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Taiyo Nippon Sanso Corporation
Tokyo University of Agriculture and Technology
Novel Crystal Technology, Inc.
NEDO (New Energy and Industrial Technology Development Organization)

Succeeded in Growing the Gallium Oxide Film on a 6 inch Wafer by HVPE System

Contribution to Cost Reduction of Power Devices and Energy Saving in Next Generation Electric Vehicles

Taiyo Nippon Sanso Corporation ("TNSC", President: Kenji Nagata) announced that it has successfully achieved the growth of a gallium oxide film on a 6 inch wafer by the HVPE system in a joint effort with Tokyo University of Agriculture and Technology, and Novel Crystal Technology, Inc.

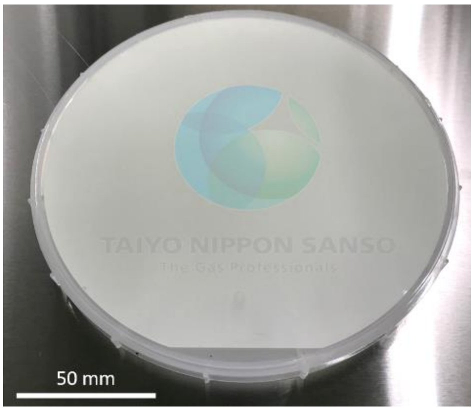

Fig. 1 β-Ga_2O_3 thin film formed on a 6 inch test wafer

1. Overview

Gallium oxide (β-Ga_2O_3) *1 has an even wider bandgap*2 than silicon carbide (SiC)*3 and gallium nitride (GaN)*4 which means that transistors and diodes made with β-Ga_2O_3 have excellent performance characteristics as power devices, *5 namely high voltage resistance and high efficiency (low loss). Japan is a global leader in the development of β-Ga_2O_3 power devices, and in 2021, Novel Crystal Technology, Inc. successfully developed a 4 inch β-Ga_2O_3 epitaxial wafer*6 using the halide vapor phase epitaxy (HVPE) system,*7 which it now manufactures and sells them.*8 The β-Ga_2O_3 wafer that forms the base of this epitaxial layer growth differs from SiC and GaN in that it can be manufactured using the melt growth method, which enables rapid formation of bulk crystals. Therefore, β-Ga_2O_3 wafers are easily obtained in large diameter and low cost, which is useful for reducing the price of power devices.

However, while the HVPE system used in growth of a β-Ga_2O_3 film has the benefits of low material cost and high purity film, there is an issue that the HVPE system has only been built for small diameter (2 or 4 inch) and manufacturing for single wafer. Therefore, it was essential to build batch-type mass production system with capability of producing large diameter (6 or 8 inch) wafers by the HVPE system to reduce the growth cost.

Based on this background, Taiyo Nippon Sanso Corporation started on developing mass production epi growth system corresponding to large diameter wafers (mass production system) for growth of β-Ga_2O_3 film under the "Strategic Innovation Program for Energy Conservation Technologies*[9]/Research and Development of Mass Production Epi Growth System Corresponding to Large Diameter Wafers for Next Generation Power Devices of Gallium Oxide" of the New Energy and Industrial Technology Development Organization (NEDO). During the program's incubation research phase (fiscal 2019), we conducted development of external supply technology*[10] for metal chloride, *[11] which is the raw material for the HVPE system. In the practical application development phase (fiscal 2020–fiscal 2021), we developed HVPE system for 6 inch single wafer and conducted growth to establish basic technology for mass production system, and evaluated it. Now, we have succeeded in the growth of a β-Ga_2O_3 film on a 6 inch wafer. If β-Ga_2O_3 power devices become widely adopted, power saving is expected to be possible for industrial motor control inverters, residential solar power generation system inverters, and next-generation electric vehicles, and other applications.

2. Results

Taiyo Nippon Sanso Corporation developed HVPE system for 6 inch single wafer (Fig. 2), and achieved the successful growth of a β-Ga_2O_3 film on a 6 inch test wafer (using a sapphire substrate (Fig. 1)).

Moreover, the optimization of growth conditions and the adoption of a proprietary raw material nozzle construction, enabled verification of the β-Ga_2O_3 growth on the 6 inch test wafer as well as uniform film growth, and achieving a β-Ga_2O_3 film thickness distribution is less than ±10% (Fig. 3). This result established the technology for growing films on large diameter substrates along with hardware design technology, which enables the building of a platform for β-Ga_2O_3 growth system. This in turn paved the way for a significant advance in the development of large diameter batch type mass production system. These β-Ga_2O_3 growth process and device application are expected to reduce electricity consumption with an effect in 2030 of saving the energy equivalent of 210,000 kL of oil per year.

Fig. 2 Exterior view of the HVPE system of 6 inch single wafer for growing β-Ga_2O_3 film

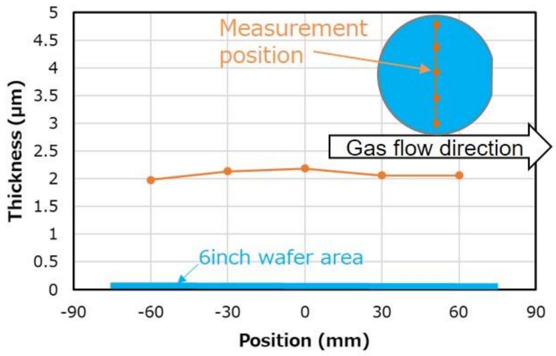

Fig. 3 Thickness distribution of β-Ga_2O_3 film formed on a 6 inch test wafer

3. Future Plans

Taiyo Nippon Sanso Corporation will continue to develop mass production system for β-Ga_2O_3 growth under the NEDO project, and going forward, we will develop high quality β-Ga_2O_3 epi growth technology with using 6 inch β-Ga_2O_3 wafers through evaluating of the electrical characteristics and defect of β-Ga_2O_3 thin films. Moreover, after establishing β-Ga_2O_3 epitaxial wafer mass production technology, we aim to commercialize mass production system in fiscal 2024. β-Ga_2O_3 epitaxial wafers manufactured using the HVPE system is mainly to be used in SBD*[12] and FET*[13], and the market is expected to grow to a scale of around ¥59 billion (Fuji Keizai Co., Ltd. "2020 Current Status and Future Prospect of Next Generation Power Devices & Power Electronics Related Equipment Market") by fiscal 2030. Looking ahead, we will contribute to the effort to save energy in next-generation electric vehicles etc., by realizing mass production system, entering the β-Ga_2O_3 growth system market, and promoting the spread of Ga_2O_3 power devices.

Notes:

*1 Gallium oxide (β-Ga_2O_3)
Gallium oxide is a composite semiconductor that is drawing attention as a third wide-bandgap semiconductor for power devices following silicon carbide and gallium nitride. Its theoretical performance as a power device is far higher than that of silicon, and also exceeds that of silicon carbide and gallium nitride, making this an excellent material.

*2 Bandgap
The bandgap refers to the energy needed for electrons or holes to transition from the valence band to the conduction band. Semiconductors in which this value is large are held to be wide-bandgap semiconductors, with a wider bandgap corresponding to higher dielectric breakdown strength. The bandgap of β-Ga_2O_3 is approximately 4.5 eV, a larger value than that of Si (1.1 eV), 4H-SiC (3.3 eV), and GaN (3.4 eV).

*3 Silicon carbide (SiC)
SiC is a composite of carbon and silicon used as a wide-bandgap semiconductor material, mainly in high-withstand voltage and high current applications.

*4 Gallium nitride (GaN)
GaN is a composite of gallium and nitrogen. It is a wide-bandgap semiconductor with an even more stable compound structure than SiC and an even high dielectric breakdown strength. GaN is used mainly in miniature high-frequency applications such as switching power supplies.

*5 Power device
Power devices are semiconductor elements used in electric power conversion. They are used in power converters such as inverters and converters.

*6 β-Ga_2O_3 epitaxial wafer
A thin-film wafer formed with β-Ga_2O_3 deposited on a wafer. By growing crystals on a wafer of crystal so that the atomic array aligns with the crystal surface of the substrate wafer is called epitaxial growth (epi growth).

*7 Halide vapor phase epitaxy (HVPE) system
HVPE is a method of growing crystals using metal chloride gas. Advantages of the method include rapid growth and high purity film growth.

*8 Novel Crystal Technology, Inc. succeeded in developing 4 inch β-Ga_2O_3 epitaxial wafers, and now manufactures and sells them.
Reference: Novel Crystal Technology, Inc. news release dated June 16, 2021
https://www.novelcrystal.co.jp/2021/2595/

*9 Strategic Innovation Program for Energy Conservation Technologies
Overview: https://www.nedo.go.jp/english/activities/activities_ZZJP_100039.html

*10 External supply technology
A technology used in the HVPE system, whereby the metal chloride generation zone and film growth zone are independently separated, and the metal chloride is supplied from outside to the reactor using a pipe, etc.

*11 Metal chloride
Metal chloride is a compound used as the metal material in the HVPE system. Typical metal chlorides include GaGl, $GaCl_3$, AlCl, $AlCl_3$, InCl, and $InCl_3$.

*12 SBD
Schottky Barrier Diode. This is a diode that uses the junction of a metal and an n-type semiconductor, rather than a PN junction. The advantage of SBD over other diodes is their higher efficiency and faster switching speed.

*13 FET
Field Effect Transistor. A transistor in which the application of voltage to the gate electrode generates an electrical field in the channel area that controls the density of electrons or holes in the area, thereby enabling control of the current between the source and drain electrodes.

4. Inquiry

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