

Enabling Advances in High Efficiency Lighting and Power Electronics

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Company Opportunity

The high efficiency LED and high power transistor markets have a critical need for high quality, large area, economical bulk gallium nitride (GaN) substrates to meet device performance requirements. Sandia National Laboratories is developing a disruptive new crystal growth technology, called Electrochemical Solution Growth (ESG), with high potential for producing such substrates, which currently do not exist and are required for GaN devices to reach their full market potential. Substrates are the bulk wafer material on which opto/electronic thin film devices are fabricated; substrates dictate the crystalline quality and thus the performance of those devices. The technology is early-stage, patented, and is available for licensing.

Markets: All these devices have a critical need for GaN-based substrates to improve market acceptance

LEDs:

- General Illumination
- Backlighting
- Displays
- Automotive



Samsung 42" LED TV

Lasers (Ultraviolet through Green Wavelengths):

- Homeland Security and Military
- Illumination
- Data Storage
- Vehicle Electrification—future market
- Down-hole Drilling Diagnostics – future market
- Utility Grid Modernization (incorporation of renewables using energy storage)—future market

Fully Adopted LED Market = \$80-120B*
Substrates = 8% of LED cost = \$6B market

*Source: CanaccordAdams, 2009

AND-- Many New Markets Will Be Enabled

Market Need/Statement of Problem

Historically, new semiconductor materials have gained wider market acceptance as the quality, area, and cost of the native substrate have improved. GaN has unusual materials characteristics that enable it to perform well enough to penetrate specialized niche markets despite the immaturity of its native bulk substrate technology. However, like its III-V predecessors, its true potential will be realized only when an economical, high quality, large area native substrate becomes readily available.

Attribute	Market Pull (Requirement)	Current Status
Diameter (inches)	4" to 6"	2" or less
Quality (dislocations/cm ²)	10 ³ to 10 ⁵	10 ⁶ – 10 ⁹
Orientation	Selectable: Polar, Non-polar, Semi-polar	Polar
Cost	\$200-\$400 for 4" diameter wafer	\$2000/cm ²
Availability	High volume, on-demand	Research quantities

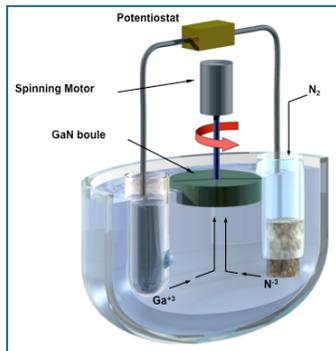
Unfortunately, GaN is an unusually challenging material to grow in bulk by traditional crystal growth techniques because its natural melting/freezing conditions are very similar to those required to make large volume diamonds. Most alternative approaches are not scalable or high throughput; others are limited by quality. All are expensive. A new technique for bulk crystal growth is required to solve these problems.

Our Unique Technology Solution—Electrochemical Solution Growth (ESG)

Billions of dollars have been invested worldwide over the past two decades to engineer work-arounds for the defects produced by the use of non-GaN substrates. Billions have also been spent trying to apply traditional crystal growth techniques to grow this challenging material; still, it is utterly absent from the commercial space. A substrate “vacuum” exists in the marketplace. As introduced on the opposite page, ESG approaches bulk GaN crystal growth from a drastically fresh perspective, which is what is required to address the root of the crystal growth *and* device performance barriers. This approach represents a revolution in crystal growth technology—ESG is a true solution to the problem, not just another clever engineering trick or compromise. For further information, please contact Dr. Karen Waldrip.

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Electrochemical Solution Growth (ESG) – The Technology



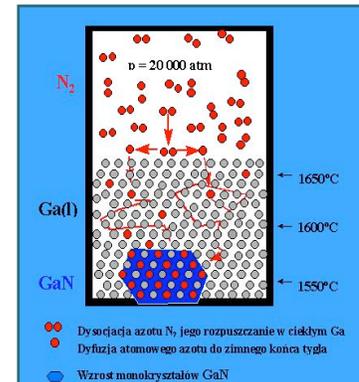
The Electrochemical Solution Growth method is a radically different approach to bulk GaN crystal growth. It attacks the fundamental limiting factor common to all other bulk GaN growth techniques in a unique way, by electrochemically generating a reactive form of nitrogen *at atmospheric pressure* in a solution. One gallium ion is generated for every nitride ion—precisely the ratio needed for GaN growth. Borrowing well-developed concepts from Rotating Disk Reactor MOCVD technology, the ions are delivered to a rotating seed crystal surface via the fluid dynamics imposed by the rotating seed and/or susceptor. The ions then diffuse across a fluid boundary layer near the surface of the seed, where they react and deposit to form single crystal GaN. The nitride and gallium ionic precursors can be controlled reliably and precisely using common electrochemical techniques,

programmed through the potentiostat. Because the growth conditions remain steady state throughout the process, a single crystal boule may be pulled from the surface. The reactor design is fully laterally scalable, and the vertical direction can be grown as long as the supply of gallium and nitrogen gas allow. Solution growth techniques produce the highest quality material (10^2 dislocations/cm²), which will incite new markets due to the vastly improved performance and new capabilities of GaN-based devices. The growth rate is high for high throughput and low cost. Wafers may be sliced out of the boule from any direction to produce substrates of any desired orientation. *n*-, *p*-, and *i*-GaN are all possible, as may be InN. If successful, ESG is the only proposed technique that could meet all of industry's requirements.

Competing Technologies

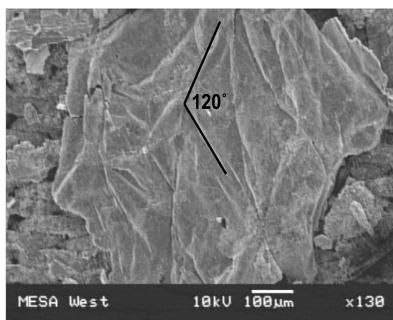
Probably a dozen approaches are being explored or developed for bulk GaN growth technology. Of these, the most mature and promising are:

- High Nitrogen Pressure Solution Growth (HNPSG) from Poland
 - Nitrogen gas dissolved into gallium metal at very high pressures and temperatures
 - Highest quality crystals—required by laser industry to meet its device reliability needs
 - 25 years of investment; not scalable, output volume is research quantities
- Ammonothermal process—toughest competitor for ESG
 - GaN dissolved in supercritical ammonia and re-precipitated
 - Sustained, heavy Japanese investment for 15+ years
 - Even when fully developed, limited by scalability and expense
- Fully-developed ESG will not suffer these limitations



HNPSG Technology

ESG Development Status



This unoptimized crystal measured 0.8 x 1.25mm

All of the concepts have been individually tested and confirmed:

- GaN grown in test tube at atmospheric pressure, demonstrating:
 - Viable chemistry and high growth rate (0.5 mm/hr)
 - Surprisingly good quality (band-edge photoluminescence at room temperature)
 - Large crystals possible (at the time, were 2nd largest in world)
 - N₂ reduction has been developed (2nd lab in world to report controlling this novel, important electrochemical reaction)
 - Fluid dynamics schemes viable
- Path Forward (6 month full time effort, go/no-go milestones):
- Demonstrate GaN growth at seed surface
 - Demonstrate autonucleation of high quality seed crystal