

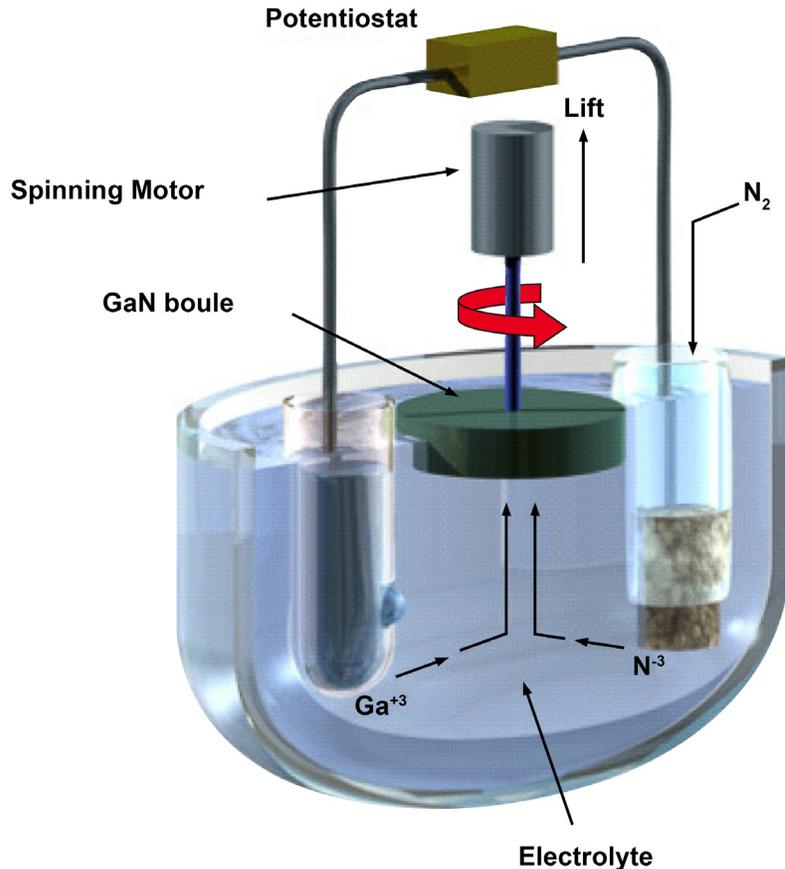
## High-Quality, Low-Cost Bulk Gallium Nitride Substrates

Electrochemical Solution Growth: A Scalable Semiconductor Manufacturing Process

The ever-growing demand in the past decade for more energy efficient solid-state lighting and electrical power conversion is leading to a higher demand for wide bandgap semiconductor-based devices, such as gallium nitride (GaN), over traditional silicon (Si)-based devices. High cost and limited availability, however, have hindered the adoption of GaN substrates to date.

When utilizing GaN, current LED and power electronic device applications employ GaN epitaxially grown on top of non-GaN substrates. The lattice mismatch between the epitaxial GaN layer and the non-native substrate surface leads to considerable stress and high defect densities, ultimately compromising device yield and performance. While bulk growth of GaN can combat these issues, current growth methods for bulk GaN have not fostered widespread adoption to date due to limited scalability, low material quality, high operating temperatures and pressures, and slow growth rates. A fundamentally different manufacturing route for bulk growth of GaN not driven by thermal processes is needed to provide an adequate value proposition such as a desirable combination of growth rate, scalability to larger wafer sizes, electronic-grade material quality, and manufacturing costs.

Electrochemical Solution Growth (ESG) is a novel process for achieving GaN bulk growth without the limitations of traditional crystal growth methods. This process, which operates at a low temperature and at atmospheric pressure, promises to be scalable and low cost while providing a high growth rate capable of producing large-area, high-quality GaN wafers.



Conceptual diagram of the ESG reactor. Photo courtesy of Sandia National Laboratories

This project will help develop ESG into a viable GaN bulk growth process that is well suited for scalability to large-area wafer manufacturing. Bulk GaN is important to bolstering U.S. competitiveness in high-efficiency power electronics and solid-state lighting.

### Benefits for Our Industry and Our Nation

Scaling the ESG growth method to large area GaN crystals could reduce the production cost of bulk GaN wafers by up to a factor of 10. These substrates could allow U.S. manufacturers to cultivate emerging clean energy technology markets in solid-state lighting and power electronics, including applications in energy-efficient motors used in large-scale industrial processes and appliances, electric vehicles, and renewable power generation and integration onto the electric grid. Better-performing and lower-cost GaN substrates could accelerate the adoption of energy-efficient GaN-based lighting and high-voltage power switching devices, ignite new market applications, and reduce U.S. power consumption.

### Applications in Our Nation's Industry

ESG is well suited for semiconductor manufacturing in existing six to eight inch (150–200 millimeter) silicon (Si) wafer fabrication plants. GaN substrates could be utilized in applications such as optoelectronic devices for lasers, solid-state lighting, high-voltage power electronics, high-performance backlights for displays, ultraviolet light-emitting diodes (LEDs), ultraviolet detectors, high power switching devices, and quantum cascade lasers.

## Project Description

This project will develop ESG into a viable bulk growth process for GaN that is more scalable to large-area wafer manufacturing and able to produce cost-effective, high-quality bulk GaN substrates compared to the current state of the art. Further refinement will result in the development of GaN that is useable in the production of solid-state lighting, high-brightness LEDs, and laser diodes. The first phase of this project will work to refine the laboratory-scale processes, develop a better understanding of molten salt electrolyte reaction kinetics, and develop crystal growth enabling computational flow models. The goal of the second phase is to establish a pilot-scale electrochemical reactor capable of growing wafers six inches and larger.

### Barriers

- Existing heteroepitaxial growth techniques of large area GaN on sapphire, silicon carbide, or Si substrates result in high defect densities (i.e. wafer bowing and GaN film cracking) and poor device yield and performance (i.e. higher leakage currents and lower breakdown voltages).
- Traditional semiconductor bulk crystal growth techniques are not transferrable to GaN due to its unusual thermodynamic properties.
- Homoepitaxial approaches (i.e. GaN films grown on GaN substrates) are not pursuable due to lack of native GaN substrates.

### Pathways

All of the individual components of this novel process have been previously demonstrated at the laboratory scale. This project will advance ESG through two phases. The first phase involves developing the rotating seed growth process including optimizing and configuring the electrolyte chemistry and electrode type and configuration for enhanced ion production, conducting extensive modeling to understand ion mobility, and developing flow models to optimize ion transport to the growth surface of the GaN seed. The second stage involves scaling up to a larger reactor and producing high-quality crystal for extensive materials characterization and prototype device development.

### Milestones

This project began in September 2012.

- Reproducible films of GaN over large areas using ESG achieved with dislocation densities matching the seed template (2013).

- GaN reproducibly produced by ESG on two inch (50mm) diameter substrates and used to epitaxially grow GaN films to compare with epitaxial GaN grown on other substrates (2014).
- Functional ESG GaN-based power and optical devices from two inch (50mm) diameter substrates fabricated and tested. Commercial prototype ESG reactor manufactured and tested for growth diameter scalability beyond four inch (100 mm) (2015).

## Commercialization

MEMC is a world leader in semiconductor crystal growth and wafer processing technologies and can capably address scale-up of the ESG process and commercialization of the bulk GaN products. MEMC technology transfer and marketing staff are coordinating with the research team to ensure that a commercially viable solution is presented. MEMC intends to provide potential customers with the confidence needed to pass the rigorous qualification processes and deliver the promised quality and reliability upon scale-up.

## Project Partners

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