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Crystallinity improvement of 100-mm-diameter β-Ga_2O_3 epi-wafer

Success in further improving the quality of 100-mm-diameter β-type gallium oxide epi-wafers
This is expected to contribute significantly to the energy conservation of power semiconductors for electric vehicles, etc.

Novel Crystal Technology, Inc.
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Summary

- **On March 14, 2022, Novel Crystal Technology, Inc. announced that it successfully improved the quality (reduction of killer defects) of 100-mm-diameter gallium oxide (Ga_2O_3) epi-wafers, which are expected to be the next generation of power semiconductors, thereby facilitating the widespread deployment of Ga_2O_3 power semiconductors for the requirement of 100 A-class power semiconductor markets. (Figure 1).**

- **Ga_2O_3 power semiconductors can sustain an higher voltage and current compared with conventional silicon semiconductor, recently industrialized silicon carbide semiconductor and gallium nitride semiconductor, and therefore are expected to be used for large-power semiconductors required for electric vehicles and other applications.**

- **Ga_2O_3 semiconductors, an originated producing technology from Japan, are expected to enter the global market of power semiconductors in the next few years owing to a possibility of mass production with low cost and more energy conservation than other conventional semiconductors.**

Novel Crystal Technology, Inc. has been working on the commercial development of β-Ga_2O_3 Schottky barrier diodes under the NEDO Strategic Energy Conservation Technology Innovation Program and collaborated with the Saga University to develop a third-generation 100-mm-diameter Ga_2O_3 epi-wafer (*1). In this development, the epi-wafer manufacturing technology has been improved, and defects (killer defects*2) that inhibit the development of high-current Ga_2O_3 power semiconductors and degrade the breakdown voltage characteristics, have been successfully reduced to one-tenth of the conventional level. This achievement will facilitate the widespread deployment of Ga_2O_3 power semiconductors for the requirement of 100 A-class power semiconductors in markets for such as trains, industrial equipment, and electric vehicles, etc. Ga_2O_3 semiconductors are expected to contribute to global energy conservation and carbon neutrality in the future because of lower power losses compared with conventional semiconductors.

Detail

Reduction of "Killer Defects" Enables to obtain 100 A-class Large-power Devices

β-gallium oxide (β-Ga_2O_3) has paid attention as a new material that can realize low power-consumption power semiconductors with a low cost. Power semiconductors are used in all types of electrical equipment, including home appliances, automobiles, trains, and industrial equipment, to control voltage and current. Conventional power semiconductors have been fabricated using silicon (Si); however, power loss is generated during power control. Power semiconductors, such silicon carbide (SiC) and gallium nitride (GaN) have, therefore been developed to solve this issue, however the use of Ga_2O_3 can further reduce the power loss and power consumption of electrical equipment.

Novel Crystal Technology, Inc. has already succeeded in developing epitaxial equipment with a producing capability of Ga_2O_3 semiconductor epi-wafers up to 100 mm in diameter, which have been manufactured and commercially available. However, the epi-wafer produced using this equipment has approximately 10 defects per cm^2 (referred to as killer defects), which degrades the breakdown voltage characteristics of devices, thereby rendering difficulty in producing large devices and limiting the current flow to approximately 10 A.
To solve this problem, the company collaborated with the Saga University and discovered that killer defects were caused by a specific powder generated during the epitaxial growth. Therefore, by improving the growth conditions, the company was able to obtain a third-generation 100-mm-diameter Ga_2O_3 epi-wafer with killer defects reduced to 0.7 defects/cm^2, which is less than one-tenth of the conventional level.

Figure 2 shows the electrical properties of Si, 4H-SiC, GaN, diamond, and β-Ga_2O_3 semiconductors. Ga_2O_3 exhibits a Baliga's Figure-of-Merits (BMOF) of 3,444, only second to the diamond semiconductor (referred to as "ideal semiconductor"). A large BMOF indicates that the high performance of power semiconductors, directly related to a "high breakdown voltage" and "low power loss", can be achieved.

Realization of low cost, high speed manufacturing, and energy conservation

Another huge advantage of Ga_2O_3 semiconductors is that bulk crystals can be made using a considerably faster manufacturing method than SiC and GaN semiconductors, which leads a expective mass production resulting in a significant cost reduction (Figure 3). SiC and GaN bulk crystals can be produced by evaporating raw materials (vapor phase growth method). However, this method has a slow growth rate of several hundred micrometers per hour and suffers a huge cost issue. In contrast, Ga_2O_3 semiconductor bulk crystals can be produced liquid raw materials (melt growth method); thus an overwhelmingly fast growth rate of several tens of millimeters per hour is possible for manufacturing semiconductor crystals. Furthermore, SiC and GaN semiconductors are hard materials that causes difficult for processing, whereas Ga_2O_3 is comparably soft and can be easily processing.

Novel Crystal Technology, Inc. has built a production line for commercializing the new development of third-generation 100-mm-diameter Ga_2O_3 epi-wafers and plans to begin sales as soon as possible. Novel Crystal Technology, as a Japanese company, is currently the leading manufacturer of Ga_2O_3 epi-wafers in Japan and other countries, and it is expected to expand its share of the power semiconductor market hereafter as continuously grow with the spread of electric vehicles.

Mr. Takekazu Masui as the chief of Novel Crystal Technology Sales Department explains the energy-conservation effects by using Ga_2O_3 semiconductors in future: "We estimate that if Ga_2O_3 semiconductors are broadly used in battery chargers, air conditioners, electric vehicles, data centers, smart grids, rail vehicles, etc., 10 million kW of electricity could be saved annually in 2050, which is equivalent to 10 nuclear power units."

Annotations

*1 Epi-wafer
A semiconductor crystal film orientated on a single-crystal substrate. The quality of the crystal film is important because the crystal film determines the performance of a semiconductor device.

*2 Killer defects
Generic term for defects that cause critical failure in semiconductor devices. Crystal imperfections, polishing scratches on the wafer surface, and defects generated in the device process can result in killer defects. The density of the killer defects must be reduced for manufacturing large (high-current) devices with high yields.

Figures

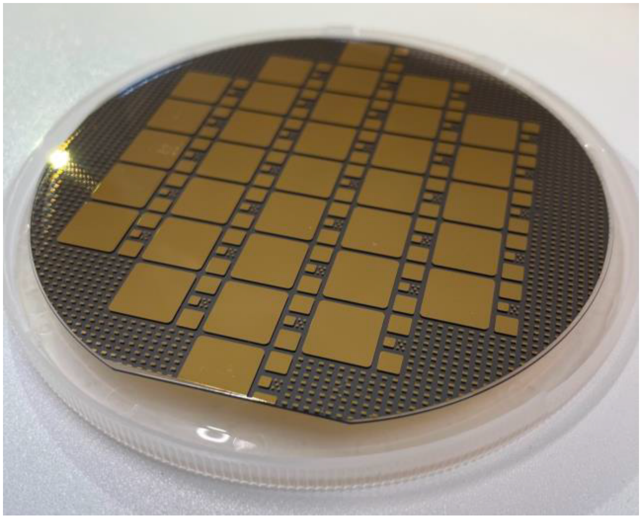

Figure 1. Third generation β-Ga_2O_3 Schottky barrier diodes prototyped on 100-mm-diameter epi-wafers. Maximum chip size of 10 mm × 10 mm .

	Si	4H-SiC	GaN	Diamond	β-Ga_2O_3
バンドギャップ：E_g (eV)	1.1	3.3	3.4	5.5	**4.5-4.9**
絶縁破壊電界強度：E_c (MV/cm)	0.3	2.5	3.3	10	**8（推定）**
電子移動度：μ (cm^2/Vs)	1,400	1,000	1,200	2,000	**300（推定）**
比誘電率 ：ε_s	11.8	9.7	9.0	5.5	**10**
バリガ性能指数：$\varepsilon \mu E_c^3$	1	340	870	24,664	**3,444**

パワーデバイスの性能を示す指数
（誘電率、電子移動度、絶縁破壊電界強度で決まる値）

Figure 2: Comparison of electrical properties of various semiconductor materials

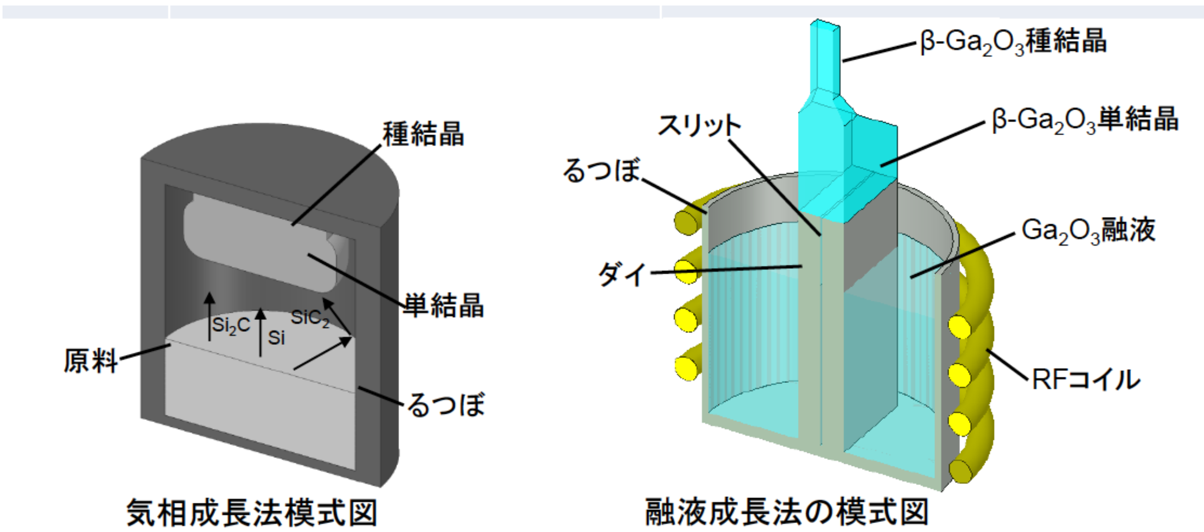

Figure 3. Schematic of vapor phase growth and melt growth methods in the production of semiconductor crystals