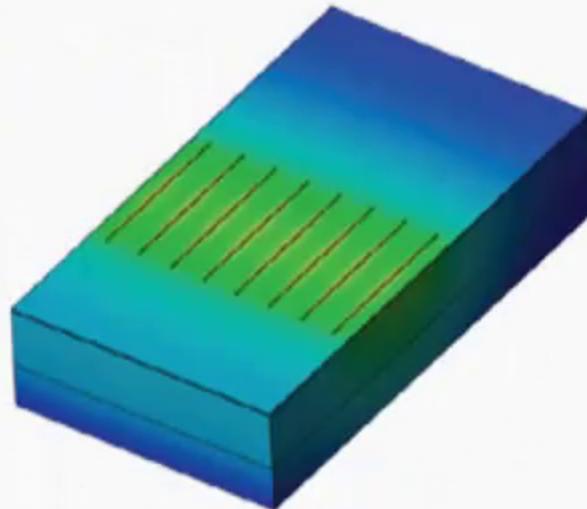
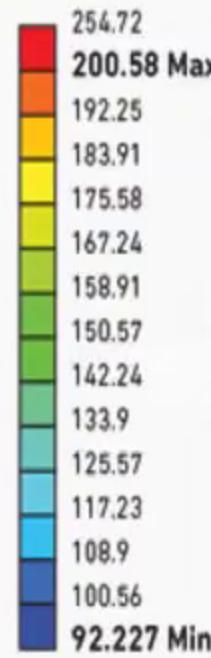
GaN on SiC更可靠，當然也更貴了

GaN on SiC

VS.

GaN on Si

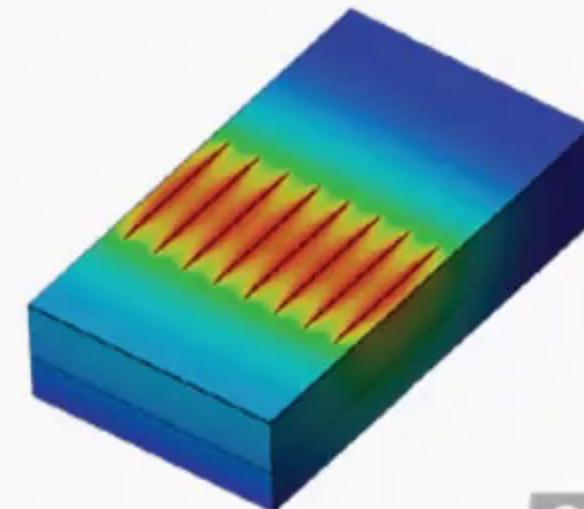
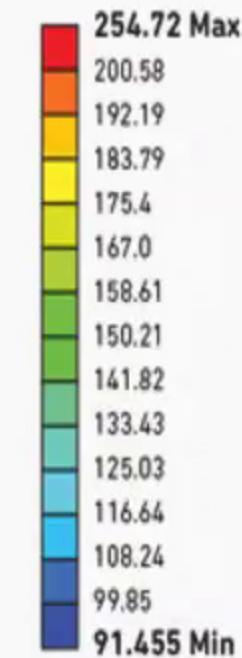
Soitec Smart-Cut SiC



54°C HOTTER
than GaN on SiC

27% HIGHER
CHANNEL TEMPERATURE

10 to 100X
DECREASE
in device life



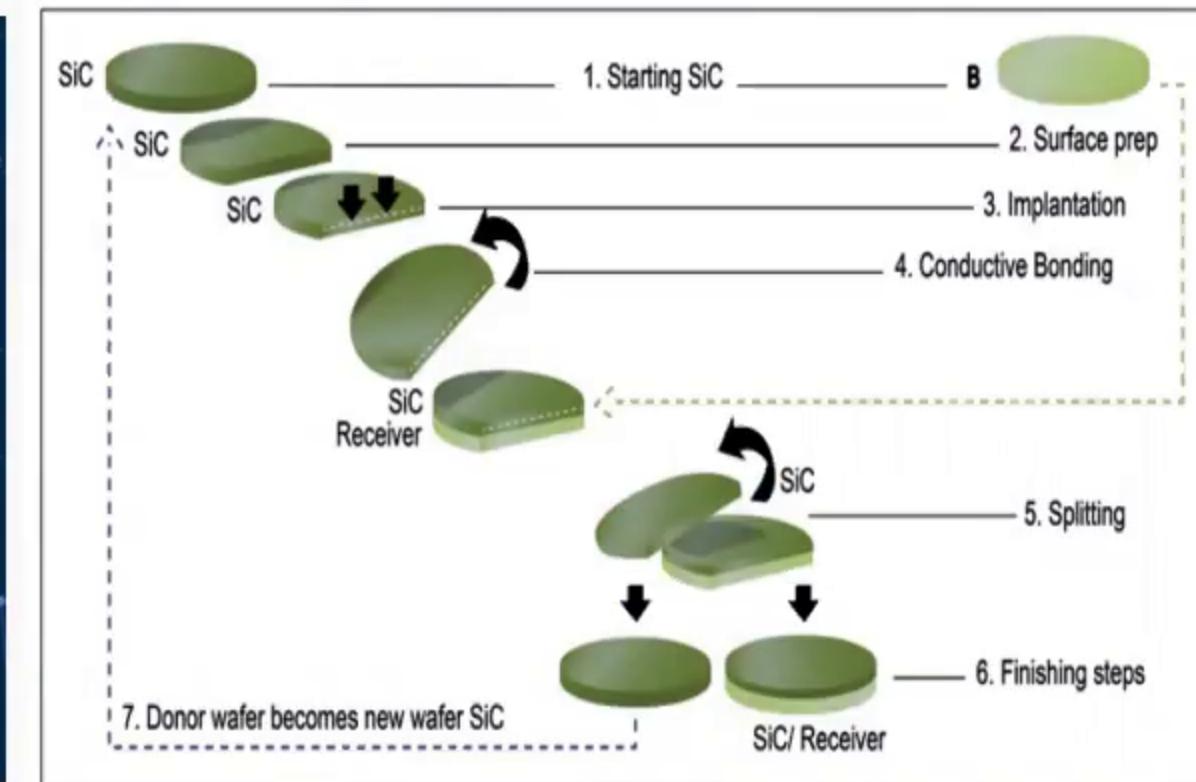
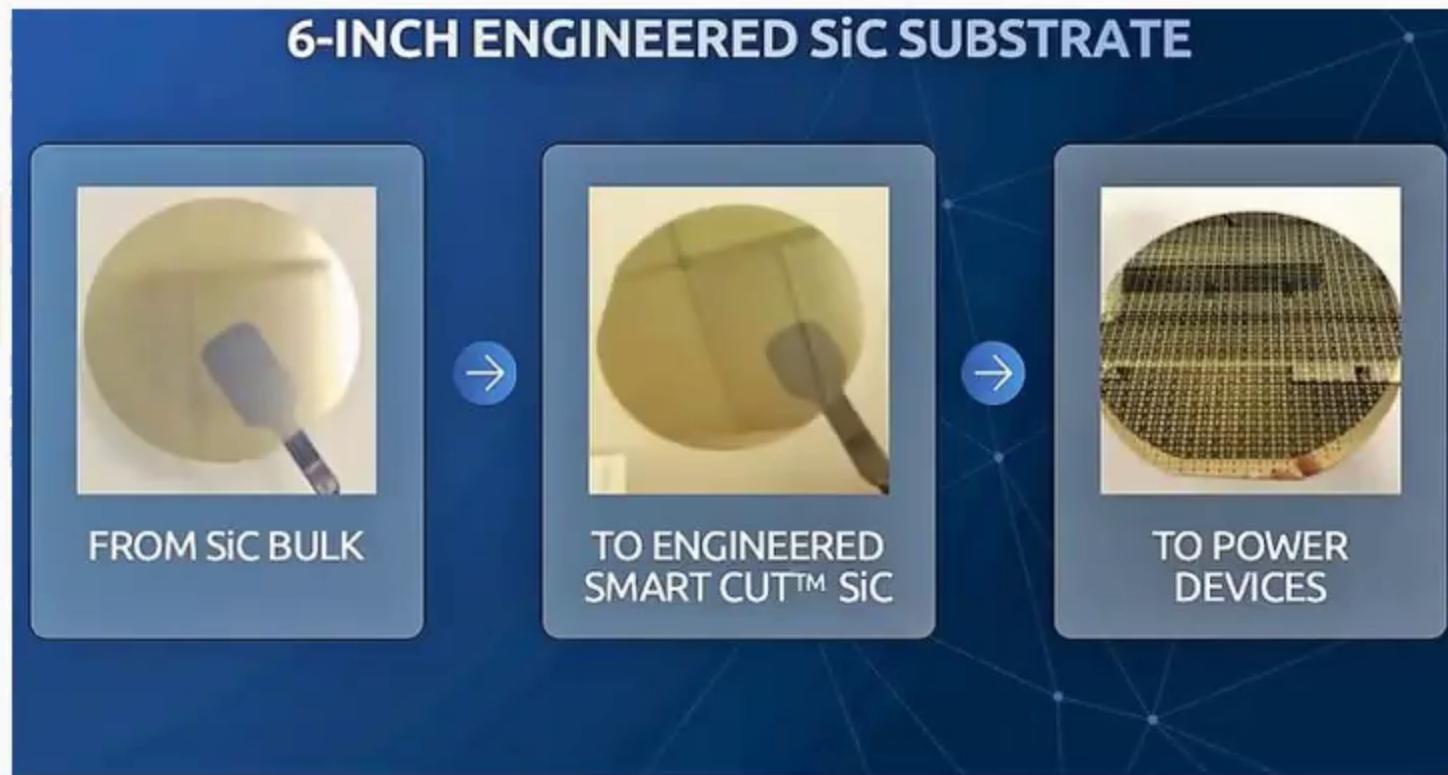
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<https://cn.qorvo.com/>

Soitec Smart-Cut SiC

- Soitec用Smart-Cut (一種以氫為刀的技術)於SiC好處甚多(見有關章節)



<https://www.i-micronews.com/soitec-aims-for-big-ev-win-with-smart-cut-sic-wafers/?cn-reloaded=1>

<https://www.soitec.com/media/files/Compound-Semiconductor-Issue.pdf>

SiC产业链

- 兵家必爭之地也

SiC产业链

大陆	衬底	外延	设计	制造	IDM模式
其他地区	Cree 道康宁 Rohm II-VI 新日铁	Cree 道康宁 Rohm Novasic 昭和电工	USCI Bruckwell CISSOID	Suny Poly 离子束 X-Fab 汉磊科技	泰科天润 中车时代 扬杰电子 中电科 华润微
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GaN产业链

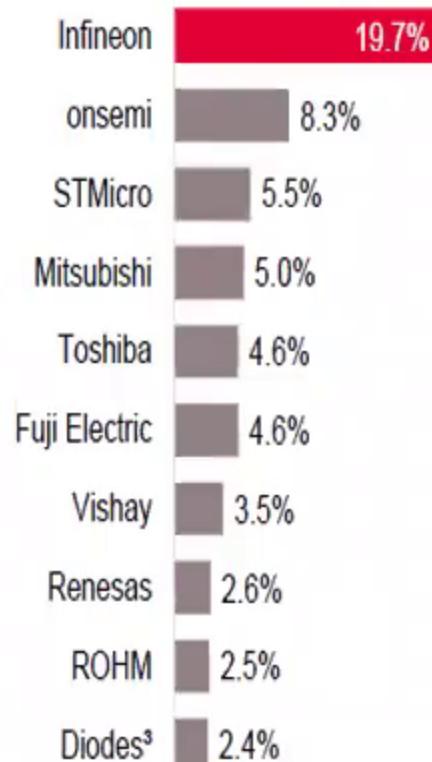
大陆	衬底	外延	设计	制造	IDM模式
其他地区	住友电工 新越化学 三菱化学 古河电气 Kyma	EpiGaN IQE NTTAT Episil Kyma	RFHIC EPC GaN Sys Dialog Nexxum Cree Onesmi Infineon Qorvo	稳懋 富士通 TSMC 世界先进 Cree Onesmi Infineon Qorvo	苏州纳维 东莞中镓 晶湛 江苏能华 英诺赛科 大连芯冠 安谱隆 华为海思 RFHIC EPC GaN Sys Dialog Nexxum Cree Onesmi Infineon Qorvo
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Soitec Wolfspeed for Cree

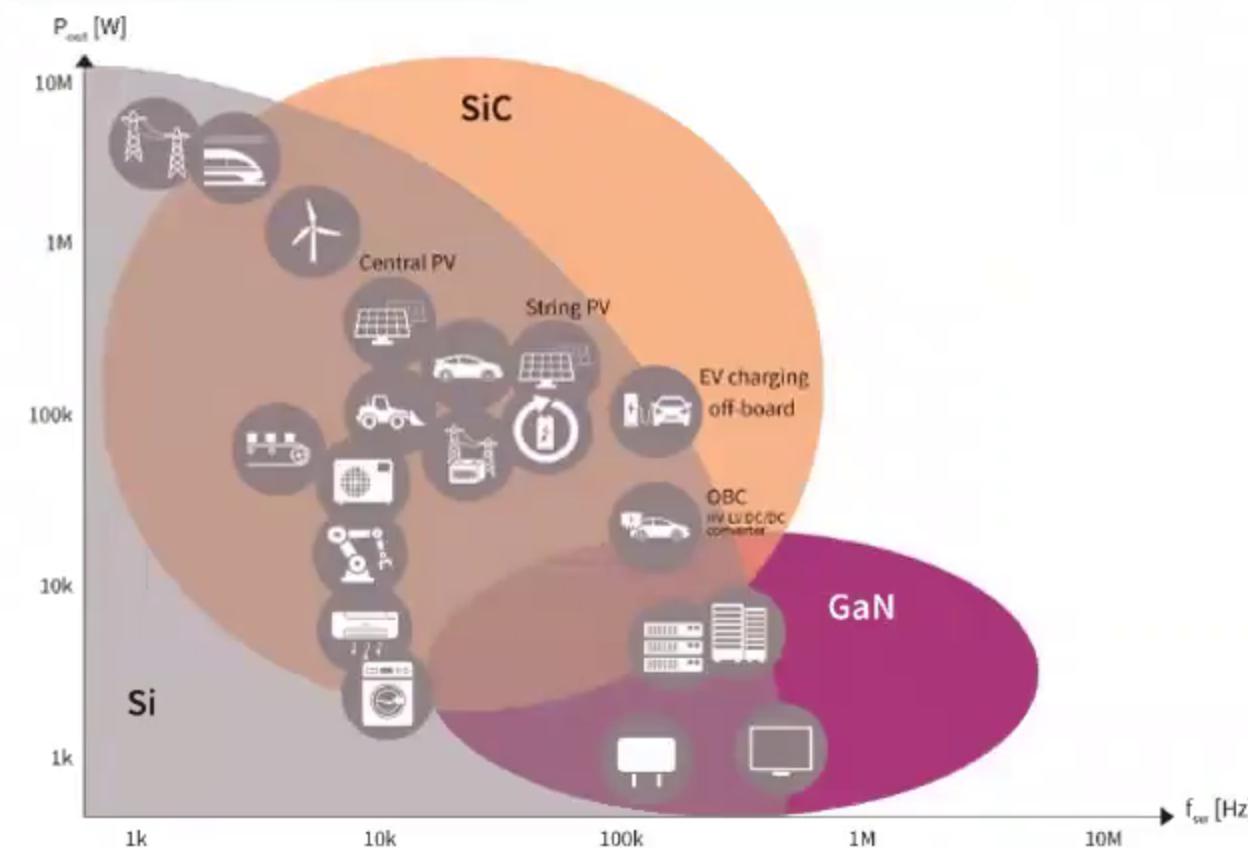
Infineon (英飞凌)市場一覽

Power discretes and modules
2020 total market: \$20.9bn²

Leveraging full potential based on the power ratings and switching frequency required by the application



Comparison of technologies



Si

- › Si remains the mainstream technology
- › Targeting 25 V - 6.5 kV
- › Suitable from low to high power

SiC

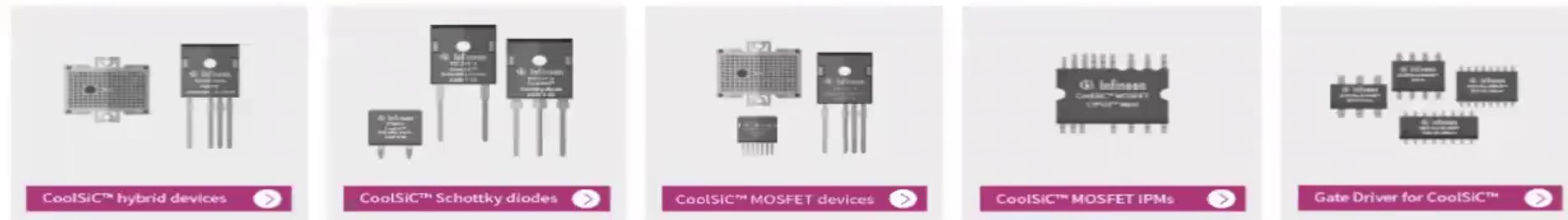
- › SiC complements Si in many applications and enables new solutions
- › Targeting 650 V - 3.3 kV
- › High power – high switching frequency

GaN

- › GaN enables new horizons in power supply applications and audio fidelity
- › Targeting 80 V - 600 V
- › Medium power – highest switching frequency

Infineon (英飞凌) SiC產品一覽

CoolSiC™ portfolio



Industrial Automotive	CoolSiC™ diode		CoolSiC™ hybrid ¹⁾			CoolSiC™ MOSFET		
	Discrete		Discrete	Module	Discrete	IPM	Module	
600 V	✓							
650 V	✓	✓	✓	✓	✓	✓		
1200 V	✓	✓			✓	✓	✓	✓
1700 V						✓		
...	Extensions of portfolio in preparation							



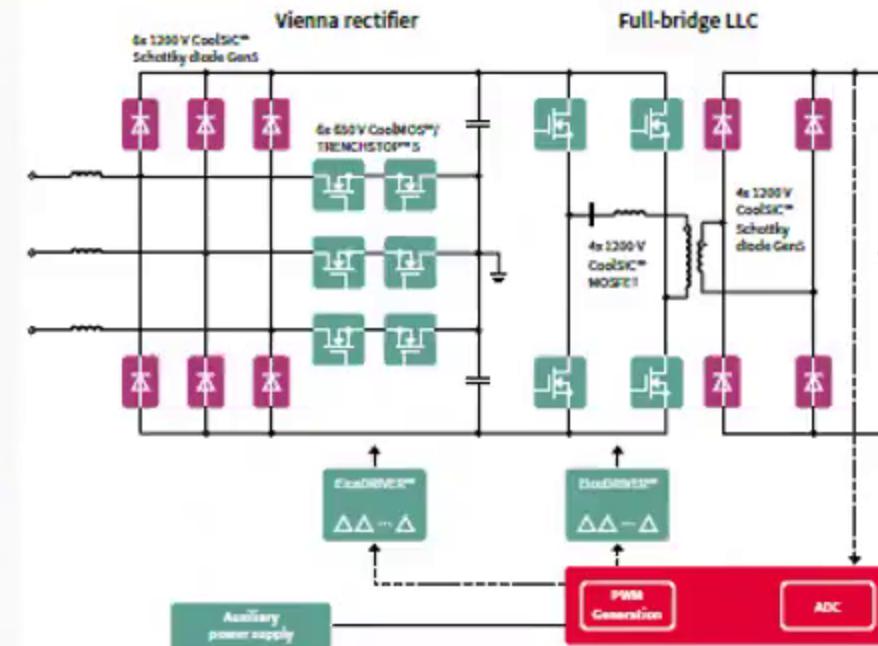
Complement the vast portfolio of CoolSiC™ MOSFETs with matching EiceDRIVER™ gate driver ICs.



The available evaluation boards will help you get started with Infineon's CoolSiC™ technology.

Infineon CoolSiC Schottky diodes 1200 V

- 混搭硅源开关 + SiC二极管，可实现更高的输出功率與开关频率
- 廣告一下：將在未來章節解釋 key features and benefits



Features and benefits

Key features

- Zero Q_{rr} leading to no reverse recovery losses
- High surge current capability up to fourteen times of the nominal current
- Tight forward voltage distribution
- Temperature-Independent switching behavior
- Low forward voltage ($V_F = 1.4 \text{ V}$) even at high operating temperature
- Available in both through-hole and SMD packages
- Up to 40 A rated diode

Key benefits

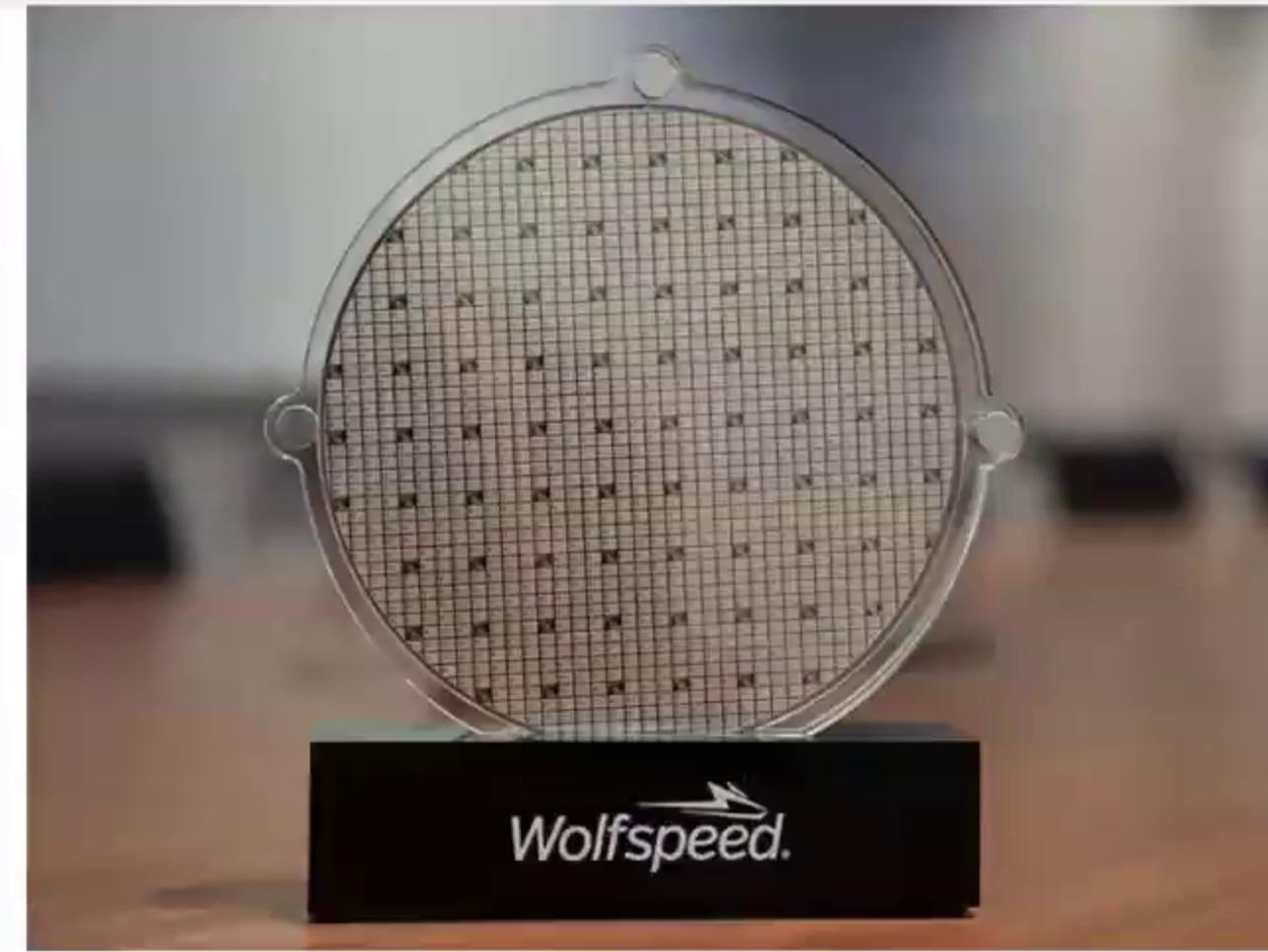
- System efficiency improvement over Si-based diodes
- Enabling higher frequency/increased power density solutions
- High system reliability by extended surge current
- Reduced cooling requirements through lower diode losses and lower case temperatures
- System size/cost saving due to reduced heatsink requirements and smaller magnetics

Wolfspeed 世界第一个8吋SiC廠

- 用SiC晶圓自動切冰
展示



SiC cut ice



<https://www.youtube.com/watch?v=wqybaZKBjoc>

Wolfspeed, formerly Cree, opens the world's first silicon carbide semiconductor fabrication facility in New York to provide energy efficient chips for EVs

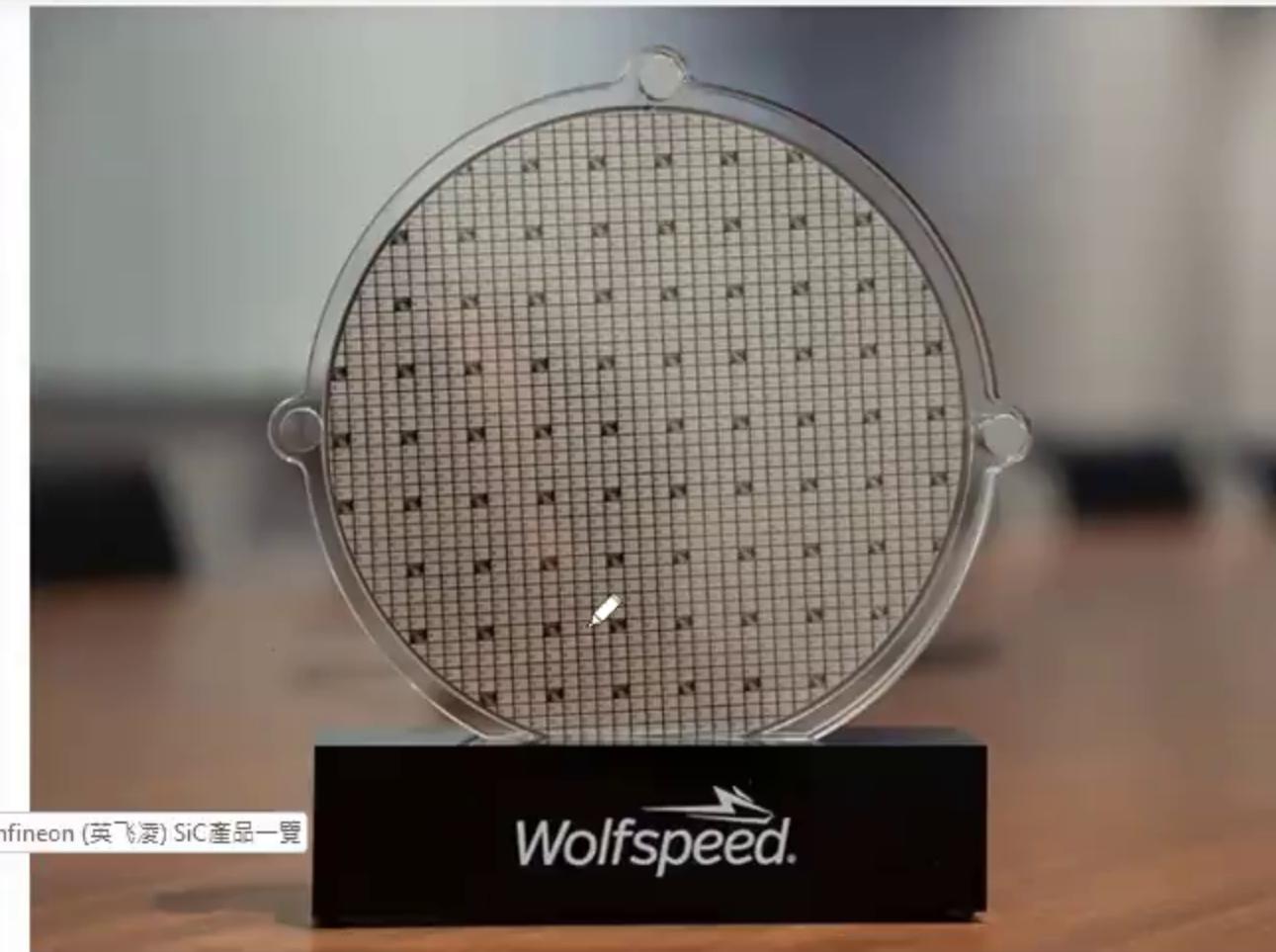
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<https://businesschief.com/technology-and-ai/wolfspeed-opens-world-first-silicon-carbide-chip-facility>



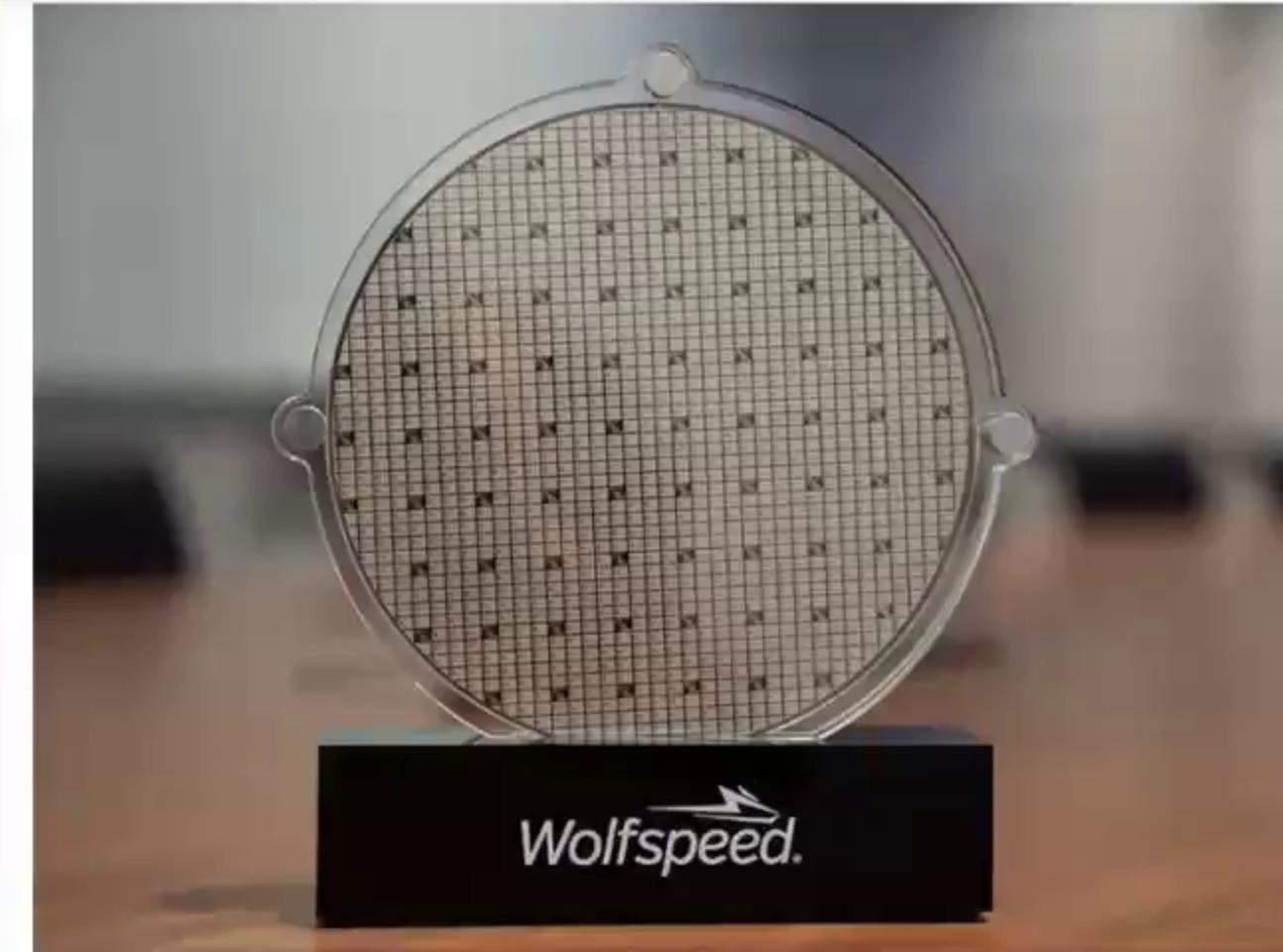
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⚠️ Wolfspeed Silicon Carbide 200mm Wafer Fab.mp4 - VLC media player

Media Playback Audio Video Subtitle Tools View Help



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Wolfspeed

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<https://businessmier.com/technology-and-ai/wolfspeed-opens-world-first-silicon-carbide-chip-factory>

SILICON CARBIDE SEMICONDUCTOR MANUFACTURING FACILITY IN NEW YORK TO provide energy efficient chips for EVs

⚠️ Wolfspeed Silicon Carbide 200mm Wafer Fab.mp4 - VLC media player

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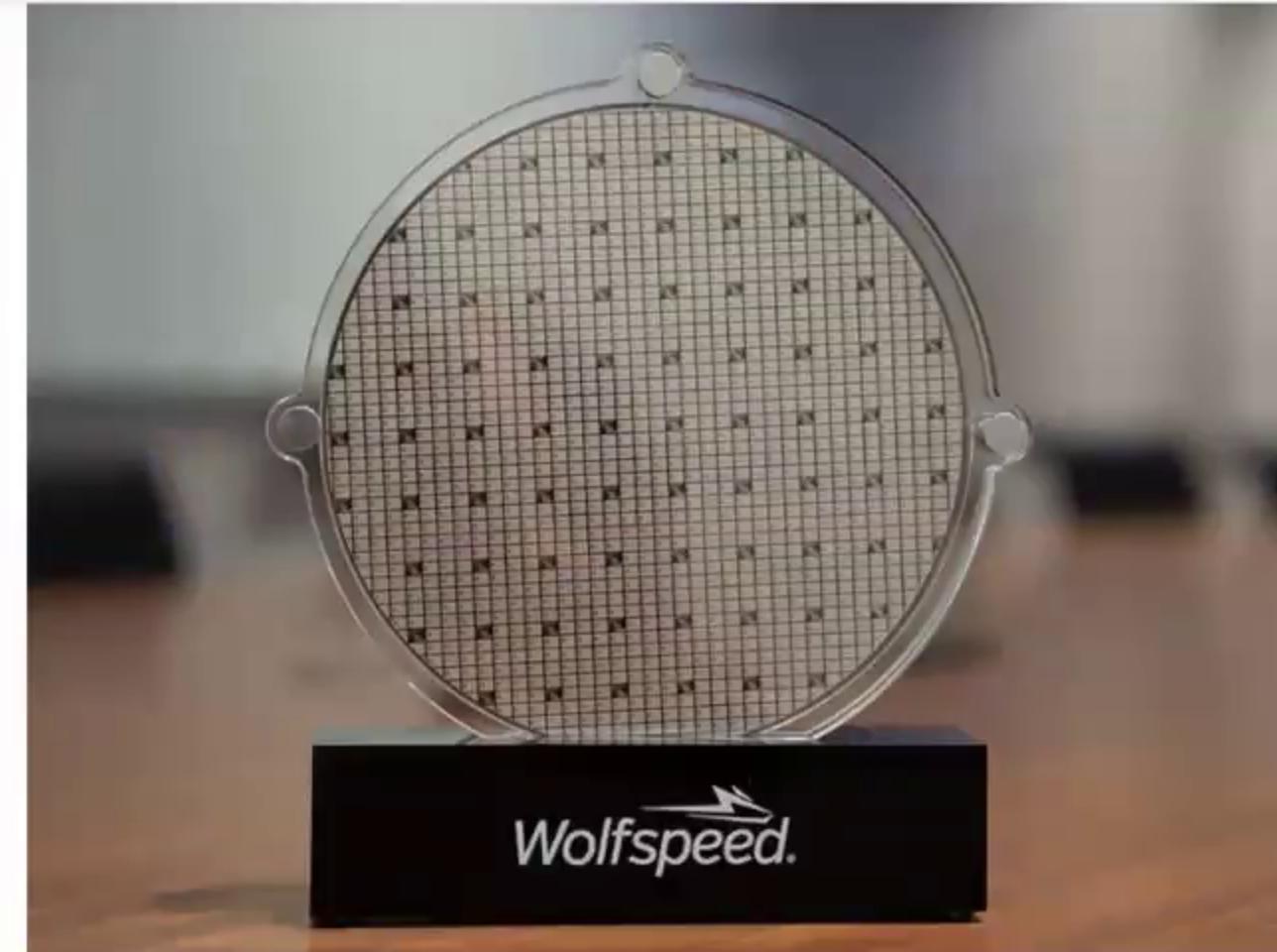
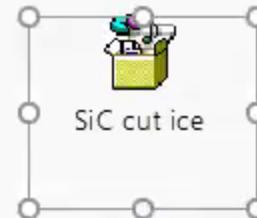


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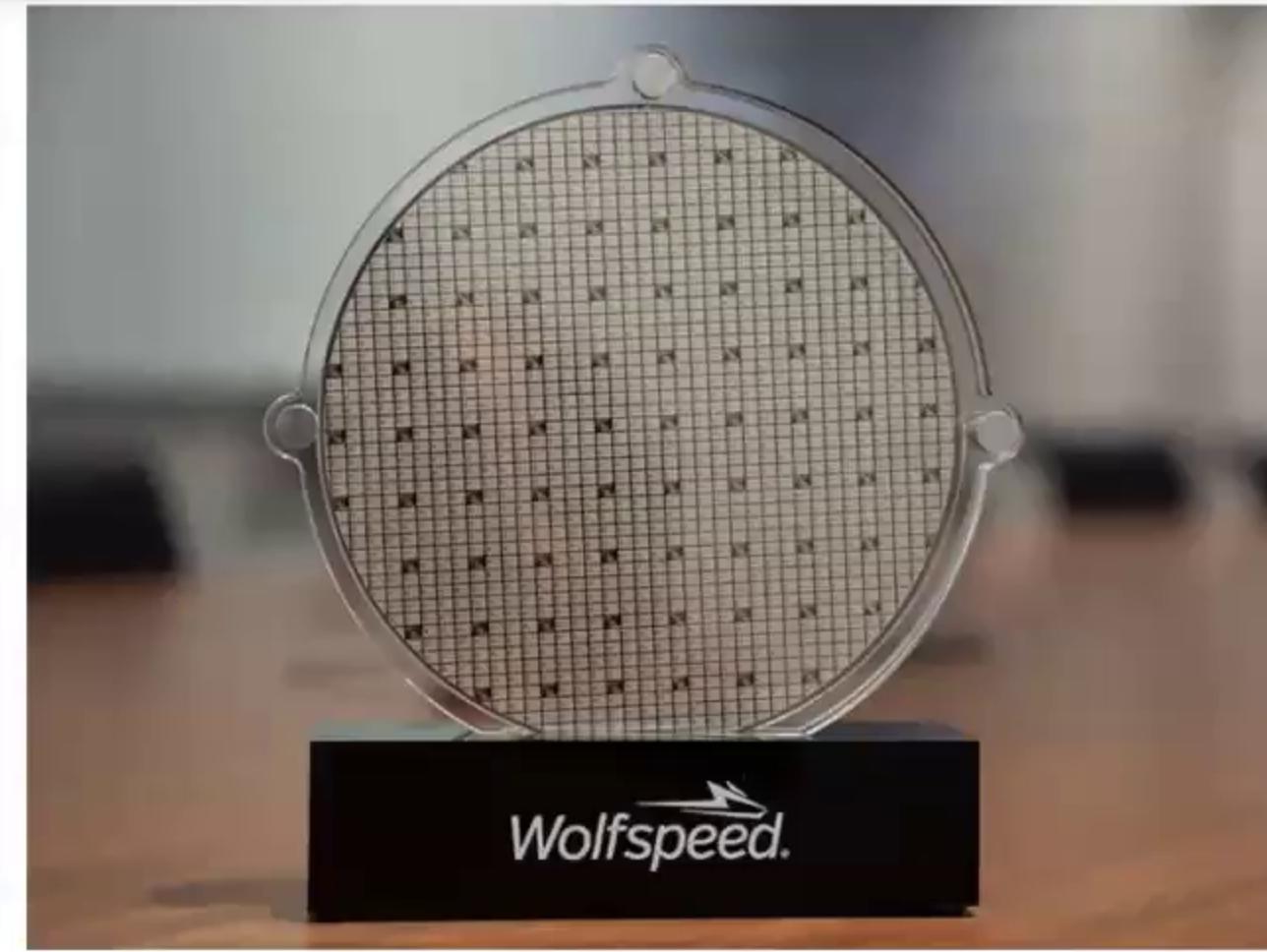
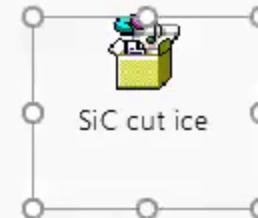


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SiC电子器件一覽

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深解釋各式
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SiC器件

Wolfspeed 世界第一个8吋SiC廠

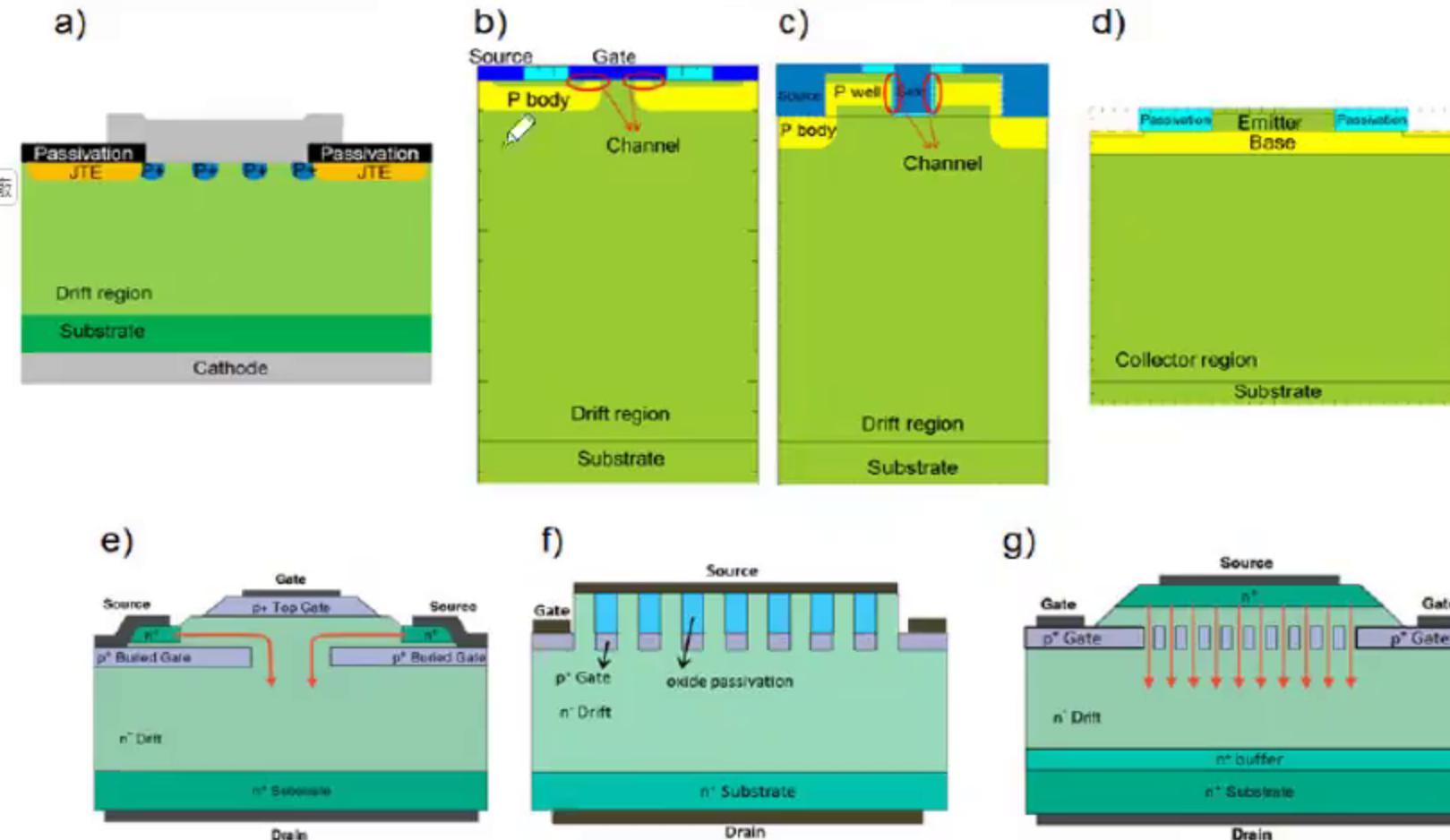


Figure 1.2 Basic structures of a) SiC JBS-type SBD, b) SiC planar MOSFET, c) SiC trench MOSFET, d) SiC BJT, e) SiC Lateral-Channel JFET [PAPER IV], f) SiC Recessed-Gate JFET, g) SiC Buried-Gate JFET [PAPER IV].

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