# p-type Be-Doped AlN Films and Layered Films (#8810, 8666, 8786)

## Leveraging the advantages of AIN for ultra-wide bandgap semiconductors as transistors

This technology enables the production and use of p-type beryllium-doped AlN (AlN:Be) films as key components in ultra-wide bandgap semiconductors for the first time. These films can be used in high-power and high-temperature diodes and transistors. Georgia Tech researchers use a unique metal modulated epitaxy (MME) method, a technique performed with widely available, commercial molecular beam epitaxy reactors, to grow the films, overcoming the safety concerns of beryllium-doping using traditional MOCVD methods and enabling break through substantial p-type conduction not observed prior to this work. Two technologies extend this ability to create materials for junction barrier Schottky (JBS) diodes and Schottky barrier diodes (SBDs).

In the first extension of the innovation, the MME method is used to construct a JBS diode, which is an advanced structure to achieve high breakdown voltage with good forward voltage characteristics. Using MME, p-ALN:Be/i-GaN:Be/n-GaN:Ge structures were grown. The lattice mismatch between AlN and GaN results in cracked films. The degree of cracking can be exploited to create a new form of JBS diode that incorporates a p-type AlN layer grown beyond the crack formation thickness on top of the unintentionally doped (UID) layer. Because the cracks extend down to the UID layer, Schottky metals deposited on the surface will cover the p-type AlN and contact the UID layer forming cyclic Schottky diodes in the crack gaps separated by p-AlN/ UID/ n-type gallium nitride (GaN) diodes adjacent to the Schottky diodes. This is a simpler fabrication method and results in higher breakdown performance.

In the second extension of the innovation, a high breakdown, high-power SBD was achieved using the MME method to grow AlN:Be in layers along with additional levels of doping of AIN. This new Schottky diode fulfills the potential of Be-doped AIN for the creation of ultra-wide bandgap (UWBG) semiconductors for high-power, high-frequency devices capable of operation in extreme heat and radiation environments.

See also:
#8789, “Thin Current Spreading Layers Improve Breakdown Performance”
#8790, “Cascaded Nickel Hard Mask”

### Benefits/Advantages

- **Enabling**: Leverages MME method to provide the first access to p-type AlN:Be films, a superior ultra-wide bandgap semiconductor material good for high-power, high-temperature diodes and transistors
- **Ease of fabrication**: Avoids costly and complicated methods unfavorable for beryllium doping
- **Improved breakdown performance**: Achieves high reverse breakdown voltage—a significant advantage over WBG materials such as silicon carbide (SiC) and GaN
- **Higher efficiency**: Leverages the critical electric field of doped AIN, which is three times that of GaN, five times SiC, and 50 times silicon (Si)
- **Customizable**: Accommodates various dopants (Be, C, or p-type) and flexible selection of anode and cathode metals, thereby enabling control of the forward conduction and reverse breakdown voltage for a range of high-power AlN Schottky diode applications (SBD)

## Potential Commercial Applications

- Ultra-wide bandgap semiconductors
- High-power, high-voltage, high-frequency devices capable of operation in extreme heat and radiation environments

## Background/Context for This Invention

The core Georgia Tech innovation leverages the advantages of AIN for high-power and high-temperature devices compared with other wide bandgap (WBG) materials such as silicon carbide and gallium nitride. These latter materials are reaching their theoretical limits for high-power and high-temperature applications and cannot meet the further increasing demand of key performance parameters such as high reverse breakdown voltage, high switching speed, and low forward conduction loss.  AIN is superior in terms of energy bandgap, saturation velocity, critical electrical field, thermal conductivity, and Johnson’s Figure of Merit (JFOM). AIN:Be has substantial p-type conductivity with hole concentrations up to $3.1\times10^{18}$ $cm^{-3}$.

Because the limitation in the development of high-performance AIN-based devices was previously challenged in AIN doping, this new MME method enables the creation of p-type AlN:Be films as key components in ultra-wide bandgap (UWBG) semiconductors and semiconductor devices. Extension of this technology uses layers of these films with other WBG materials to access JBS and SBD diodes for use in UWBG applications as high-power, high-voltage, high-frequency devices capable of operation in extreme heat and radiation environments. This experimental achievement opens new doors for AIN-based novel deep ultraviolet, high-power, and high-frequency devices.

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## Patent/IP Information

**U.S. Application Filed**

**Publications**

*Georgia Tech’s New Aluminum Nitride-based Semiconductor is Posed to Transform the Industry*, Georgia Tech School of Electrical and Computer Engineering News, August 4, 2022

*Realization of homojunction PN AlN diodes*, Journal of Applied Physics, May 2, 2022

**For more information about this technology, please visit:**
https://licensing.research.gatech.edu/technology/p-type-be-doped-aln-films-and-layered-films