Mitsubishi Chemical Newsletter

September 2021
Mitsubishi Chemical Corporation

Gallium nitride (GaN), a material to support future society

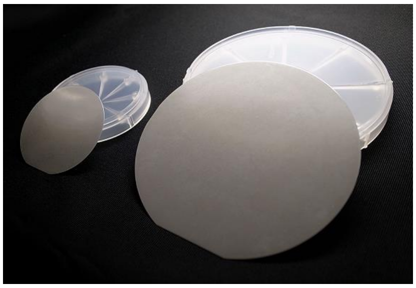
GaN will contribute toward developing

high-efficiency, high-tolerance power semiconductors, improving the performance of EVs and the quality of communication technology, including 5G, and ultimately achieving carbon neutrality.

Mitsubishi Chemical is working on the production of semiconductor materials, precision cleaning service for production equipment and the development of materials for next-generation semiconductors. Among these efforts, we are focusing on the mass production of GaN, a material used for achieving high-efficiency, high-tolerance semiconductors, as a substrate for next-generation semiconductors. In this newsletter, we will introduce GaN, the featured material that will play a major role in changing society toward a better future.

【1】A material to support future society: GaN

GaN



GaN substrates

GaN is a compound consisting of Gallium, a type of metal, and Nitrogen. The crystal structure of the compound serves as a semiconductor material. GaN is known as the material in blue LED, which was awarded the Nobel Prize in Physics in 2014. GaN is also applied to laser devices that serve as the light source in Blu-ray Disc players and projectors. Its physical properties enable the achievement of a power semiconductor that can operate at high speed, with low resistance and low power loss. Replacing conventional silicon semiconductors with high energy consumption and high power loss, GaN semiconductors are expected to lower power consumption by about 10%.

However, high-quality GaN substrates were considered difficult to manufacture and, due mainly to manufacturing cost, almost impossible to mass produce.

With the keywords of high speed, energy saving and compact, GaN contributes toward achieving the technologies shown in the figure below.

GaN crystals → Crystal growth and processing → GaN substrates

Fields that will benefit from GaN substrates

Power semiconductors

Power semiconductors can handle high voltages and large currents. While silicone substrates currently predominate, demand is increasing for power semiconductors that can withstand higher voltage and be energy efficient. There's also demand for small-sized, high-efficiency power semiconductors that enable the downsizing of devices and equipment. We strongly believe that GaN will meet such demand.

Next-generation technologies for EVs

Power semiconductors made of GaN are expected to control large amounts of power for EVs and other electronics with low power loss.

5G

Since it can cause electrons to move faster, compared to silicon power semiconductors, we expect to see GaN power semiconductors used for 5th generation mobile communication (5G) and post-5G communication, in items such as high-frequency devices and optical communication devices that can instantaneously transmit and receive large amounts of data. Semiconductors will also contribute to power saving for servers and base stations, where power demand will increase in the future.

Another benefit

Carbon neutral

GaN is expected to offer an environmental benefit since the material can reduce CO_2 emissions as a result of a drastic reduction in power consumption.

【2】Trend words related to the application of GaN

Power semiconductors

In the future, our life will depend greatly on power semiconductors.
Power semiconductors can handle high voltages and large currents and are mostly used in power conversion, such as changing voltages and frequencies, and changing DC to AC and AC to DC. Power semiconductors play an indispensable role in accurately driving motors from low to high speeds, supplying power grids with power generated from solar cells with less power loss, and providing a stable source of electricity to various home appliances and electrical equipment.
Their application fields range from solar power, railroad, wind power, and other industries to EVs and consumer electronics.

They possess a structure different ordinary semiconductors, enabling them to handle high voltages and large currents without sustaining damage. As semiconductors can handle large amounts of electricity, they often generate heat and reach high temperatures, causing failure. Some improvements are required to avoid this, such as reducing power loss, which is the cause of heat generation, and efficiently dissipating the generated heat to the outside. In recent years, there has been greater awareness of the need for energy savings and reduction in power consumption. As a result, demand for power semiconductors that can minimize power loss has increased.

Although silicone substrates are now commonly used, demand is increasing for power semiconductors that can operate with much larger amounts of current and lower power loss and, additionally, are smaller-sized and capable of handling higher power.

GaN power semiconductors characteristically can perform high-speed operations at a wide range of voltages and with low power loss. Demand for GaN power semiconductors is growing, as they can perform high-current operations despite their small size, thus allowing for reduced device and equipment size. Device cost is expected to decrease due to the development of larger-sized substrates, and GaN power semiconductors will have many more applications in the future.

Next-generation technologies for EVs

Promoting the shift to electric vehicles is the core action plan of the “Automobile, Storage battery” field in the Japanese government’s “Green Growth Strategy through Achieving Carbon Neutrality in 2050.” The government’s aim is that “For passenger vehicles, electrified vehicles will account for 100% of new vehicle sales by 2035.”

Following the trend, the shift to EVs is accelerating, and technologies are developing rapidly. Going forward, research and development will be vital for furthering functional advancements, such as non-contact chargers for EVs on the road. To achieve such next-generation technology, electronics and other devices must be practical and capable of operating with a large current.

GaN enables more efficient power conversion with less heat exhaustion by applying to power converters, as GaN can convert a large volume of electricity. GaN is expected to contribute toward developing wireless chargers for EVs and in-wheel motors and improving the distance to empty and the efficiency of renewable energy generation.

5G

5G is the fifth-generation mobile communication system after 4G (LTE-Advanced), currently used mainly for mobile phone and internet communications. In Japan, 5G service began in 2020. Experts expect the generational shift from 4G to 5G to significantly change our daily lives and businesses.

The distinctive features of 5G include high speed/high capacity, ultra-low latency, and massive device connectivity. Download speed is 20 gigabits per second. That means you can download a two-hour movie within three seconds. In addition, communications between individual devices, including smartphones, and a base station take 0.001 seconds, a tenth of that needed for 4G, drastically improving latency. As this enables remote control of robots without latency, we expect the application of robots in medicine and other fields to expand.
5G is the future of communication systems and plays an essential role in the Japanese government’s efforts to achieve a super-smart society.

**GaN is expected to serve as a high-frequency device for 5G,
as the high electron mobility of GaN enables high-frequency operations with wide bands.
GaN will be applied to wireless base stations for next-generation communication, including 5G.**

Carbon neutral

In October 2020, Prime Minister Yoshihide Suga declared that by 2050, Japan would reduce greenhouse gas (GHG) emissions to net-zero, realizing a carbon-neutral, decarbonized society. GHGs include not only carbon dioxide but also methane, nitrous oxide (N2O) and chlorofluorocarbons. It is impossible to reduce GHG emissions to zero, but Japan aims to achieve net-zero emissions by balancing GHG emissions with absorption and removal. Therefore, to achieve net-zero emissions, Japan will offset unavoidable CO_2 emissions in various ways: such as planting trees to increase the volume of CO_2 absorbed from the atmosphere for photosynthesis, using CCS technology to capture and store CO_2 and developing a system for artificial photosynthesis, which utilizes CO_2 as an energy source, hence the word carbon "neutral."

Currently, one region and 124 countries, including Japan, aim to achieve carbon neutrality by 2050. Including China, which declared its intention to achieve carbon neutrality by 2060, two-thirds of all countries in the world share the same goal.
The key to achieving carbon neutrality is reducing CO_2 emissions from energy sources, which account for a large part of GHG emissions. Since much of the CO_2 emissions are generated during energy production by burning fossil fuels such as coal, petroleum, and natural gas, decreasing the amount of energy consumption is considered effective for CO_2 emissions reduction. The means for energy consumption reduction can include power-saving and energy-saving through digitalization and optimization of energy use by IoTs.

Application of GaN to high-brightness and high-power lasers, high-efficiency illumination and new-generation displays will save energy.
As a key material for power semiconductors, EVs and 5G, which are related to digitalization and efficient uses of energy, GaN can also contribute to carbon neutrality by reducing the amount of energy we use in our daily lives.

【3】GaN manufactured by Mitsubishi Chemical

GaN substrates manufactured by Mitsubishi Chemical are high-quality, single-crystal substrates. They are manufactured with epitaxial technology to grow crystals called Hydride Vapor Phase Epitaxy (HVPE), which we have cultivated for years, and compound semiconductor processing technology. With the features of high crystallinity, good uniformity, and superior surface quality, the substrates have been applied to a wide range of uses, such as substrates for high-brightness LEDs, light sources for projectors, and substrates for blue laser diodes for high-intensity headlights.
We are now focusing on developing the application of GaN to substrates for power semiconductors, such as power devices and high-frequency devices. To achieve higher quality and productivity, we are working on demonstration experiments jointly with The Japan Steel Works, Ltd. (JSW) for new mass production technology with our unique Super Critical Acidic Ammonia Technology (SCAAT™).

JSW and MCC have completed construction of the world's largest manufacturing facility for GaN substrates.

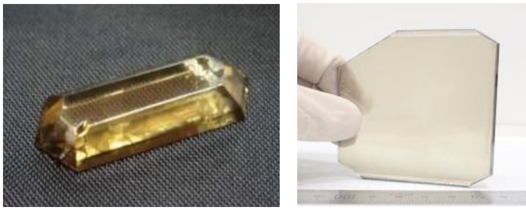
《New manufacturing process jointly developed by JSW and MCC》
JSW manufactures autoclaves (pressure vessels) for producing synthetic quartz crystals and has sold 415 autoclaves in Japan, with 100% market share, and 24 autoclaves overseas in total. One of its affiliates has been manufacturing synthetic quartz crystals for 30 years and distributes several optical components mainly to domestic camera manufacturers. With the technology to manufacture high-quality GaN substrates based on HVPE and compound semiconductor processing technology, Mitsubishi Chemical is developing GaN substrates with its unique SCAAT™ to achieve higher productivity.
The two companies had been developing the technology to manufacture large-diameter, high-quality, and low-cost GaN substrates in collaboration with Tohoku University and have established a joint research system for crystal growth and properties evaluation in cooperation with Amano Laboratory, Nagoya University.
In 2017, both companies successfully developed the low-cost manufacturing technology for transparent GaN substrates with minimal crystal defects at a pilot facility and confirmed uniform crystal growth on 4-inch substrates. The newly-developed manufacturing process, known as "SCAAT™-LP," is a new manufacturing technology that uses low-pressure acidic ammonothermal technology featuring approximately half the pressure conditions of conventional SCAAT™ to achieve future mass production.

Currently, we have completed the construction of a demonstration facility for the mass production of GaN single-crystal substrates. We will conduct demonstration experiments to mass produce 4-inch GaN single-crystal substrates from May 2021 and start market supply early FY 2022.

Features of GaN substrate manufactured with the new manufacturing process, "SCAAT™-LP"

★Low defects★
Crystal defects numbering as few as 1/100 to 1/1000 compared to existing products

★Low cost★
Cost reduction by mass production using large size autoclaves



GaN crystals grown at the demonstration facility

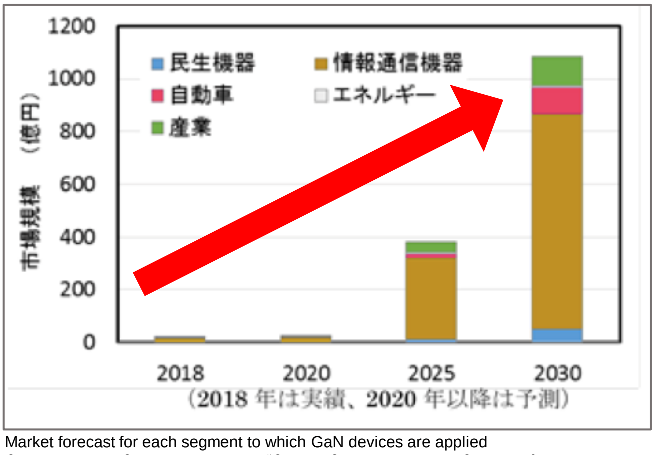
【4】The future of the GaN market and efforts of Mitsubishi Chemical

Future market

《 Market trend for GaN power devices》
Compared to power devices based on Si (silicon) or SiC (silicon carbide), GaN power devices are suitable for high-frequency and high-power applications. Due to this feature, GaN power devices are expected to be applied to a wide range of devices, such as switching devices, power ICs, high-frequency wireless devices, radars, and power transmission devices.

Above all, we will see market expansion in information and communications equipment due to its superiority in frequency performance. Demand for GaN power devices is expected to increase significantly in 2022 and beyond, with an estimated market size of 108.5 billion yen in 2030, which is 60 times larger than that in 2018.

Source: "Current Status and Future Outlook of the Next-generation Power Device & Power Electronics Related Equipment Market 2019" (Fuji Keizai, 2019)



Market forecast for each segment to which GaN devices are applied
Created by NEDO in 2019 based on "Current Status and Future Outlook of the Next-generation Power Device & Power Electronics Related Equipment Market 2019" (Fuji Keizai, 2019)

Future efforts of Mitsubishi Chemical

《Demonstration experiments for the mass production of GaN substrates toward the future》
At the just-completed large-scale facility, we will conduct demonstration experiments using "SCAAT™-LP" in order to materialize mass production of 4-inch GaN substrates. Based on these experiments, we will establish a stable supply system of GaN substrates and develop 6-inch substrates that can be applied to power devices for which demand has been increasing in recent years.
We aim to ship samples in 2022 and start market supply early in FY 2023 and beyond. Forecasting application to data centers and growing demand for the high-speed 5G communication standard, we are planning to expand the business to a scale of several billion yen in FY 2030.

GaN substrates are expected to have a wide range of uses as power semiconductors for various devices, such as optical devices, power devices, and high-frequency devices.
We are dedicated to contributing to a minimum energy society with enhanced fuel efficiency and power generation efficiency by supplying high-quality GaN substrates regarded as an essential material to support future society.

【Reference】History of GaN

《Research on LEDs》
GaN was originally investigated as a material for blue LEDs, components of semiconductor lasers for next-generation DVDs. High-brightness blue LEDs, green LEDs, and semiconductor lasers for Blu-ray Discs to which GaN is applied have been developed and commercialized.
In the beginning, growing a single-crystal GaN was challenging. It wasn't until 1986 that scientists developed the method to create single-crystal GaN. Following this advancement, Dr. Isamu Akasaki, Dr. Hiroshi Amano, and Dr. Shuji Nakamura shared the Nobel Prize in Physics in 2014 for the development of blue LEDs, which led to increased attention on GaN.

《Research on radio wave devices》
Following the development of LEDs, research and development of semiconductor devices for radio waves began, starting with the study of the physical properties of GaN. The growth of high-frequency transistors for mobile phone base stations, satellites, radars , and other systems progressed. Research began around the year 2000, and competition in development became active around 2 005.

《Toward the era of application to power devices and mass production》
To apply GaN to power devices for power conversion, large-sized GaN single crystals with low defects are necessary, rather than GaN single crystals for LEDs. The technology to manufacture high-quality GaN single crystals was highly challenging, and, in term s of manufacturing cost, considerable time and effort were needed for the practical application of GaN.
Mitsubishi Chemical succeeded in an experiment to mass produce high-quality GaN substrates developed jointly with JSW. We ai m to start market supply in FY 2022.

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Note: Images for illustration purposes are included in this newsletter.