CS International 2023

Underpinning the growth of gallium oxide

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Novel Crystal Technology, Inc.

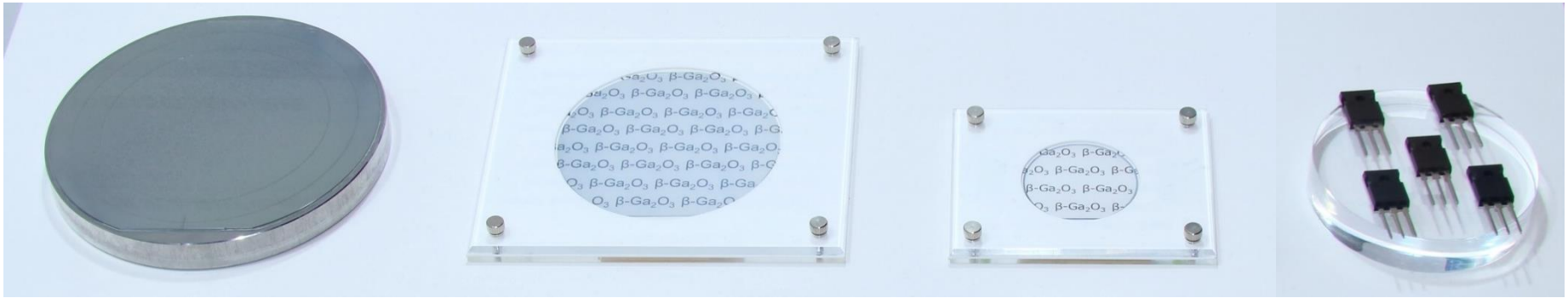
April 19, 2023

Novel Crystal Technology (NCT)

Novel Crystal Technology, Inc.

- **Carve out venture from Tamura Corporation**
- **Established in 2015**
- **Located in Sayama, Saitama, Japan**
- **Products:**

  Ga_2O_3 substrates & epi wafers
  Ga_2O_3 power devices (TBA)

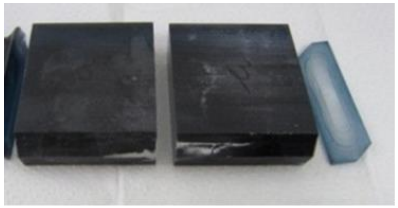


6 inch substrate | 4 inch substrate | 2 inch epi wafer | SBDs

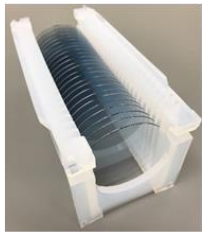
Products

Novel Crystal Technology, Inc.

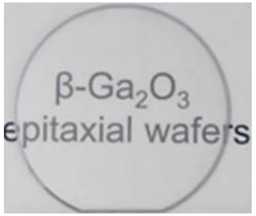
Production flow of Ga_2O_3 power devices



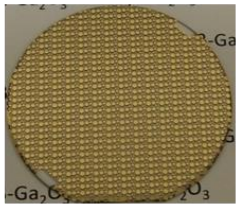
Bulk crystals



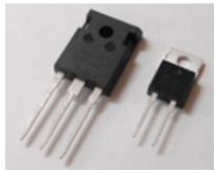
Substrate wafers



Epitaxial wafers



Device wafers



Packages

Modules

EV

Railroad vehicle

Power supply, UPS

Inverter

Power conditioner

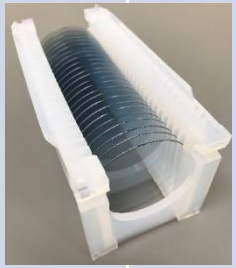
NCT's Products

Product Roadmap

Novel Crystal Technology, Inc.

FY2021	FY2022	FY2023	FY2024	FY2025	FY2026	FY2027	FY2028	FY2029	FY2030

100mm wafer

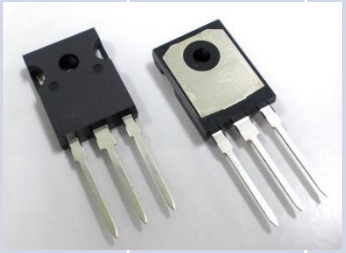


150mm wafer

200mm wafer

Diode

Aiming for cost performance that surpasses SiC SBD

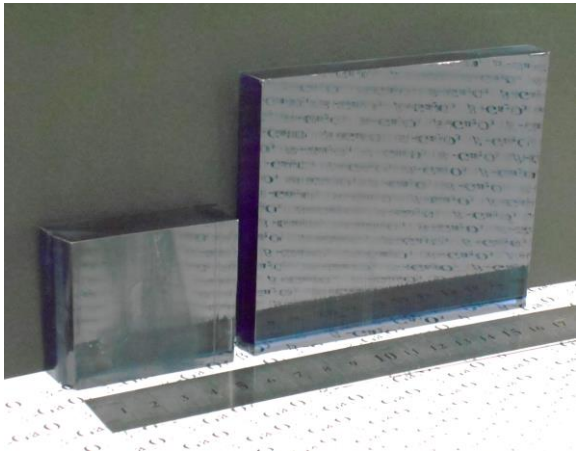


Transistor

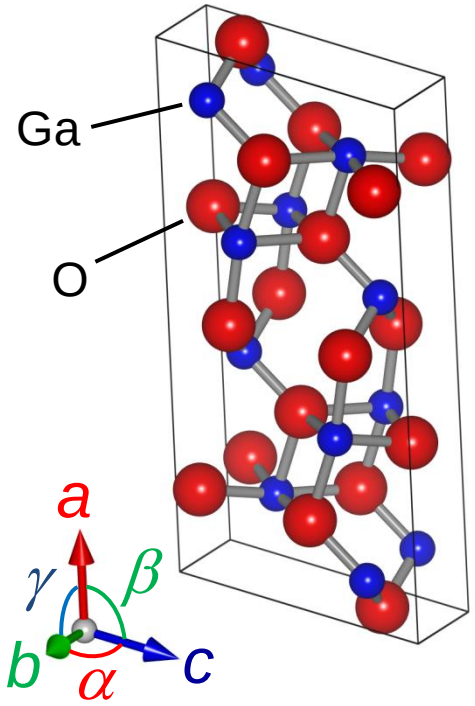
Aiming for cost performance that surpasses Si IGBT

Features of Ga_2O_3

- **Ultra wide bandgap semiconductor**
- **Bandgap: 4.5-4.8 eV**
- **High electric field strength: ~8 MV/cm**
- **Bulk crystals can be grown from melt**



Ga_2O_3 bulk cstal



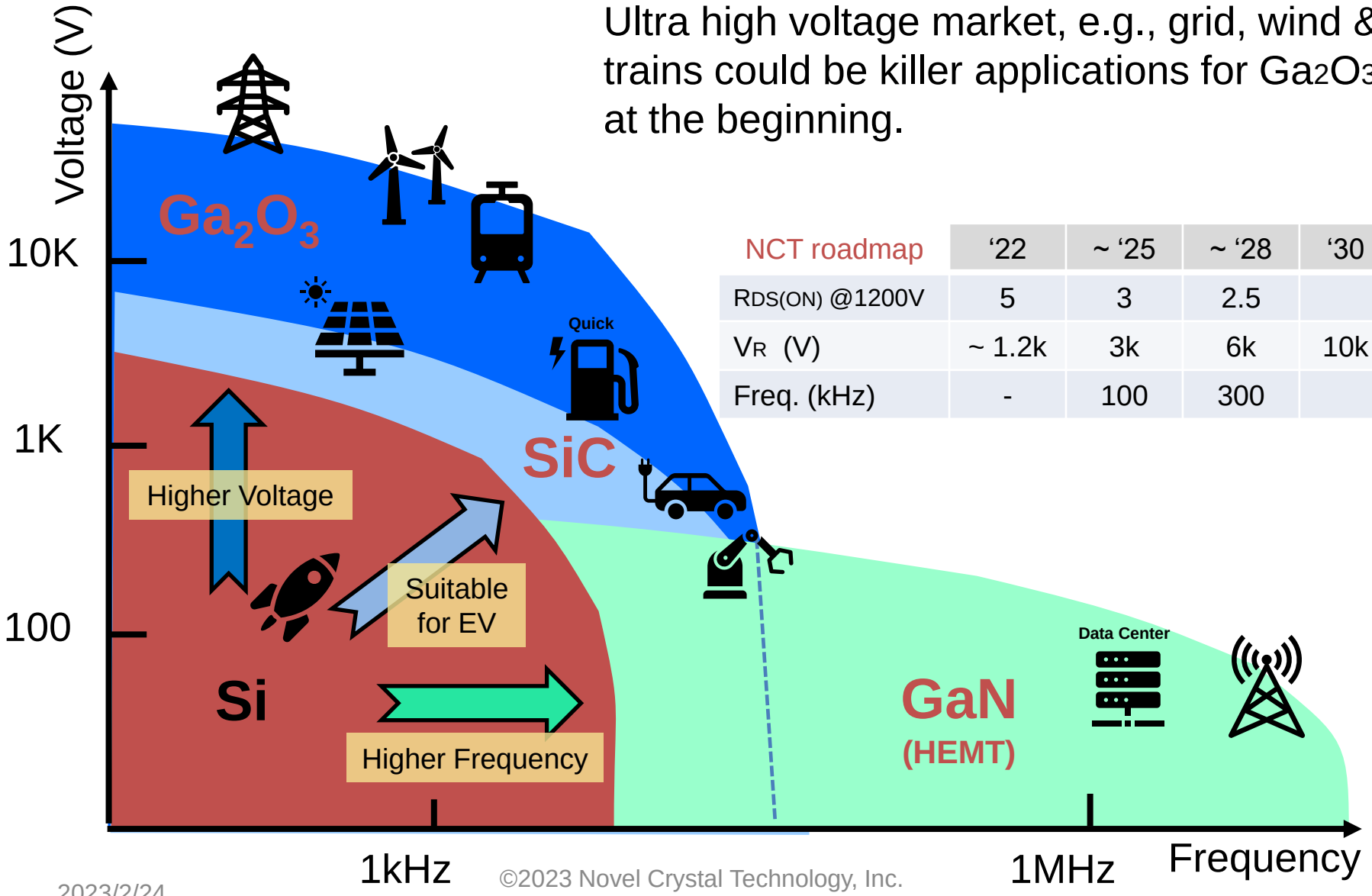
Crystal structure of Ga_2O_3

Applications

Novel Crystal Technology, Inc.

Ultra high voltage market, e.g., grid, wind & trains could be killer applications for Ga_2O_3 at the beginning.

NCT roadmap	'22	~ '25	~ '28	'30 ~
$R_{DS(ON)}$ @1200V	5	3	2.5	
V_R (V)	~ 1.2k	3k	6k	10k ~
Freq. (kHz)	-	100	300	



Ga_2O_3 Bulk Growth Methods

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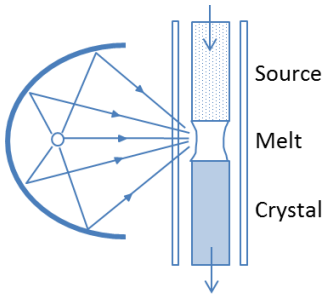
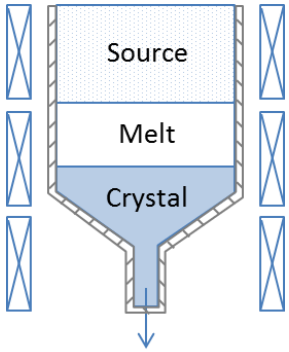
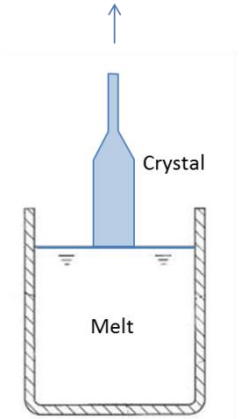
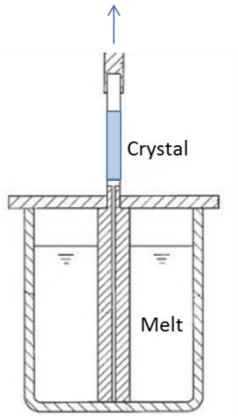
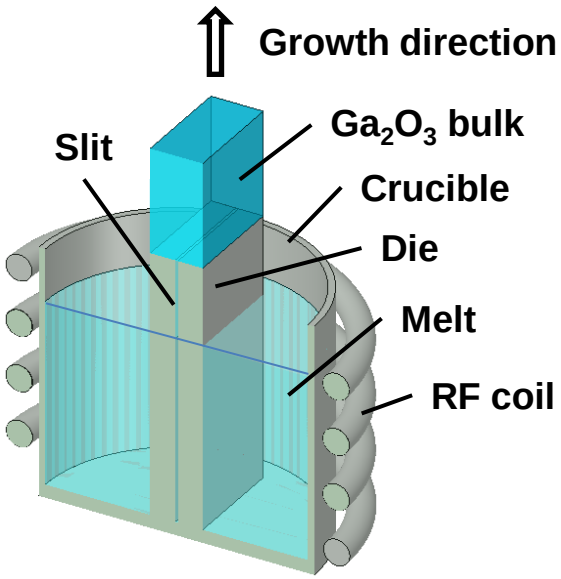
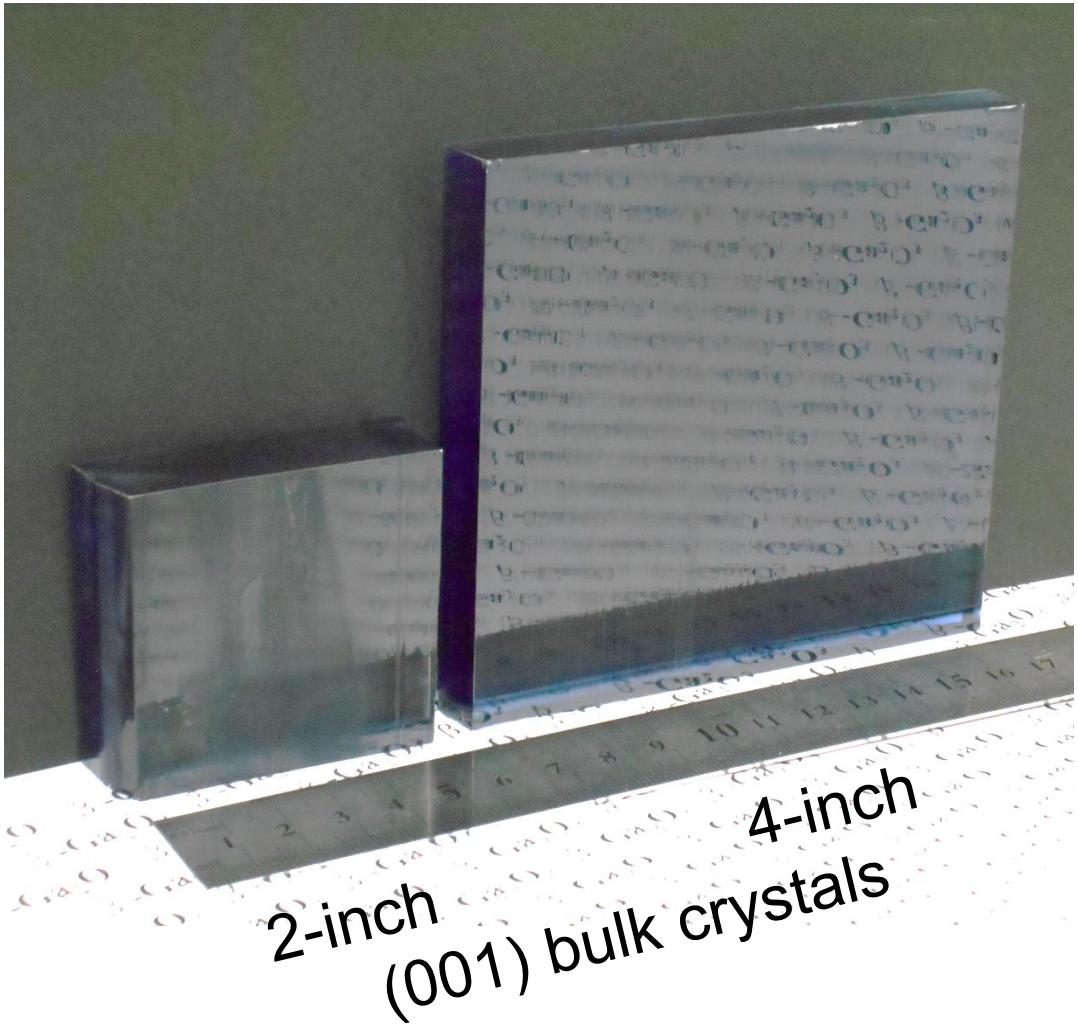
Method	FZ	VB	CZ	EFG
				
Bulk size reported	**1 inch**	**2 inch**	**2 inch**	**6 inch**
n-type doping	**Possible**	**Possible**	**Possible**	**Possible**
Growth rate (mm/h)	**5**	**1**	**2**	**15**
Strong point	**High purity**	**High quality**	**Large boule**	**Large n-type**

Edge-defined Film-fed Growth (EFG)



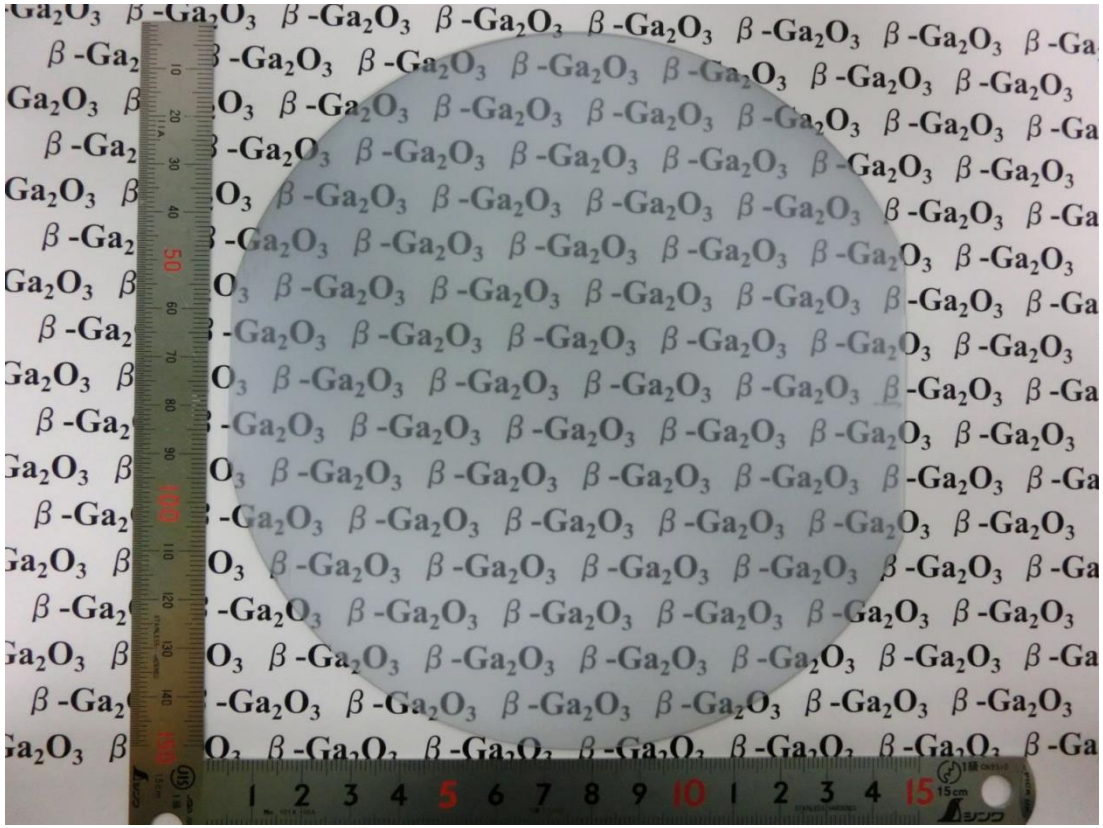


A. Kuramata *et al.*, Jpn. J. Appl. Phys. **55**, 1202A2 (2016)

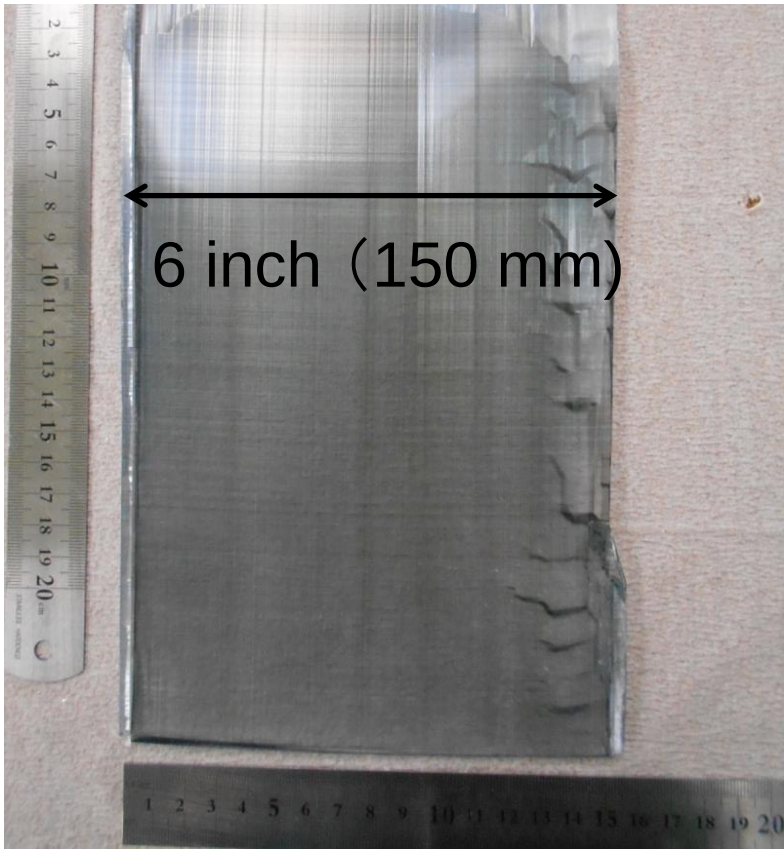
6-inch Substrates

Novel Crystal Technology, Inc.

For demonstration



(001) 6-inch substrate



(001) 6-inch bulk crystal

There have been no commercial order for 6 inch substrates. But, once we get the order, we can quickly establish production of the 6-inch substrates.

Vertical Bridgman (VB)

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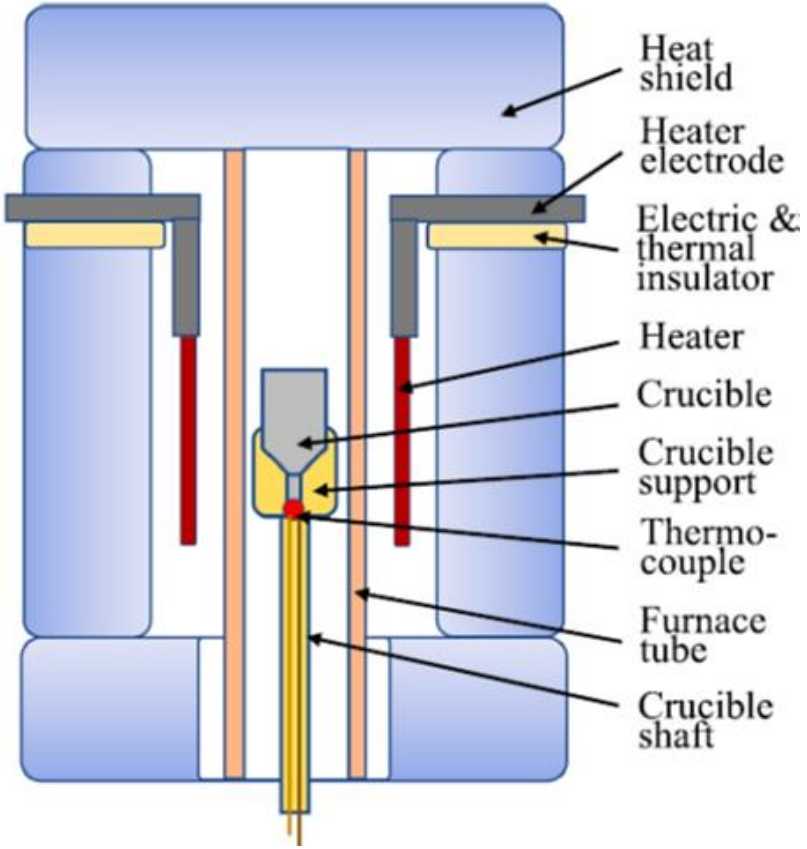
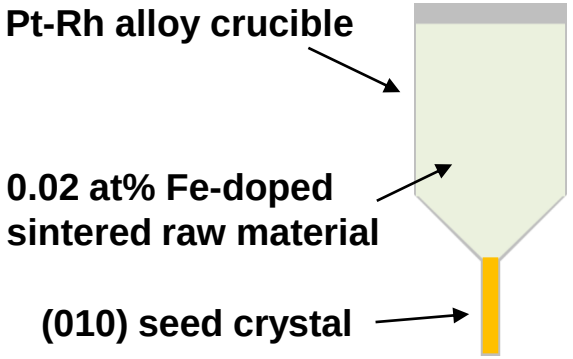
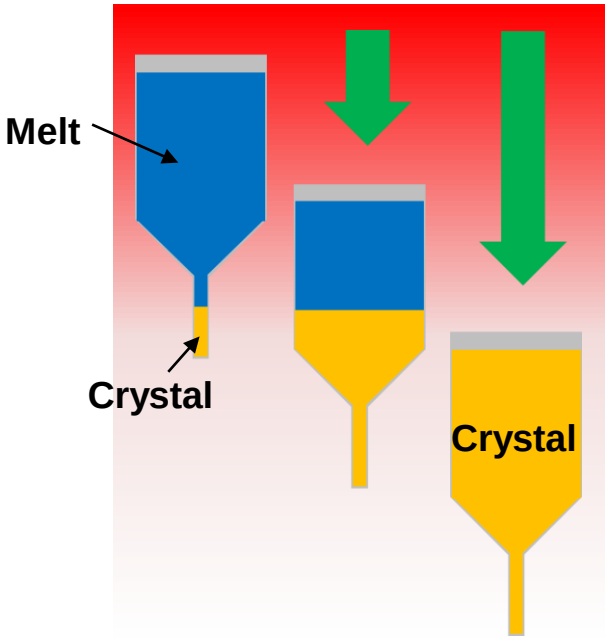
Vertical Bridgman (VB)



Crucible



Way to grow crystal



Fe-doped 2-inch (010) Crystal

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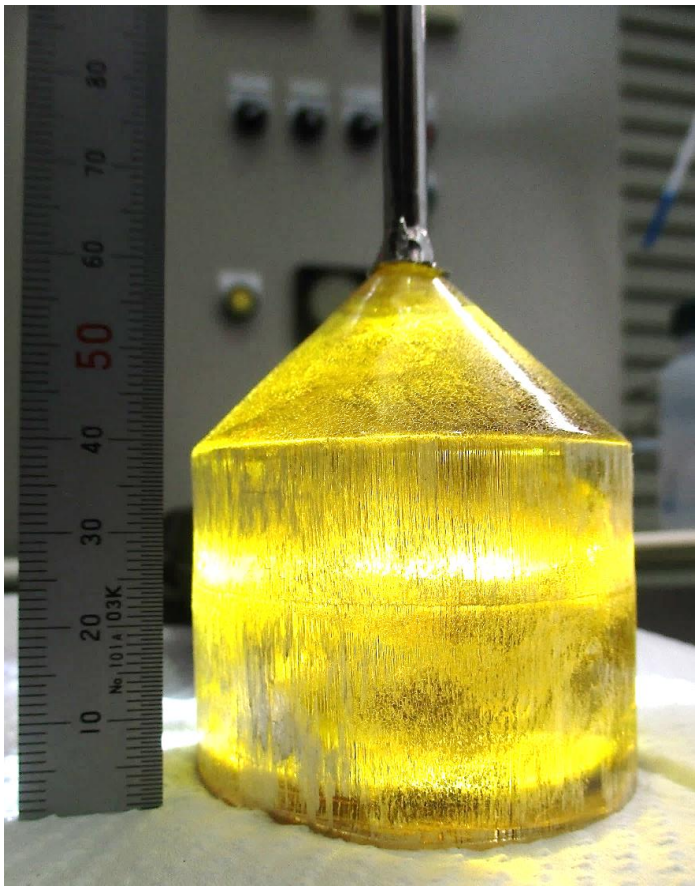
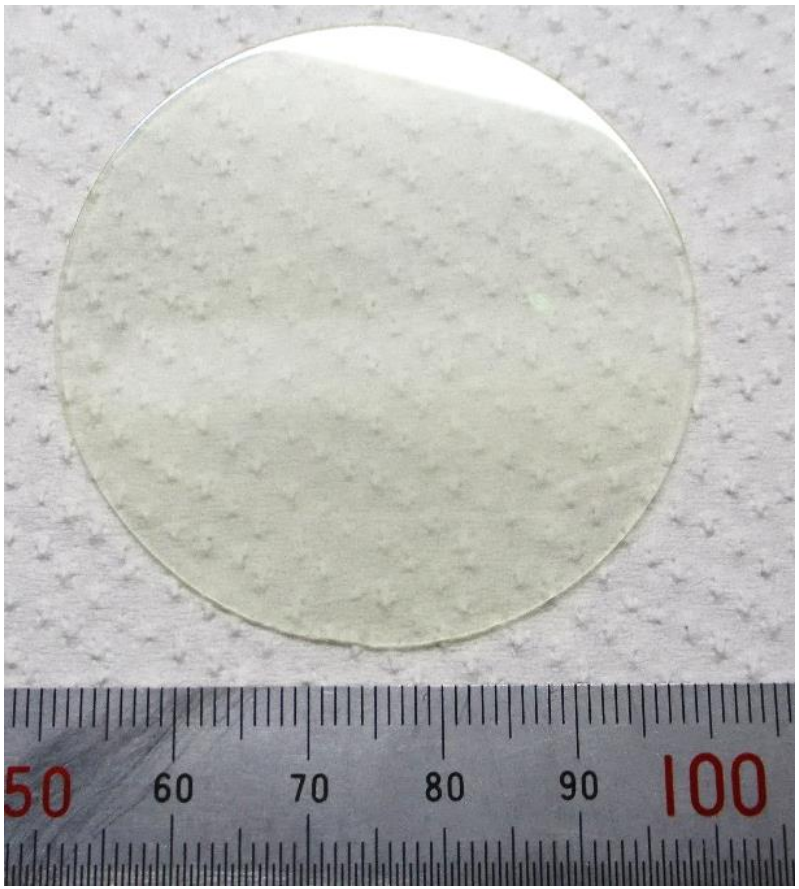


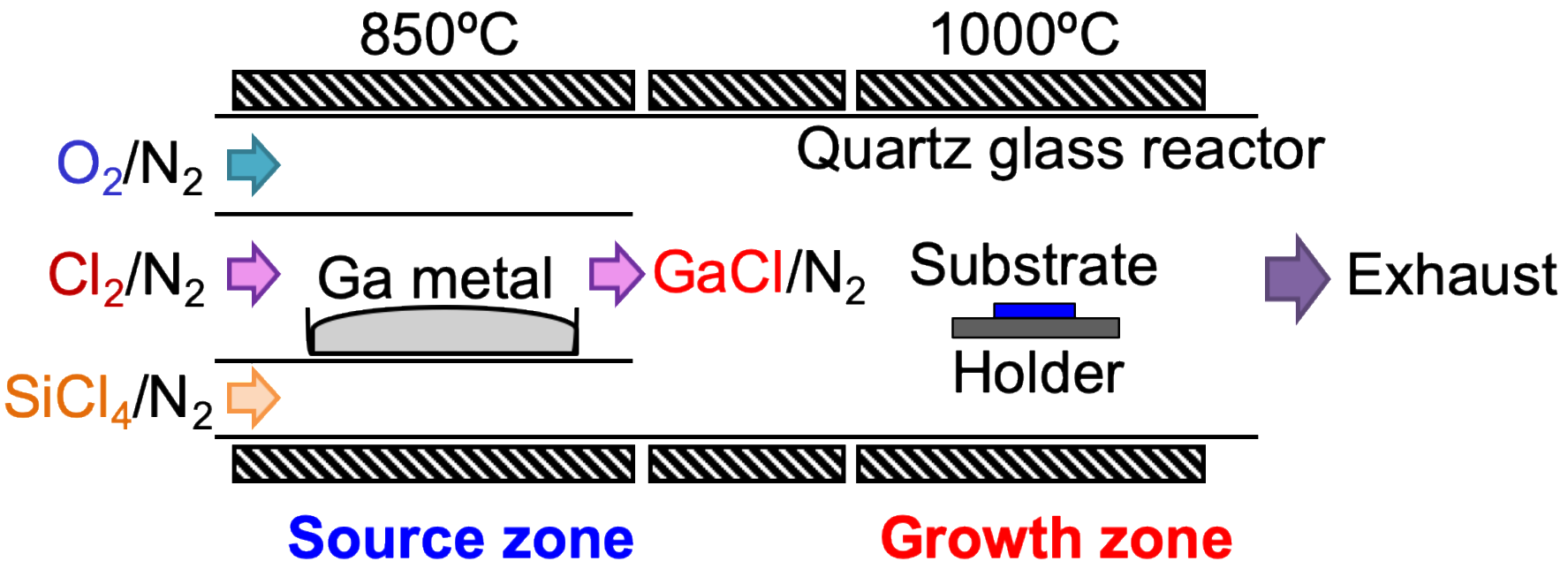


- **Yellow coloration in the crystals origin to incorporation of Fe dopant and crucible-derived Rh**
- **Successfully obtained 2-inch (010) substrates, the largest size (010) substrate ever reported**

Halide Vapor Phase Epitaxy (HVPE)

Novel Crystal Technology, Inc.

β-Ga_2O_3 HVPE system

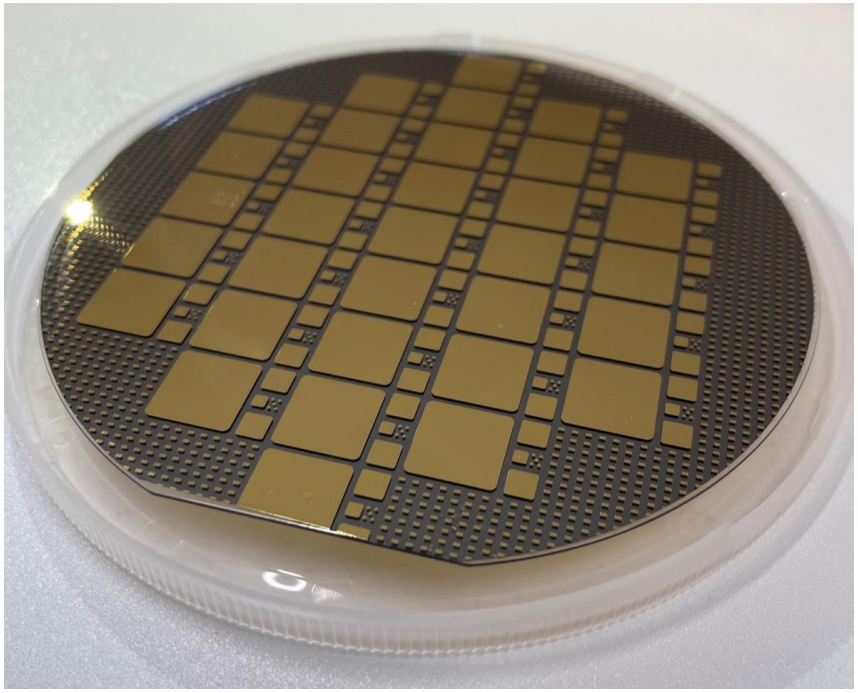


The technology was transferred from Tokyo University of Agriculture and Technology.

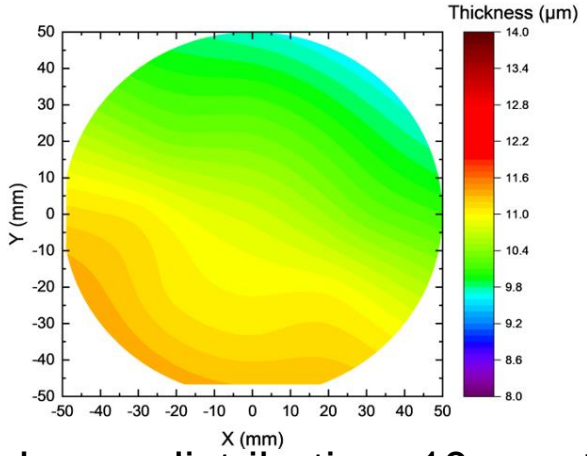
100-mm HVPE Epi Wafer

Novel Crystal Technology, Inc.

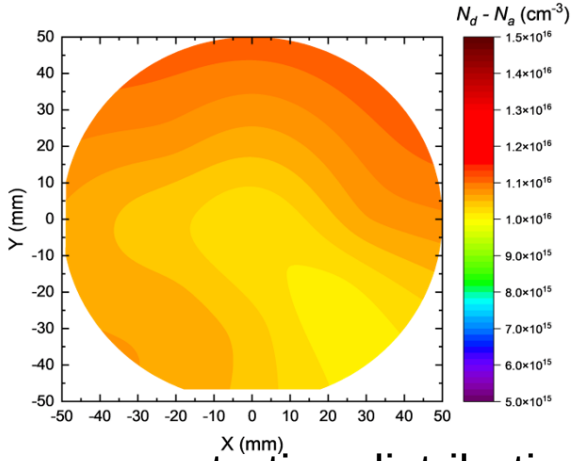
In collaboration with Saga University



100-mm β-Ga_2O_3 epitaxial wafer with SBD electrodes. Maximum chip size is 10 mm x 10 mm.



Film thickness distribution: 10 μm ±5%



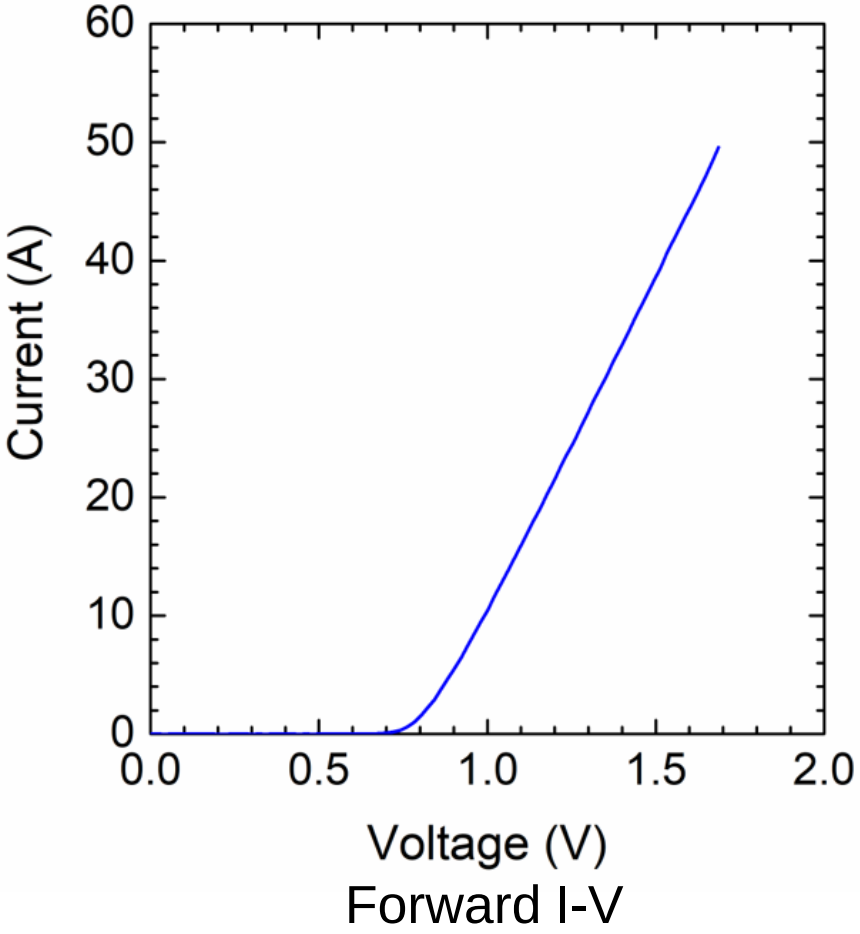
Donor concentration distribution:
1×10^{16} cm^{-3} ± 7%

We have developed 100-mm gallium oxide epitaxial wafers by using HVPE.

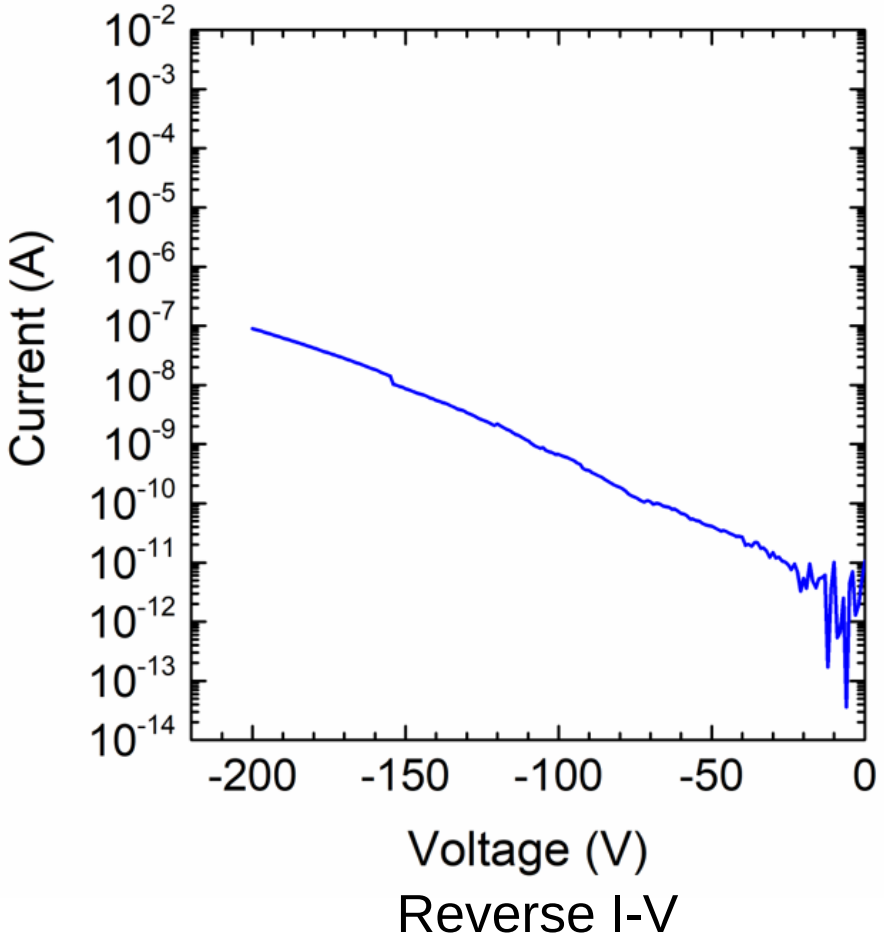
100-mm HVPE Epi Wafer

Novel Crystal Technology, Inc.

10 mm × 10 mm SBD



Forward I-V



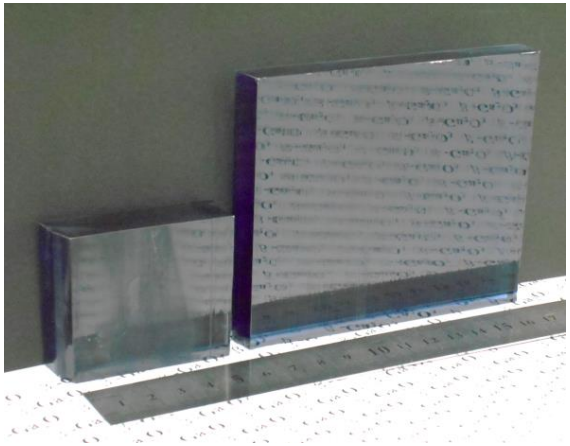
Reverse I-V

The yield of the 10 mm × 10mm diodes was as high as 51%.
The killer defect density is estimated to be about 0.7 cm^{-2}.

Summary

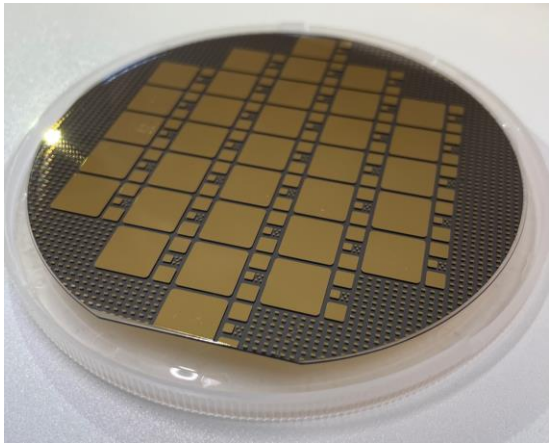
Novel Crystal Technology, Inc.

- Ga_2O_3 is a UWBG material for next generation power devices.
- Ga_2O_3 covers the application area of high voltage.
- Large and high-quality native wafers are already commercially available.



EFG Crystal

VB Crystal



HVPE epi wafer