Trend and Prospect of 3rd Gen. Semiconductor Materials

Tainergy Tech Co., Ltd.

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Outline

1. Company Profile
2. Introduction & Application of 3rd Gen. Semiconductor Materials
3. Overview of SiC Market
4. SiC Substrate Process
5. Conclusions

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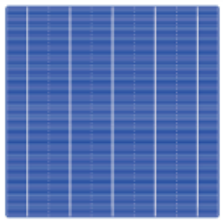
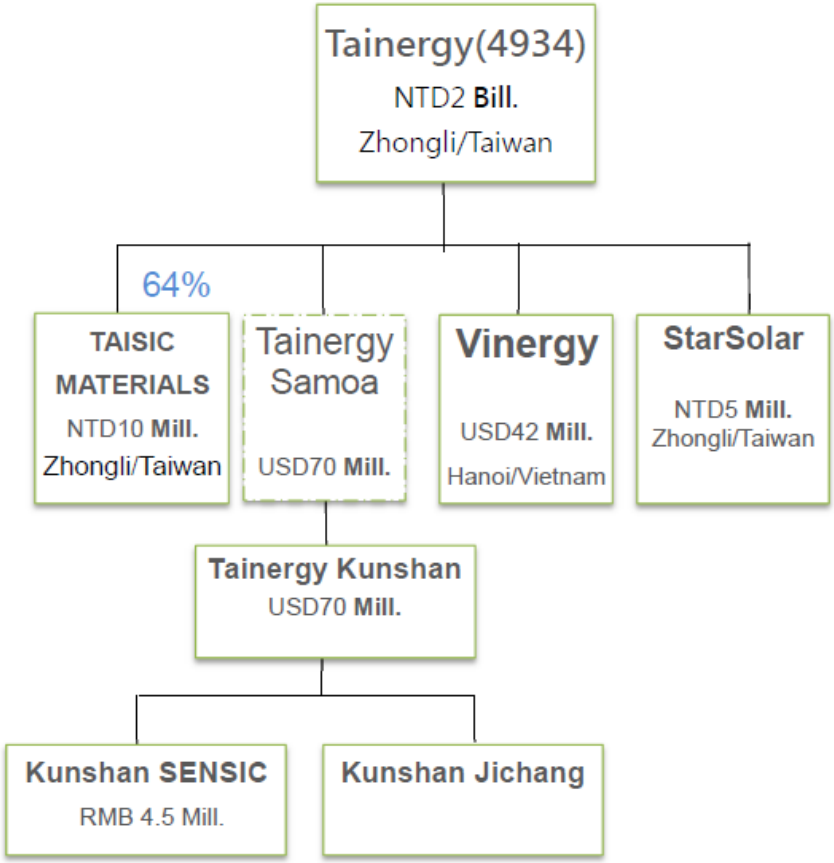
Company Profile

- Tainergy Tech Co., Ltd.
- IPO：Aug. 2011　(TSEC：4934)
- Established : 2007/5/14
- Capital：　NTD 2 Bill.
- President　：Hsieh, Ching-Fu
- General Manager　：Vincent Hsieh
- Operating Base：Zhongli/Taiwan、Kunshan/China、Hanoi/Vietnam
- Major Investor：Kenmec　　Shareholding %：28.83%
- Major Product：Solar Cells　　/　　Sic Substrates



Organizational Chart



Subsidiary: TAISIC Materials Corp.

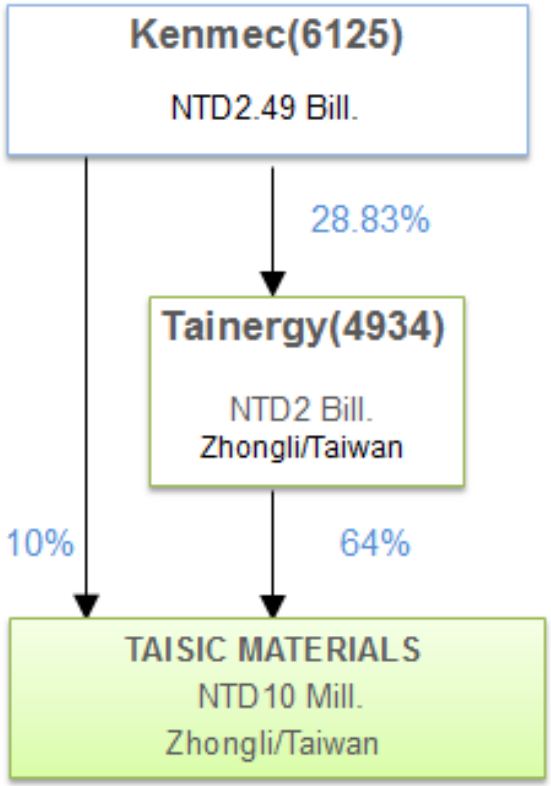
Founded：Jun. 2020

Representative：Kevin Hsieh

Main Product：SiC Substrates

Investors：Tainergy 64%

Kenmec 10%



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Category of Semiconductor Materials

	Materials	Applications	Properties
1st Gen.	Ge、Si	Microelectronics, IE	• Abundant Si element in nature • Mature purification & crystal growth technology • Excellent isolation properties of SiO2 • Restrictions on optoelectronic and HF applications due to Si physical nature
2nd Gen.	GaAs、InP	Communication, Illumination	• GaAs、InP material s rare on earth • Poisonous , environmental unfriendly • Suitable for HF, high speed, high power and optoelectronic devices
3rd Gen.	SiC、GaN	High Power 、HF Communication	• Known as Wide Band Gap semiconductors with electric properties between semiconductor and insulating materials. Sutiable for higher voltage, frequency and temperature applications

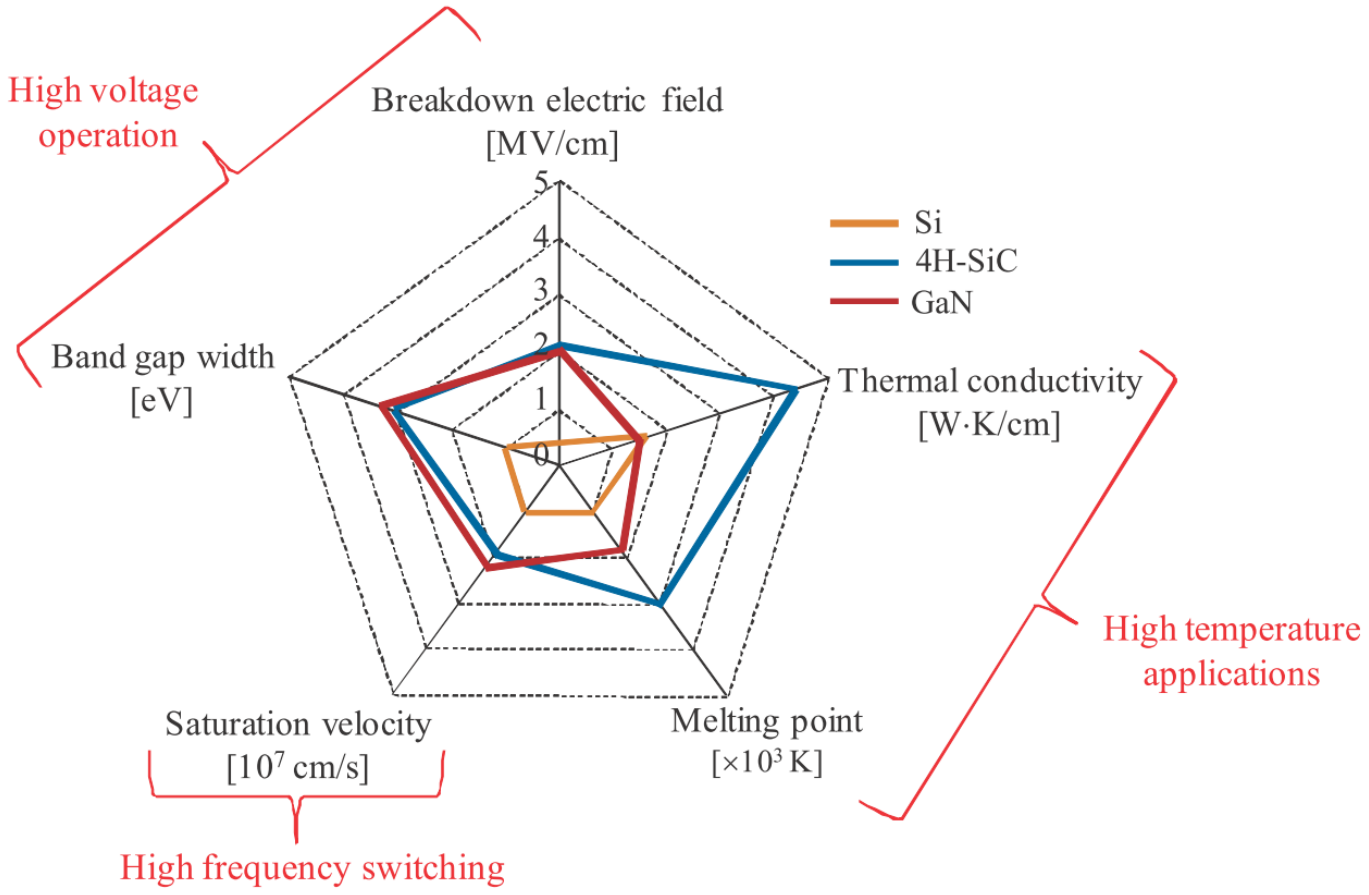
Advantages of SiC Devices

- High Power Applications
- Ultra High Working Voltage
- Ultra High Frequencies
- More Stable at High Temp.
- Excellent Radiation Resistance
- Smaller Module Size

Physical Properties of SiC

Properties		Si	SiC	GaN
Bandgap	eV	1.12	3.26	**3.39**
Electron Mobility	$cm^2/V\text{-}s$	1450	900	**2000**
Electron Field for Breakdown	MV/cm	0.3	3.5	**3.5**
Saturated Drift Velocity	x 10^6 cm/s	10	22	**25**
Thermal Conductivity	W/cm/K	1.5	4.5	**1.3**

Comparison of Physical Characteristics SiC



Comparison of 2 SiC Substrates

	N-type	Semi-insulating
Resistivity Ohm-cm Range	0.015-0.028	> 1E6
Orientation	4° Off	On-axis
Thickness	350μm +/-25μm	500μm +/-25μm
Epitaxy	SiC	GaN
Applications	Electronic Power	RF

Comparison of Substrates for GaN Epitaxy

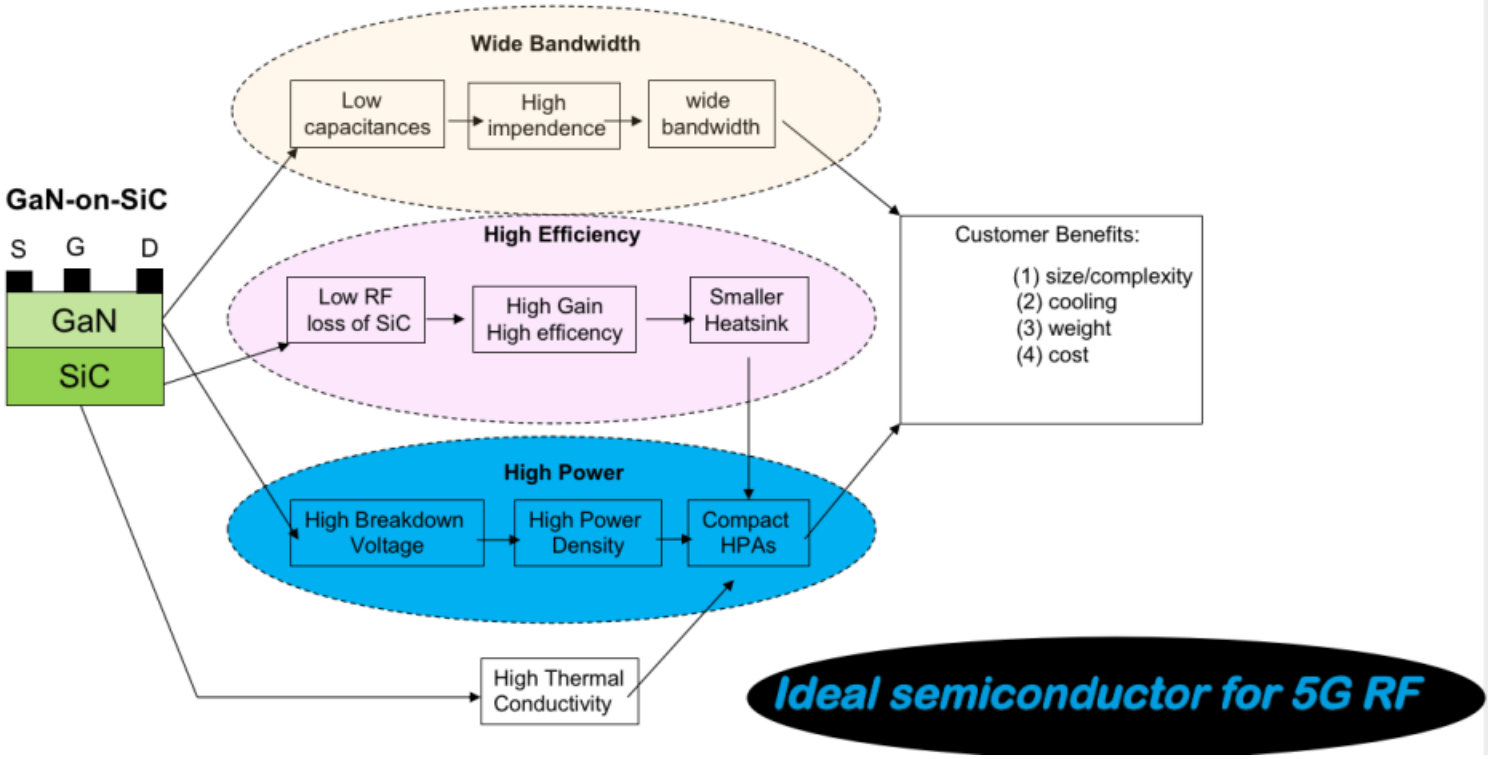
	Sapphire	Si	SiC	GaN
Lattice Constant (Å)	2.75	5.43	3.08	3.19
Lattice mismatch with GaN (%)	16	17	3.4	-
Coefficient of thermal expansion ($10^{-6}K^{-1}$)	7.5	2.6	4.2	5.6
Thermal conductivity (W/cm/K)	0.2	1.5	4.5	1.3
Maximum substrate commercially available	8″	12″	6″	

In addition to the electrical and optical characteristics, the main considerations are as follows:

1. The epitaxial materials have the same or similar crystal structure with the substrate, small lattice mismatch, good crystallization performance and low defect density;
2. Good interfacial properties are favorable for the nucleation and adhesion of epitaxial materials;
3. Good chemical stability and not easy to decompose and corrode in the temperature and atmosphere of epitaxial growth;
4. Good thermal properties, including good thermal conductivity and small thermal mismatch;
5. Good electrical characteristics to process for upper and lower structures;
6. Good mechanical properties, easy to process, including thinning, polishing and cutting;
7. Low price;
8. Large size.

GaN-on-SiC in PA Applications

GaN on SiC Value on PA



SiC Device Applications

SiC Substrates

N-type

LED

LED

Power Devices
(SBD、MOSFET…)

UPS

xEV

PV

Wind Power

HSR

SI

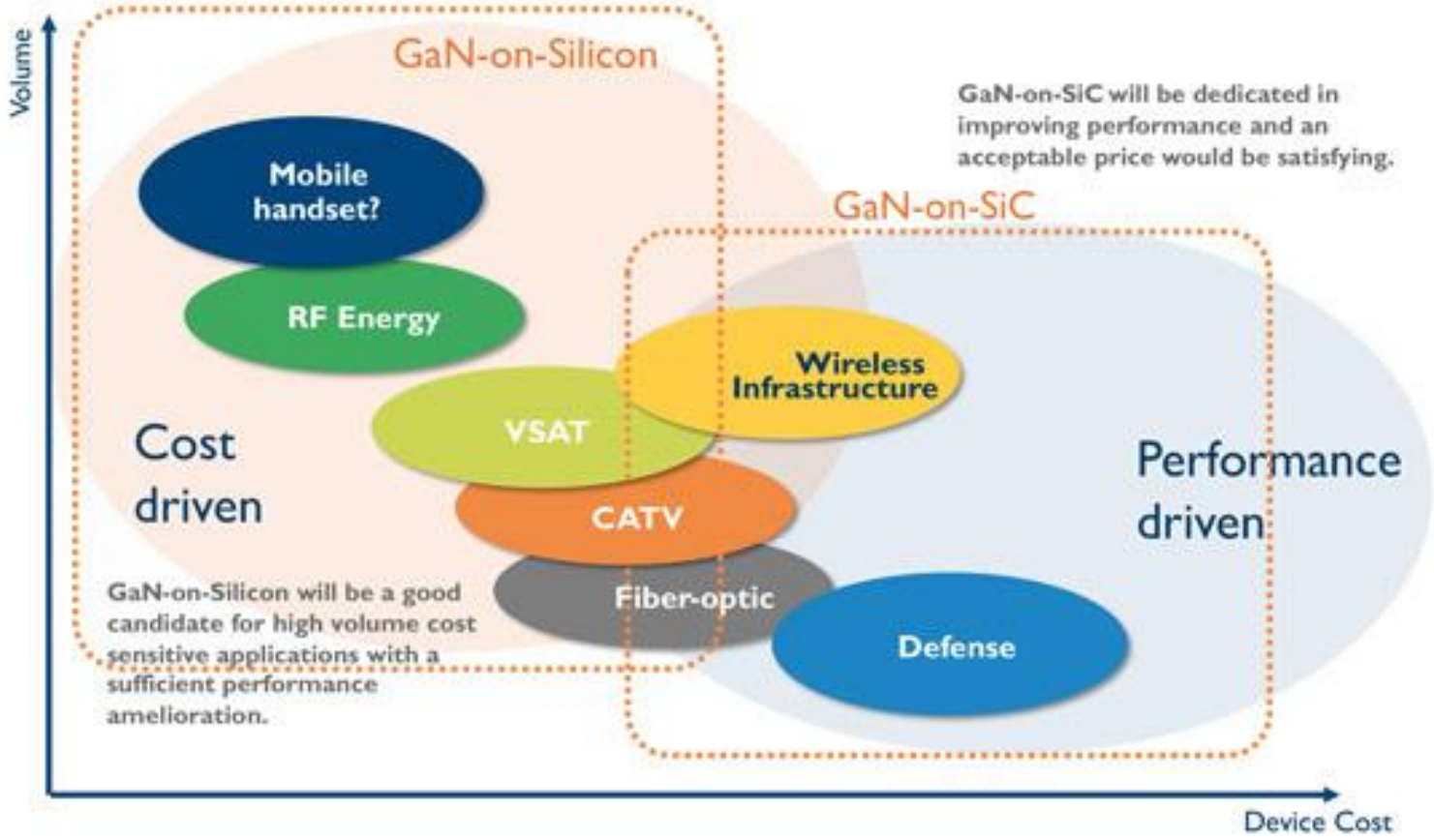
MW Devices
(HEMT)

5G small cells

Satellite

RADAR

GaN-on-Si vs GaN-on-SiC



Applications of High Power SiC & GaN Modules

Low-Voltage

PFC/Power supply

Audio Amplifer

Medium-Voltage

PV Inverter

Motor Control

EV/HEV

UPS

High-Voltage

Ship&Vessels

Smart Power Grid

Wind Mills

Rail Transport

<200V | 600V | 900V | 1.2kV | 1.7kV | 3.3kV | 6.5kV+

SiC diodes

GaN-on-Si Transistors | Battle fields | SiC Transistors

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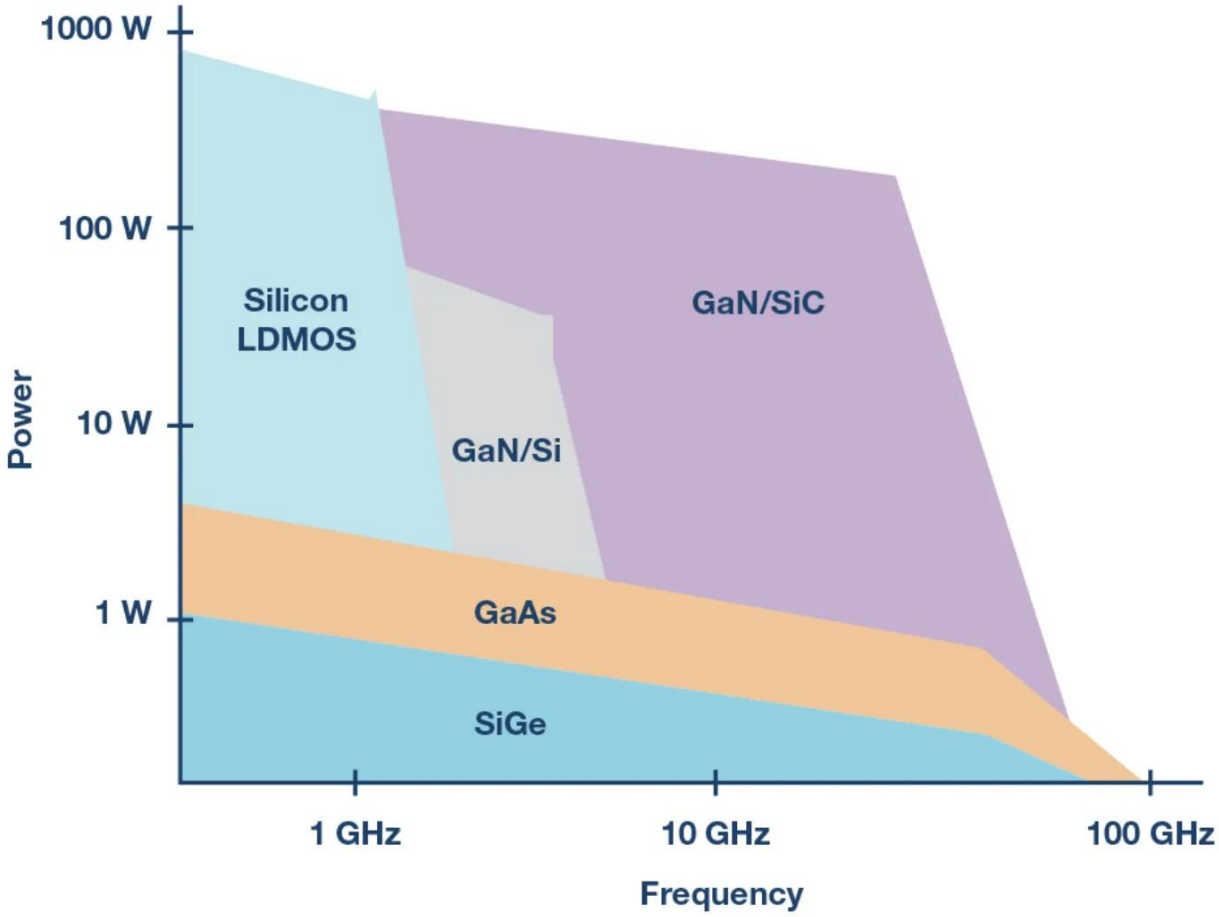
Power vs Frequency for Various Materials



Source: Analog Devices

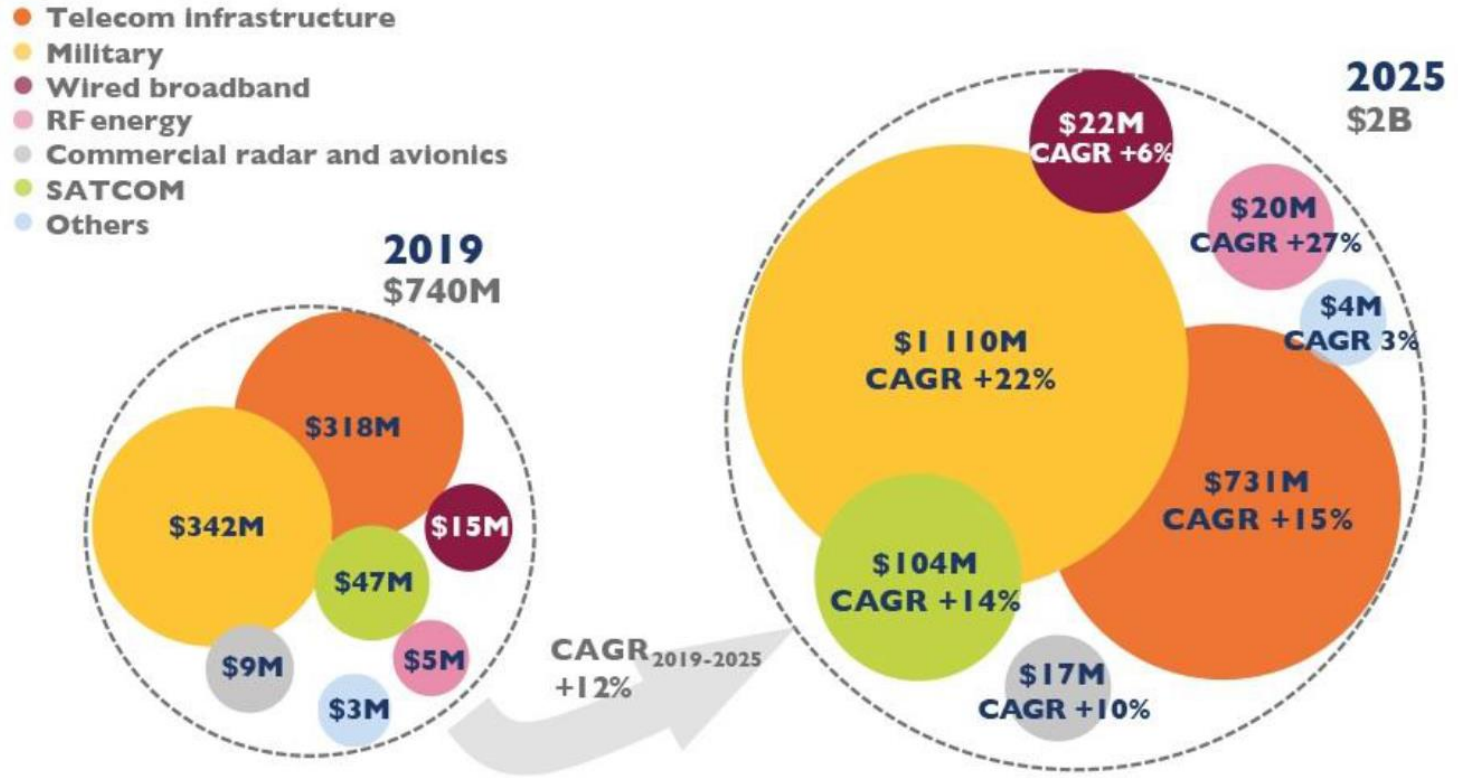
Prediction of RF GaN Device Market

SiC

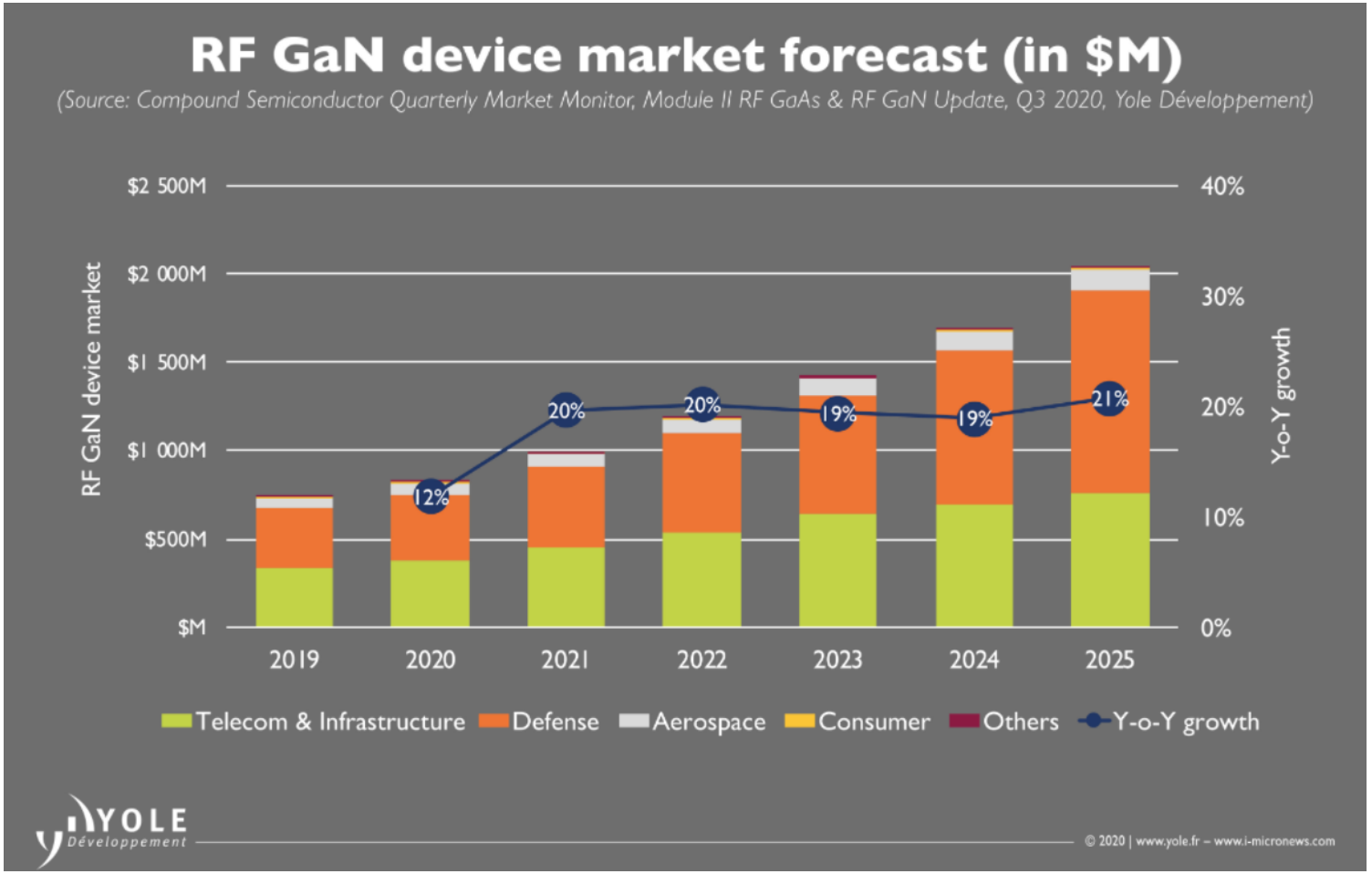
PACKAGED GAN RF DEVICE MARKET FORECAST

Split by application

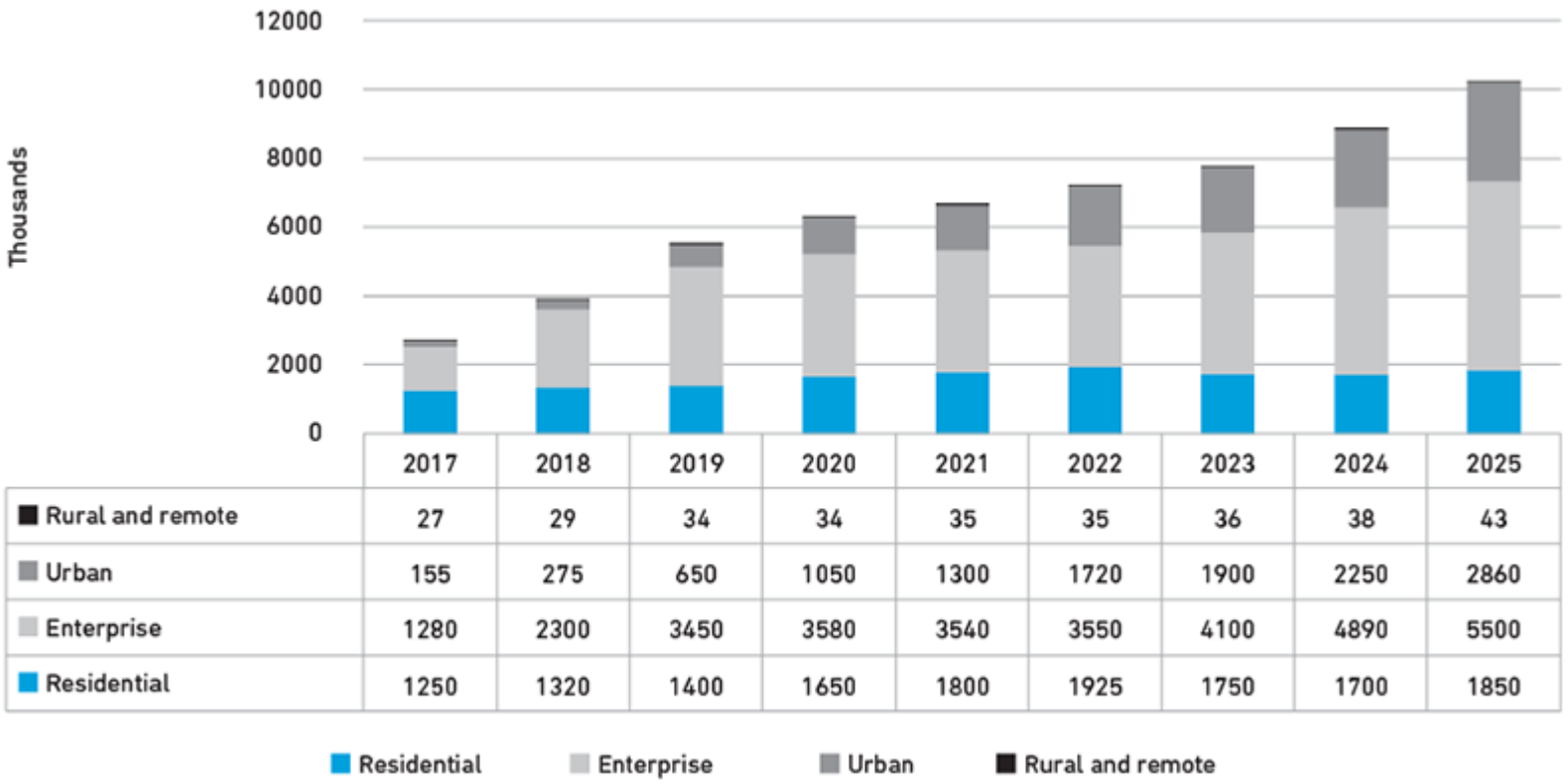
The overall GaN RF device market will increase from $740M in 2019 to around $2B by 2025, driven mainly by military radar applications.



Prediction of RF GaN Device Market



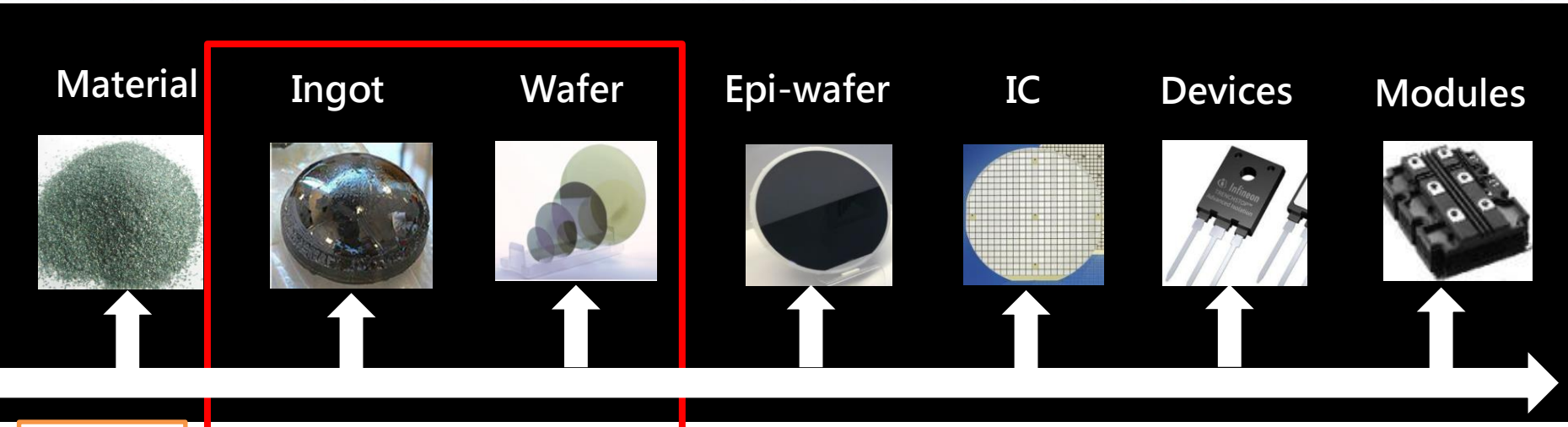
Global Demands for 5G small cells



	2017	2018	2019	2020	2021	2022	2023	2024	2025
Rural and remote	27	29	34	34	35	35	36	38	43
Urban	155	275	650	1050	1300	1720	1900	2250	2860
Enterprise	1280	2300	3450	3580	3540	3550	4100	4890	5500
Residential	1250	1320	1400	1650	1800	1925	1750	1700	1850

Global Demands for 5G small cells will be up to 10.25 millions

Industrial Chain of SiC



In House
ACME、
USIO

Crystal Growth
Finishing

4934Tainergy (Taisic)

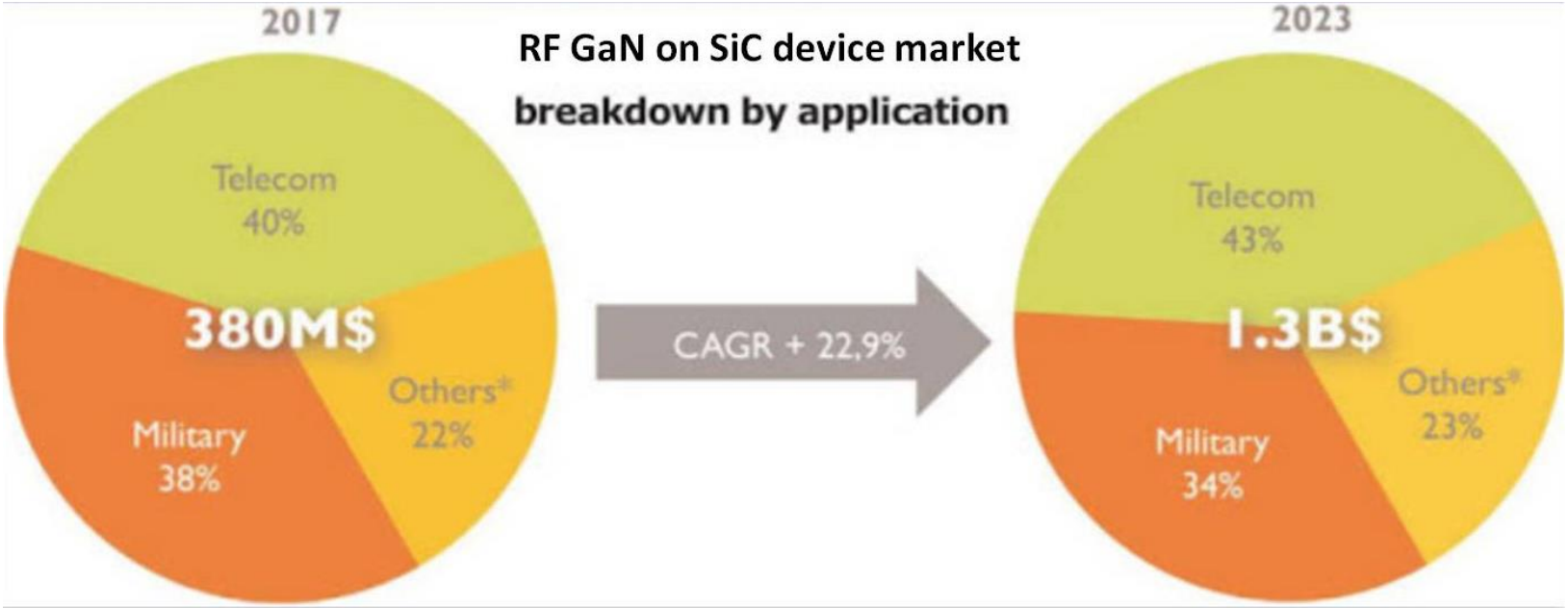
Epitaxy
Foundry
Package

Cree、II-VI、GTAT、Rohm
SK Siltron(DuPont)、NSC
TenkeBlue、SICC、Semicore、
6488 GlobalWafers、3583 Scientech、
8028 PSI

Wolfspeed、Rohm、Infineon、ON Semi、
Qorvo、Mitsubishi、STMicroelectronics、
X-Fab 、EpiWorld
3105 WIN、2455 VPEC
3016 Episil-Precision、3707 EPISIL

Prediction of SiC Communication Device market

It is estimated that the market growth will exceed 3 times in the next five years →$1.3 billion in 2023



Ref. : Yole Report 2018.

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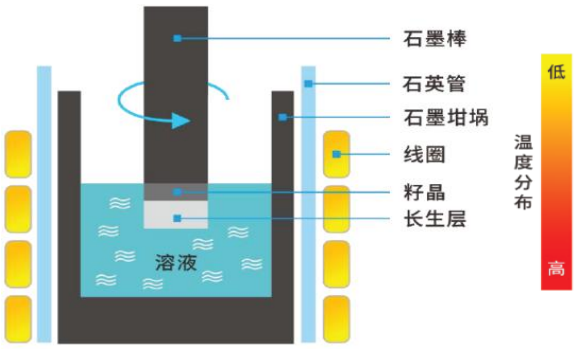
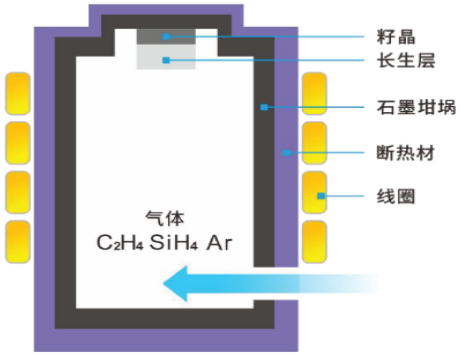
Crystal Growth of SiC

LPE



HTCVD



PVT

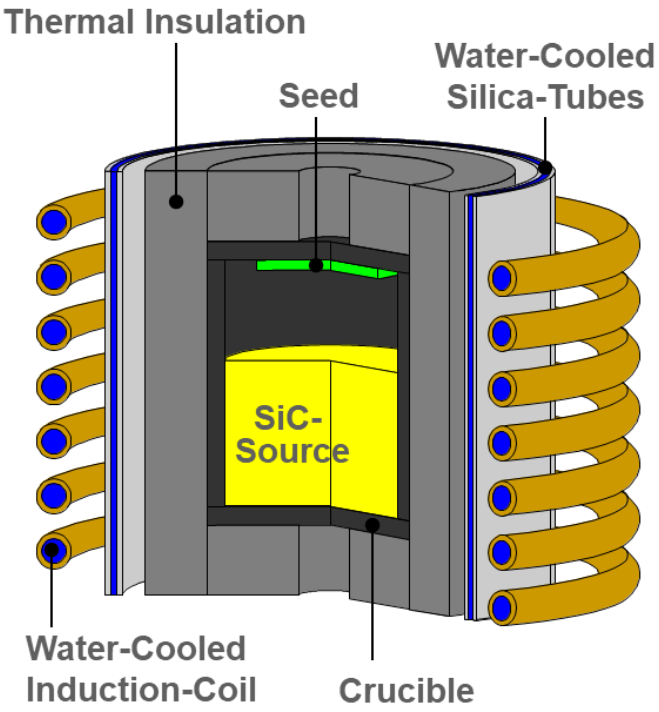
LPE: Liquid Phase Epitaxial

HTCVD: High Temperature Chemical Vapor Deposition

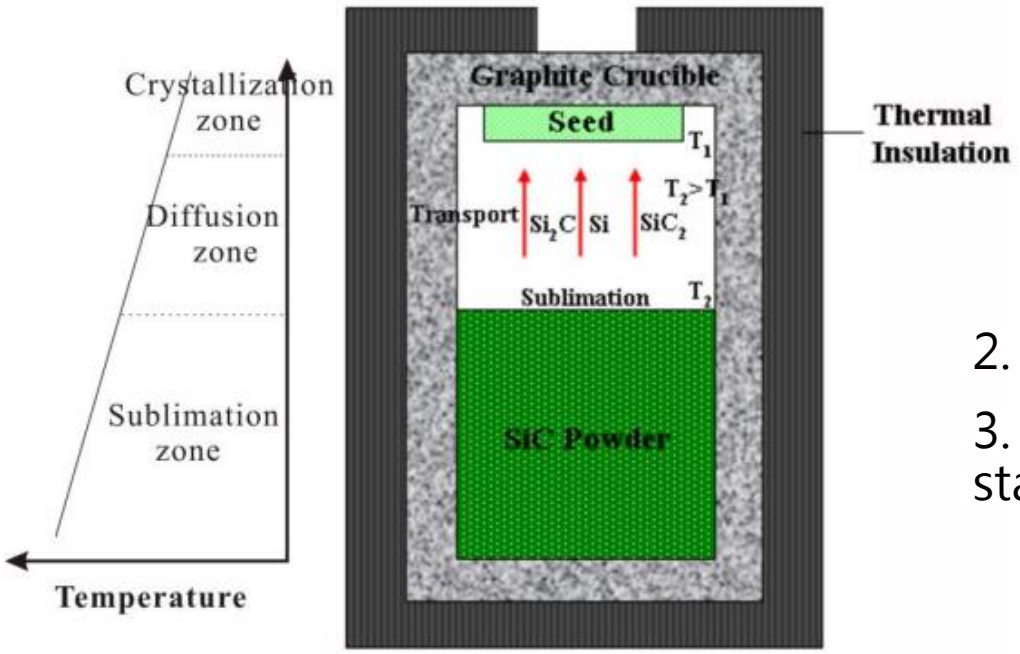
PVT: Physical Vapor Transport

Schematic of SiC PVT Crystal Growth

1. it is impossible to in-situ observe the crystal growth in the black box of graphite crucible. The SiC crystal seeds, graphite crucible and high-purity SiC raw materials can not be used again. It has to destroy the crucible to confirm the success or failure of the SiC crystal growth.
2. The crystal growth rate is slow –only 20mm thick after 7 days' growth.
3. As SiC has more than 200 polytypes, needs accurate thermal field, flow field, electrical field control as well as accumulated experiences to grow large size, defect free and uniform 4H single crystal.



Growth Process of SiC Crystal by PVT Method



1. T > 1800℃，sublimation-decomposition reaction:

$$SiC(s) = Si(g) + C(s)$$

$$2SiC(s) = Si_2C(g) + C(s)$$

$$2SiC(s) = SiC_2(g) + Si(g)$$

2. Gas phase transmission;

3. Recrystallization in supersaturated state:

$$SiC_2(g) + Si(g) = 2SiC(s)$$

$$Si_2C(g) + SiC_2(g) = 3SiC(s)$$

Features of SiC Crystal Growth

Long Time

Si：3~4 days
SiC：7 days

Short Length

Si：200 cm
SiC：2 cm

High Purity

Raw materials and Seed

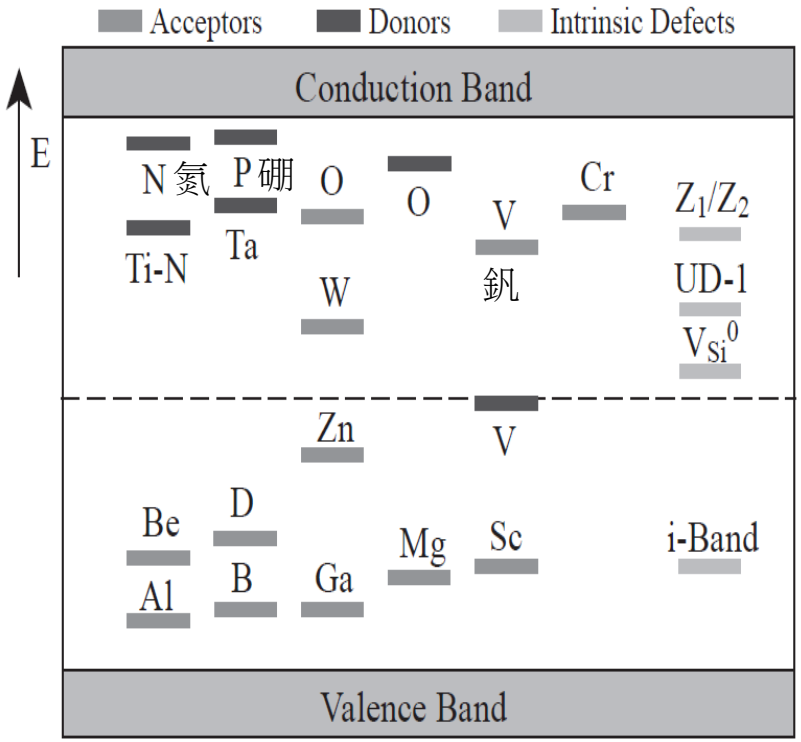
Summary of SI-SiC Crystal Growth

High purity Crystal Growth

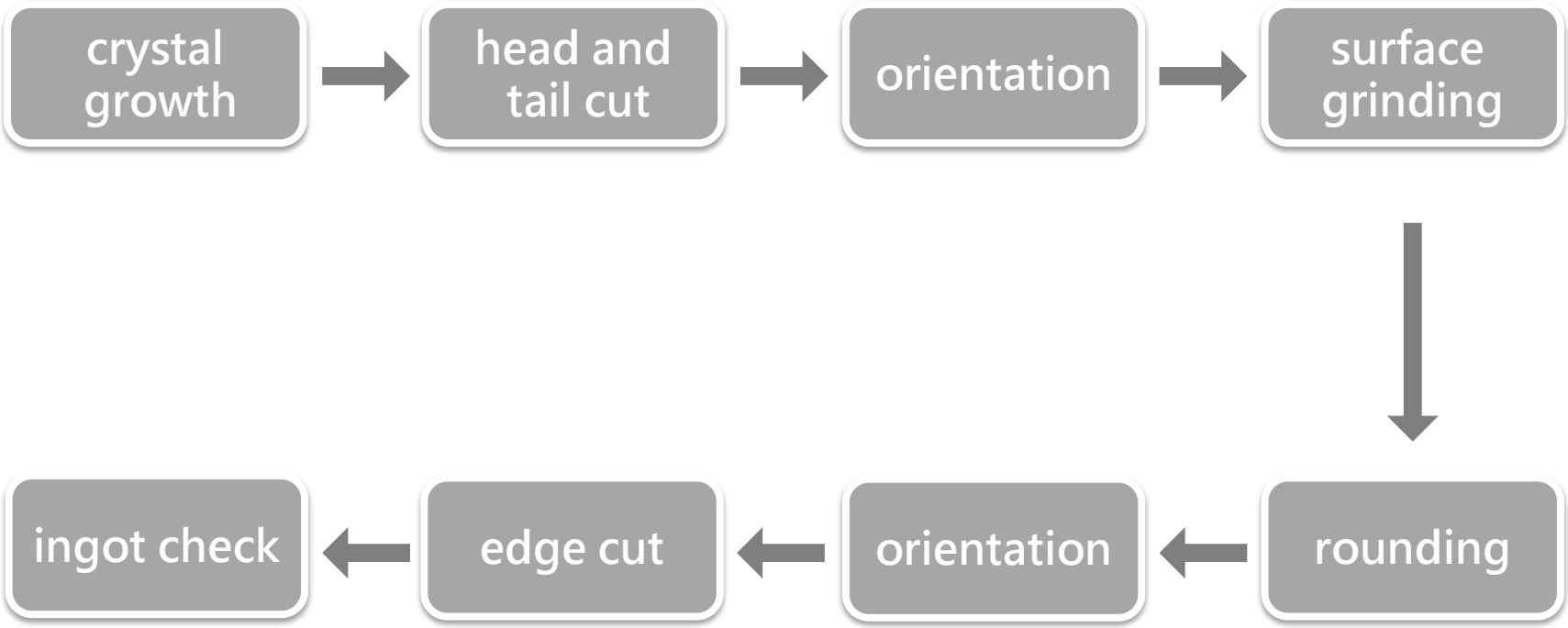
- The resistance of SI-SiC substrate is required to be more than 1e6 Ω· cm. There are two technologies to meet requirements:

1. By doping vanadium to modify the electrical properties of the substrate. It will cause crystal defects and results in reduced yield of components, which will increase the complexity of crystal manufacturing and increase the cost.
2. By controlling the purity and defects in SiC crystal growth so as to increase the resistivity. In addition to high purity raw materials and low impurity in graphite crucibles, it is also necessary to overcome the nitrogen content in the environment. (the conductivity will be increased when the nitrogen content in SiC crystal is high).

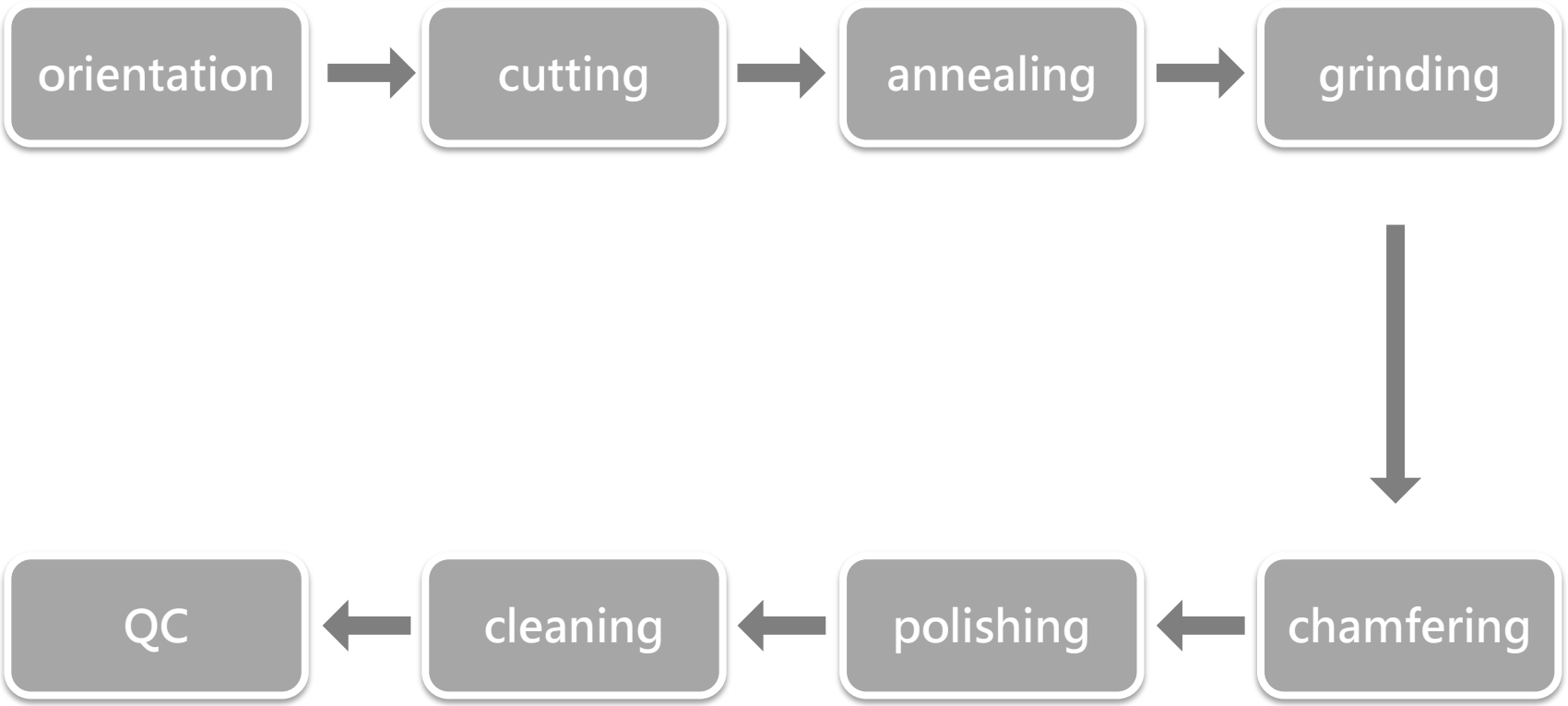
Vanadium Doping



Process Flow of SiC Ingot



Process Flow of SiC Wafer



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Conclusions

- There will be explosively market growth in SiC applied in both power devices and HF communications in the near future.
- It is the prime time to invest in SiC substrate business, as the technology barriers and demand more than supply.
- Tainergy and the subsidiary TASIC have actively stepped into the field of SiC substrate manufacturing and developed our own core patents and technologies. We are now in the stage of product verification and certification, and mass production is expected to start in Q1, 2021.

Tainergy 4934

Into The New Semiconductor Era