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AIR WATER

News Release

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Air Water Inc.

Development of new GaN (gallium nitride) layered structure for manufacturing high-performance high-frequency transistors at low cost

Establishing technology contributing to the spread of 5th-generation mobile communications systems

The Air Water Group is promoting a "New Functional Materials Development Project" aimed at creating new value through close collaboration that it has underscored with a "realignment and integration" strategy for pooling technologies, products and ideas from both inside and outside of the Group. Under this project, the Air Water Group position electronics, the environment and renewable energy as strategic markets and understand that success in the electronics market will hinge on developing and supplying electronic materials for 5th-generation mobile communications systems (5G).

From the extensive research in this project, Air Water Inc. has successfully developed a new GaN layered structure as a substrate material for manufacturing and high-performance high-frequency transistors at low cost. By commercializing this technology Air Water Inc. has developed, wireless communications will be faster and less expensive than ever before, as it will accelerate the spread of 5G networks. At the same time, the new technology will greatly contribute to the improvement in cost performance of 5G services.

Because its physical properties enable radio signals to be amplified over a wide range of the frequency spectrum, GaN is attracting attention as a raw material for high-frequency transistors, with GaN high-frequency transistors being currently developed and commercialized around the world for the widespread use of 5G communication systems. Nevertheless, various problems that need to be addressed prior to any future widespread use—such as high costs, low manufacturing yields, and limits to transistor performance capabilities in regards to the "semi-insulating SiC substrates" that are generally used as ground substrates for GaN high-frequency transistors and the "high-resistance floating-zone Si (FZ-Si) substrates" for which commercialization efforts are being made—have emerged.

Faced with these circumstances, Air Water Inc. has developed a new GaN-layered structure (hereafter referred to as "this structure") with a thick GaN layer grown on a "SiC on Si substrate" using proprietary technology, unparalleled anywhere in the world. This has enabled Air Water Inc. to successfully solve the problems mentioned above.

The results of this development work have been published in the October 2020 issue of IEEE Electron Device Letters, a scientific magazine published by the Institute of Electrical and Electronics Engineers.

Before the end of fiscal 2020, Air Water Inc. will start pilot production of "SiC on Si ground substrates for high-frequency applications", which will serve as ground substrates for growing this structure, as well as "GaN on SiC on Si substrates for high-frequency applications" for which it will be engaged in manufacturing processes up to the growth of this structure.

Note: GaN stands for gallium nitride, SiC for silicon carbide, and Si for silicon.

1. **Overview of GaN high-frequency transistor**

Commercial services based on “5G”, which enable dramatically faster communications than earlier communication systems, have started worldwide, spurring future growth expectations in supporting markets for hardware such as base stations. What holds an important key to 5G data transmission and reception is the high-frequency transistor, an electronic component that is responsible for transforming or amplifying high-frequency radio signals that carry visual images and sound in the form of digital information. GaN has saturated electron drift velocity of 2.1 to 2.7 times greater and a dielectric breakdown electric field of 7.5 to 10 times greater than conventional substrate materials Si or GaAs. Physical properties on this level embody performance capabilities of a higher dimension that serve 5G/millimeter wave communications used on higher frequency bands. For this reason, GaN high-frequency transistors are expected to become widespread in the future.

Note: GaAs stands for gallium arsenide.

2. **Background to development**

To prevent energy loss during operation, high-frequency transistors require their lower sections to be composed of a crystal material of high insulating performance. GaN high-frequency transistors built on a ground substrate of “semi-insulating SiC” have been commercialized from this point of view. However, their high cost and limited diameter (100 mm maximum) restrict their proliferation to only high-end applications such as base stations.

To address this situation, efforts are being made to develop and commercialize GaN high-frequency transistors built on a ground substrate formed by a “high-resistance floating-zone Si substrate,” which is an easy-to-obtain and inexpensive substrate of 150 mm in diameter. There are, however, problems such as a low manufacturing yield resulting from the substrates being readily susceptible to plastic deformation and large energy loss resulting from the deterioration of insulating performance due to the transistors heating up during operation.

Air Water Inc. developed “SiC on Si substrates” of a large diameter (up to 200 mm) for use as ground substrates for growing GaN using proprietary technology in 2012, and it also succeeded in developing GaN substrates for power transistor use on a commercial level, using the world’s first “SiC on Si substrates,” in April this year. This is the first time it has successfully developed this structure by putting these technologies which have been fostered to full use.

3. **Features of the GaN-layered structure**

(1) Overview of the GaN-layered structure

[1] The Si substrates used are “Czochralski Si (CZ-Si) substrates.” Being widely proliferated, they are inexpensive and used in a large amount, can be made in large diameters, and resist plastic deformation under strong external force.

[2] Proprietary film formation technology by Air Water Inc. grows high-quality SiC film on a Si substrate.

[3] A simple nitride buffer layer, an adequately thick (up to 6 μm) high-resistance GaN layer, and a transistor layer (AlGaN barrier layer) are grown on a SiC film, in that order.

Note: AlGaN stands for aluminum gallium nitride.

(2) Superiority of the GaN-layered structure

[1] Using “Czochralski Si substrates” lowers the cost of the substrates. Moreover, the plastic deformation originating in the difference in thermal expansion between the Si substrate and the GaN layer and SiC film can be stably controlled, which minimizes the lower yield associated with the deformation.

[2] An adequately thick high-resistance GaN layer can be grown on a SiC film. This thick GaN layer enables a transistor layer of less energy dissipation to be formed. As a side note, technology for growing a thick GaN layer directly on a Si substrate without a SiC film medium has not yet been established.

4. Features of GaN high-frequency transistors using the GaN-layered structure

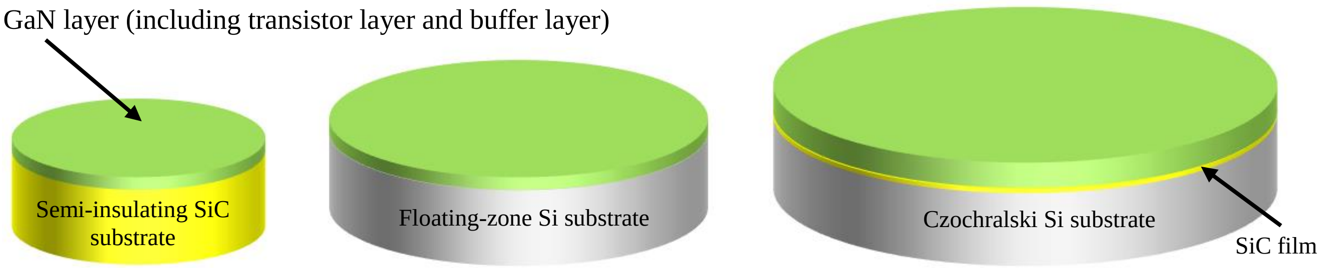
[1] The high-resistance GaN layer maintains the same high level of resistivity (insulating performance) at high temperature (100 to 200°C) as normal temperature (25°C). For this reason, even if the transistor generates heat, energy loss does not increase.

[2] When a GaN layer is grown on a SiC film, the physical property of electron transition—called "mobility"—improves by approximately 20% in comparison with that of a "high-resistance floating-zone Si substrate," which also improves high-frequency performance.

[3] Because a SiC film is highly heat-conductive, the heat dissipating performance of a transistor should improve in principle. A demonstration test of this property is currently conducted.

[Structural comparison between the GaN-layered structure (GaN on SiC on Czochralski Si substrate) and conventional structures]

Conventional structure (GaN on semi-insulating SiC)	Conventional structure (GaN on floating-zone Si)	This structure (GaN on SiC on Czochralski Si)



[Table of comparison of performance capabilities between the GaN-layered structure (GaN on SiC on Czochralski Si substrate) and conventional structures]

High-frequency-GaN structure	Conventional structure (GaN on semi-insulating SiC)	Conventional structure (GaN on floating-zone Si)	This structure (GaN on SiC on Czochralski-Si)
GaN ground substrate	Semi-insulating SiC substrate	Floating-zone Si substrate	SiC on Czochralski-Si substrate
Cost of GaN ground substrate	✖	✔	△
Size of GaN ground substrate (diameter)	100 mm or less	150 mm or less	200 mm or less
Deformation of substrate after GaN growth	✔	✖	✔
Time required for GaN-film formation (film thickness)	✔ (1–2 μm)	✔ (1–2 μm)	△ (6 μm or less)
High-frequency transistor performance capabilities (at normal temperature)	✔	✔	✔
High-frequency transistor performance capabilities (at high temperature)	✔	✖	✔

Note: "△" stands for medium or intermediate.

The performance capabilities (at normal and high temperatures) of high-frequency transistors based on this structure have been demonstrated by a study conducted jointly with Associate Professor Akio Wakejima of the Nagoya Institute of Technology at Aichi, Japan.

—— [For inquiries about this release]——

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