Commercialization of SiC and GaN Power Devices

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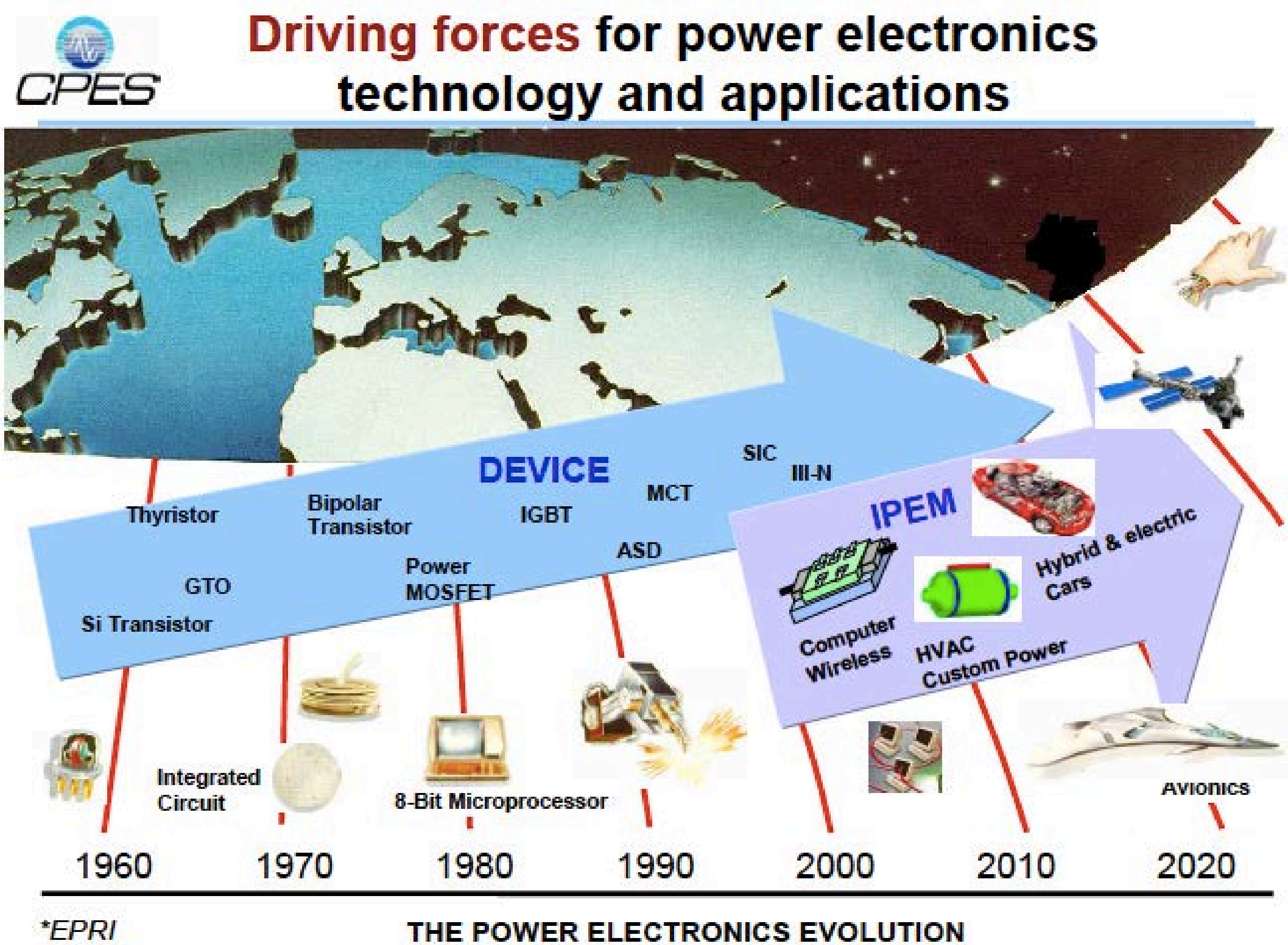
Power Semiconductor Devices



Outline

- Introduction
- Why SiC and GaN?
- Commercialization Efforts
  - Global Players
  - Processes and Foundries
  - Wafer Yield
- Future Trends

Semiconductor Properties

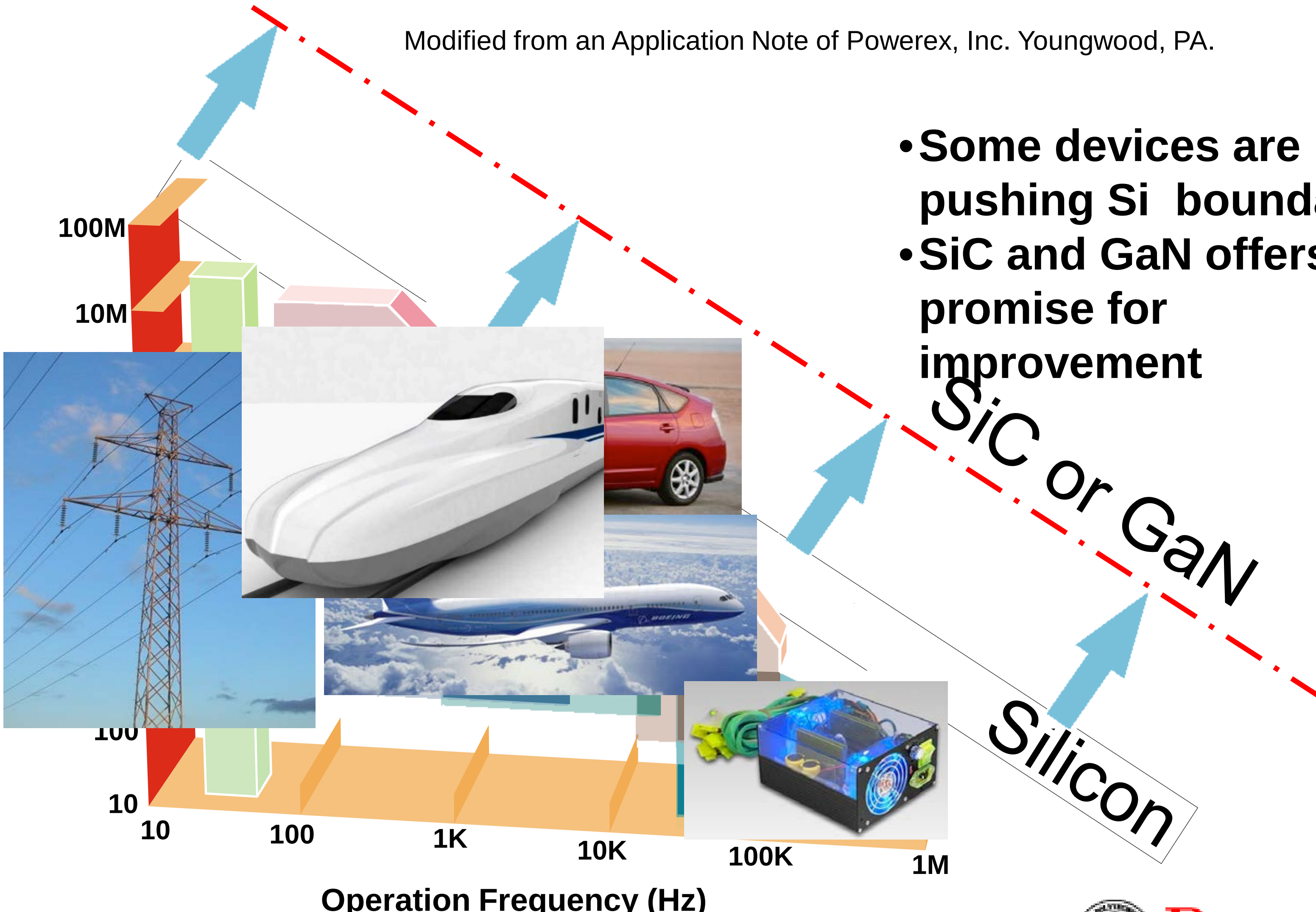
Material	E_g (eV)	*Direct/ Indirect*	n_i (cm^{-3})	ε_r	μ_n (cm^2/V-s)	E_c (MV/cm)	v_{sat} (10^7 cm/s)	λ (W/cm-K)
Conventional Semiconductors								
Si	1.12	I	$1.5x10^{10}$	11.8	1350	0.2	1.0	1.5
GaAs	1.42	D	$1.8x10^{6}$	13.1	8500	0.4	1.2	0.55
Wide Bandgap Semiconductors								
2H-GaN	3.39	D	$1.9x10^{-10}$	9.9	1000[a] 2000**	3.3* 3.75[a]	2.5	2.5 4.1*
4H-SiC	3.26	I	$8.2x10^{-9}$	10	720[a] 650[c]	2.0[a]	2.0	4.5
Extreme Bandgap Semiconductors								
Diamond	5.45	I	$1.6x10^{-27}$	5.5	3800	10	2.7	22
2H-AlN	6.2	D	$\sim 10^{-34}$	8.5	300	12*	1.7	2.85

Note: a – mobility along a-axis, c-mobility along c-axis, *Estimated value, **2DEG

- GaN grown on SiC can have a similar thermal conductivity as that of SiC
- GaN grown on Si can reduce the wafer cost, have larger wafer size and use Si foundries for processing

Applications of Power Devices

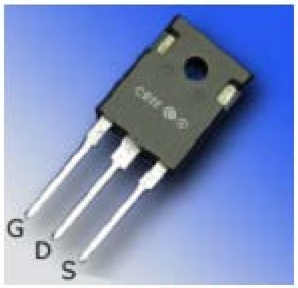
Modified from an Application Note of Powerex, Inc. Youngwood, PA.



- Some devices are pushing Si boundary
- SiC and GaN offers promise for improvement

0.6-3.3kV SiC MOSFETs

Cree/Wolfspeed

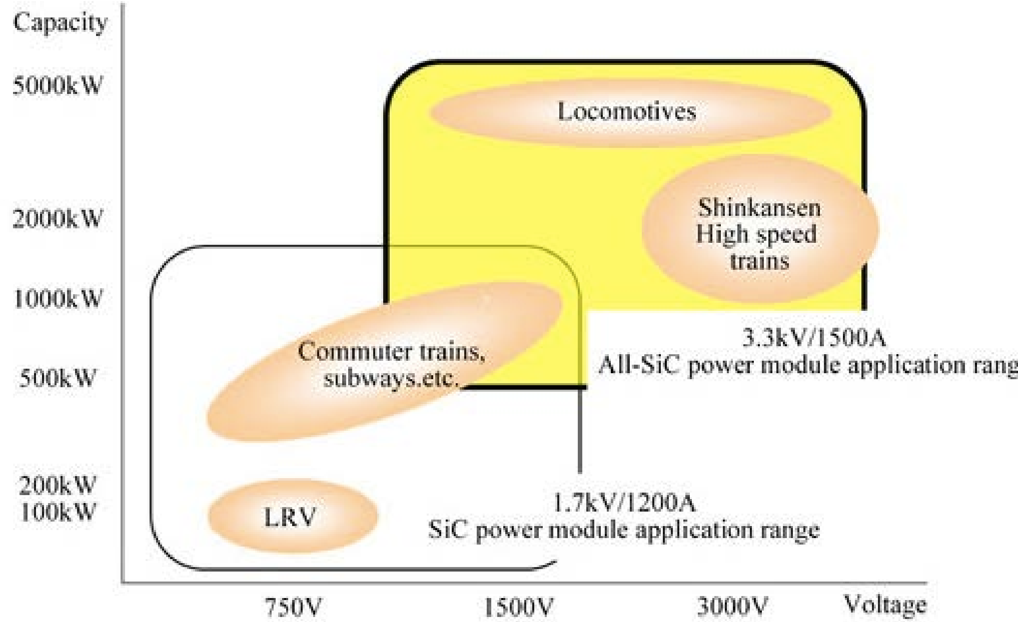


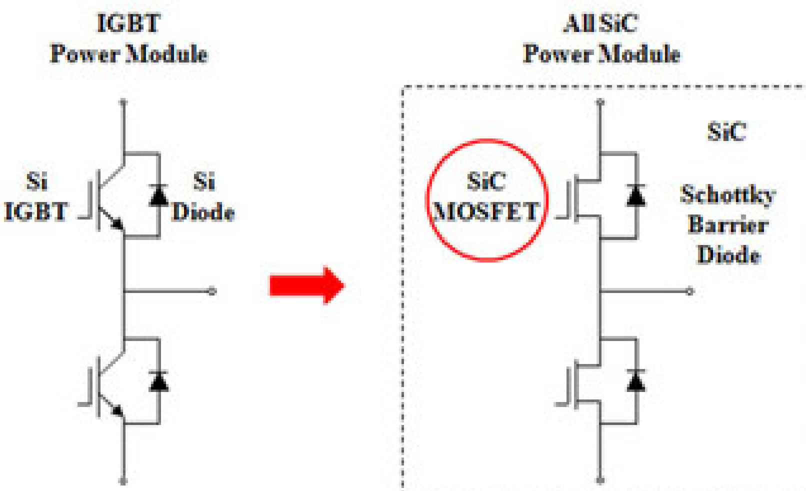
TO-247-3

V_{DS} = 1200 V

$R_{DS(on)}$ = 80 mΩ

$I_{D(MAX)}$@T_c=25°C = 33 A





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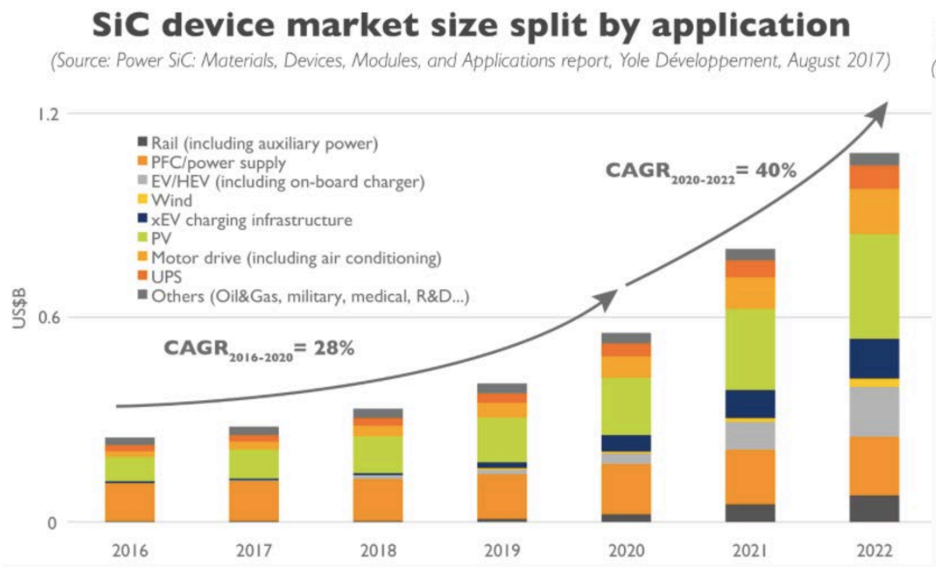
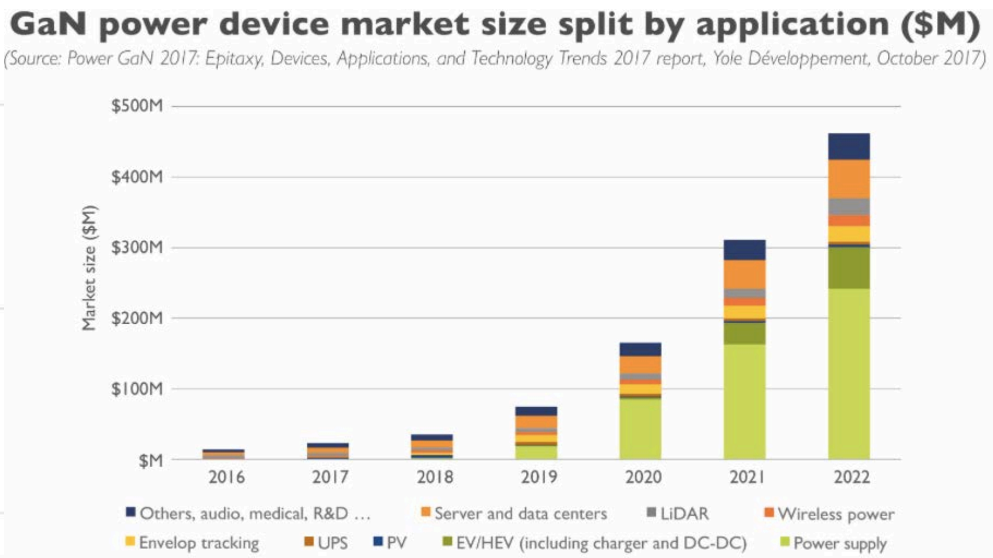
SiC and GaN Power Devices Market

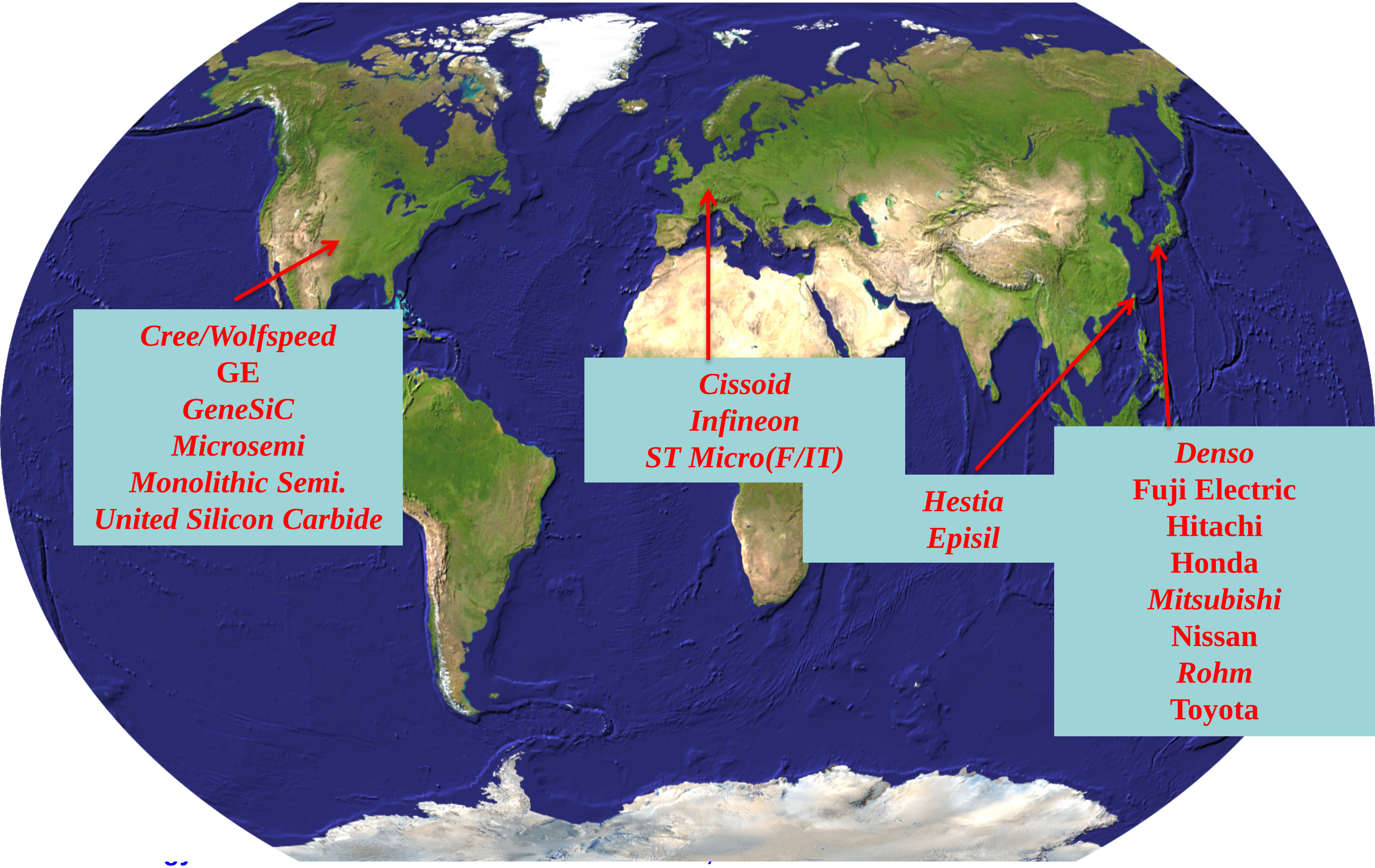




Yole

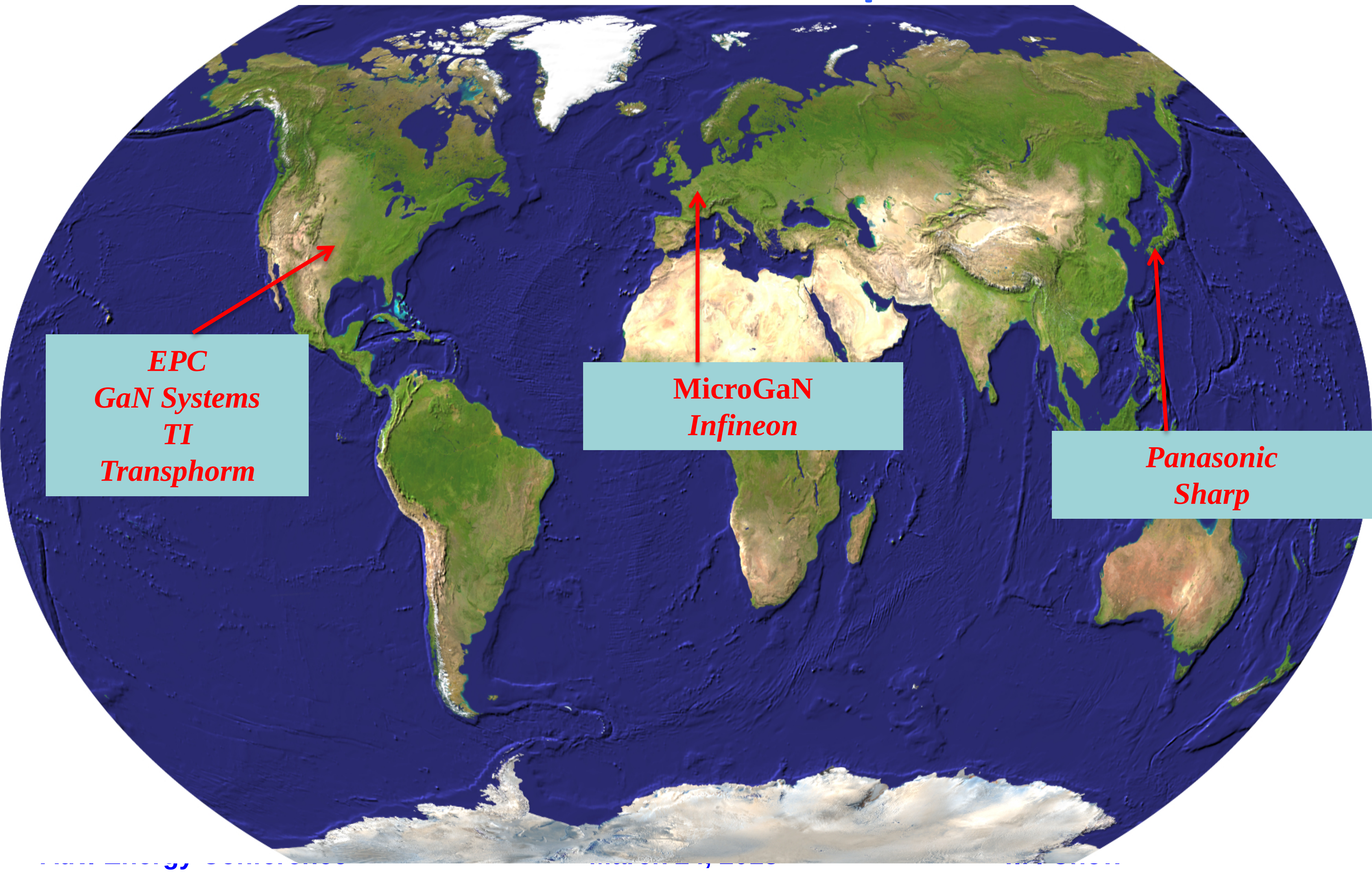
SiC Device Companies

Companies with commercial products in *Italics*



GaN Device Companies

Companies with commercial products in *Italics*



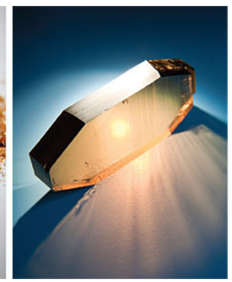
SiC and GaN

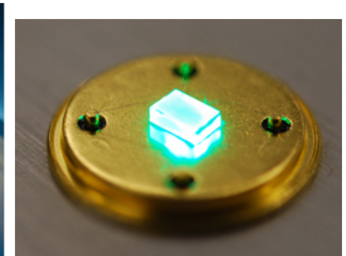
- Much tougher and brighter than Silicon

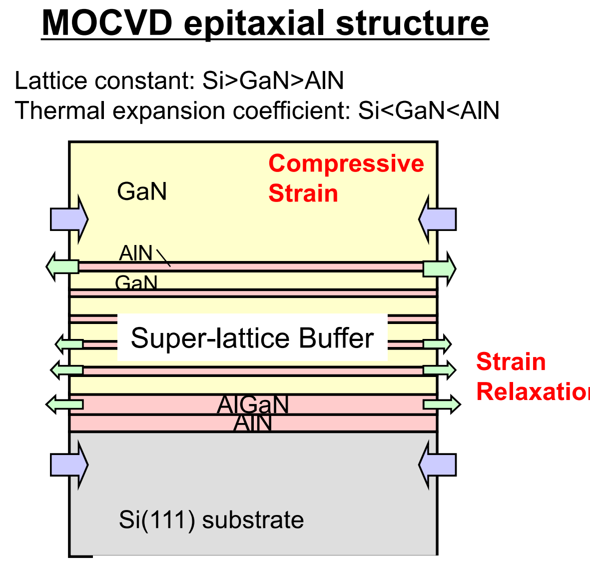
SiC ingot and wafers

GaN powder and crystal

GaN on Si







4H-SiC atomic stacking

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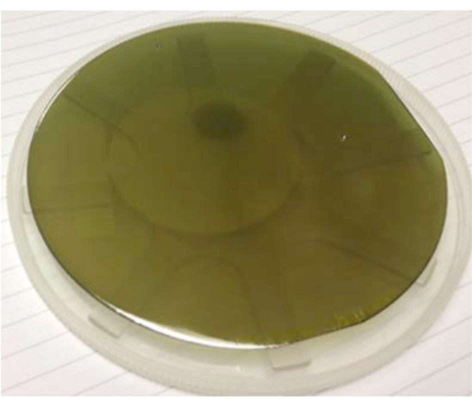
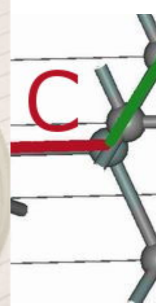
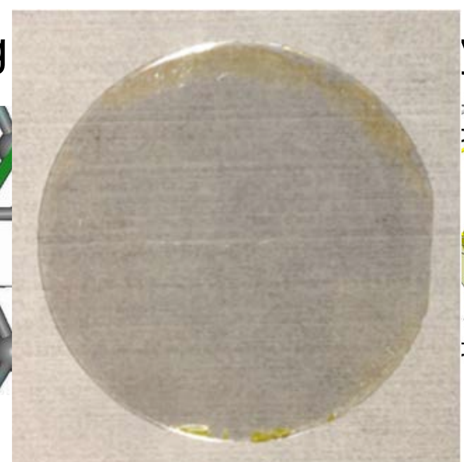
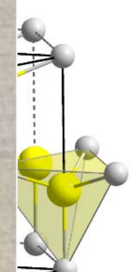
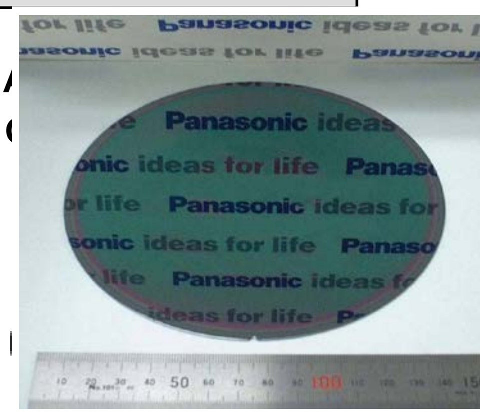


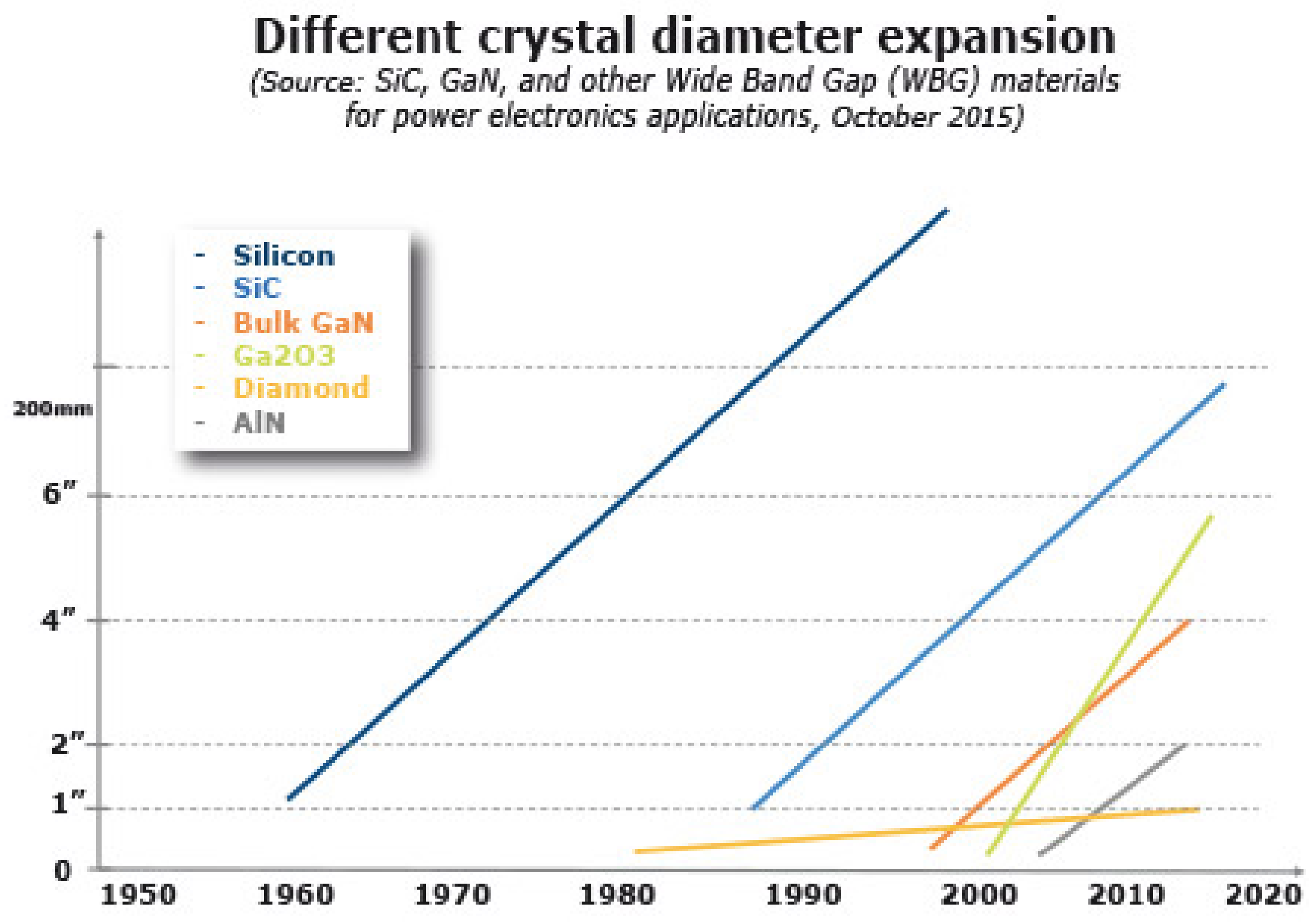








Substrate Sizes



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Present SiC vs. GaN Power Devices

- Vertical
- Homoepi
- Schottky, pn junction, MOS, implantation
- Unipolar and Bipolar devices
- Oxide or Polyimide passivation
- Avalanche capable in commercial devices

Si Discrete Power Devices

- Lateral
- Heteroepi
- Heterojunction
- Schottky, pn junction, MOS, n implantation
- Unipolar devices
- SiN, SiO_2, Al_2O_3, or AlN passivation
- Avalanche not seen in commercial devices

AlGaAs/GaAs rf transistors

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Augmented vs. Dedicated Foundry

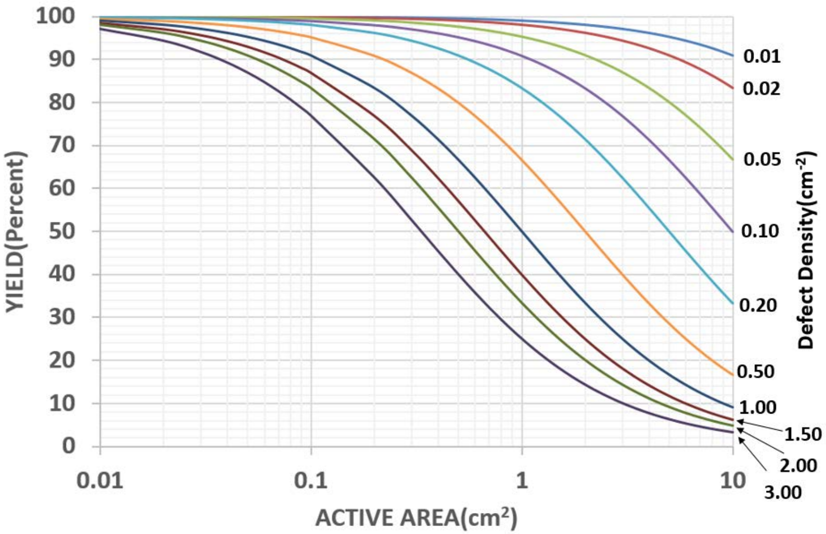
priority

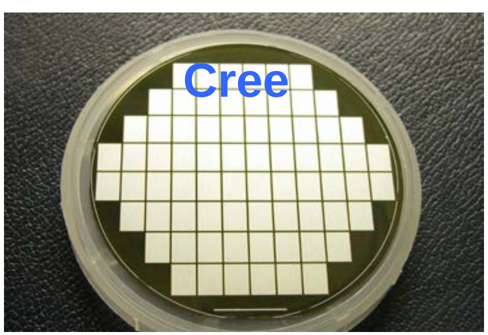
- Specially designed

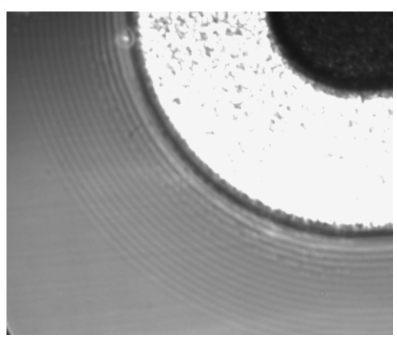
cost

Wafer Yield

$Y = 1/(1 + AD)^n$, Y – Yield,
A – Critical Area, D – Defect Density,
n – Number of Critical Levels





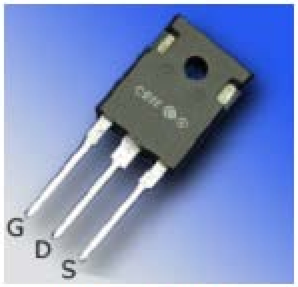


Types of Defects

- Materials
  - – Substrate
  - – Epi layer
- In Process
  - – Photolithography
  - – Thin Film Dep./Etching
  - – Implant/Anneal
  - – Oxidation
  - – Metallization

1200V SiC MOSFETs

SiC MOSFET: Cree



TO-247-3

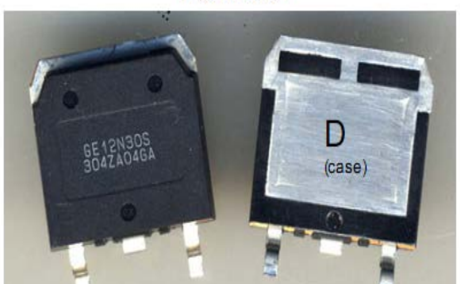
V_{DS} = 1200 V

$R_{DS(on)}$ = 80 mΩ

$I_{D(MAX)}$@T_c=25°C = 33 A

SiC MOSFET: GE

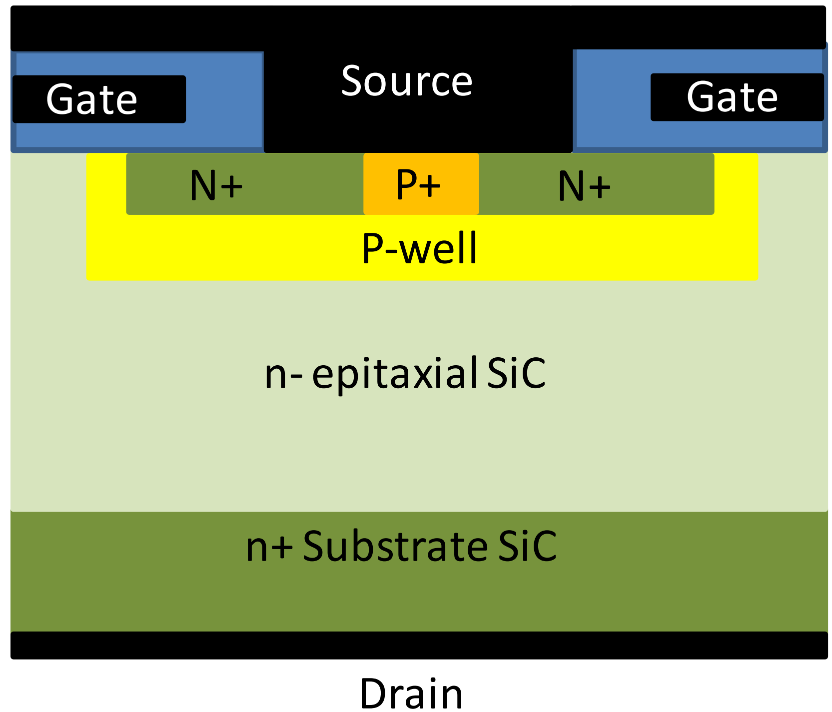
TO-268



$V_{DS,max}$=1200 V

$R_{DS(ON)}$ =55 mΩ

$T_{j,max}$=175°C



SiC MOSFET Ratings

Cree: 1200V,33A

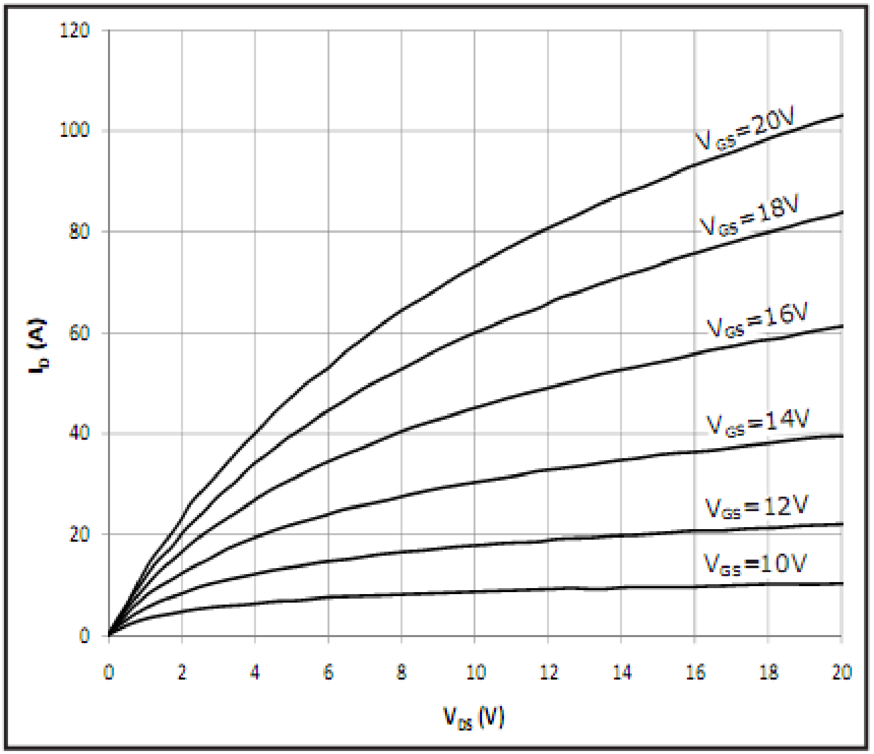
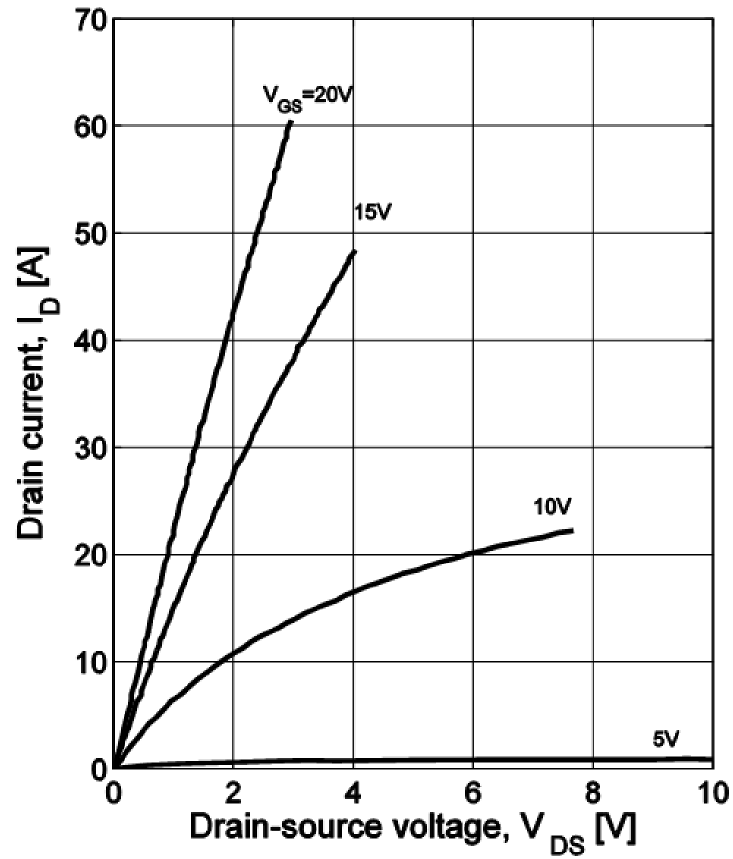


Fig 1. Typical Output Characteristics T_J = 25ºC

GE: 1200V, 53A

Figure 5. Output characteristics

$I_D=f(V_{DS},V_{GS})$; T_j=25 °C



Future Trends

- SiC and GaN power devices and ICs are finding increasing applications in energy efficient systems but enhancing their cost-effectiveness demands high-yield foundry device manufacturing
- New packaging solutions need to be developed to minimize interconnecting parasitics and maximize heat spreading and sinking
- Integrated technology teams are needed to realize and implement WBG technology solutions to sustainable green energy solutions

Thank You!