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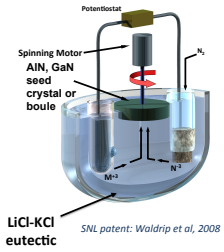
# Progress in the Development of Bulk Nitrides for High Power Electronics

## 1. Motivation

- Wide-bandgap semiconductors such and GaN have material properties that make them theoretically superior to Silicon for power electronics for energy storage systems
  - *Gallium nitride and aluminum nitride promise to reduce the size, complexity, and cost of power conversion systems*
  - *However, one of the main materials barriers to widespread adoption remains the absence of an affordable, high quality, large area lattice-matched substrate on which to grow high quality high power devices*
- ***Overall goal: Develop a growth technique capable of producing high quality, large area bulk nitrides that is economically viable***
- OE seed funding for GaN growth in previous years resulted in the 2012 award of the $4.6M Innovative Manufacturing Initiative with SunEdison and Georgia Tech Research Institute
  - 20% cost share from SunEdison (St. Peters, MO)
  - Partner with Qynergy Corporation
  - FY13 OE project focus is reactor development and application of ESG to chemistries for novel nitrides (AlN, FexNy) as opposed to GaN

## 2. Sandia's patented Electrochemical Solution Growth (ESG) Technique

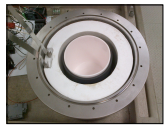



*SNL patent: Waldrip et al, 2008*

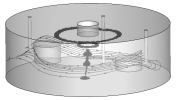
- Nitride compounds tend to decompose at temperatures far lower than their melting points → high temp, high pressure
- Traditional growth processes not economically viable
- ESG is a scalable, atmospheric pressure process based on the novel electrochemical reaction of nitrogen gas in a molten salt at ~450-500°C
- ***The unique ESG process leverages Sandia's molten salt electrochemistry expertise from thermal batteries***

## 3. FY13: Process Modeling, Hardware, Electrolyte Development

- Custom-built reactor developed
  - SunEdison developed next-gen reactor using ANSYS modeling
- Electrolyte purification techniques developed in FY12 scaled up
  - Acceptable initial purity
  - GaN successfully synthesized
  - Experiment throughput more than tripled
  - Electrolyte cost per experiment reduced from $2500 to $50
- ***Enables process scaling from 1cm² test coupons to 50 and 100mm diameter boules in FY14 and FY15***



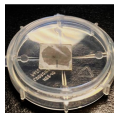
Next-gen Reactor Development

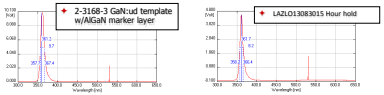


ANSYS Reactor Modeling

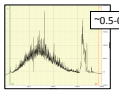
Molten Electrolyte
Pre-purification Post-purification

## 4. FY13: Seeded Growth Advances



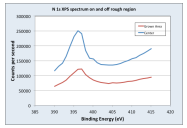



Photoluminescence spectra (a) pre-growth and (b) post-growth on the grown region




Alphastep profilometry on raised, grown region

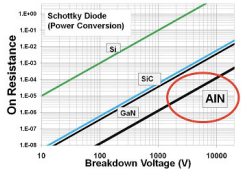
**XPS confirms Ga, N, Ni, O, Al, C on and off rough regions**



- ***NEW! Deposition occurring on the seed crystal, indicating that reactor fluid dynamics and hardware are properly functioning***
- XPS confirms presence of Ga, N in grown area, along with contaminants from reactor materials used to improve speed of development—but interfere with crystal growth
  ***(present reactor materials less expensive, have faster delivery times)***
- New choice of inert reactor materials now required to advance growth process and obtain high quality crystal growth (FY14 work)

## 5. FY13: Aluminum Nitride Electrochemistry Development

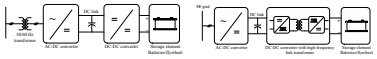
- GaN hardware development under IMI is directly applicable to large-area AlN substrate development
- AlN power electronics theoretically outperform SiC by 6X
- Crystalline defects substantially lower the Critical Field and Breakdown Voltage– decrease performance and efficiency of high power electronics
- Bulk AlN is best substrate to realize high efficiency AlN power devices
- Bulk AlN limited to 1" diameter for several years by traditional crystal growth process limitations
- Large area substrates required to lower cost and improve yield
- New effort directed towards applying the scalable ESG approach to AlN

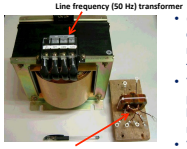



*From Hexatech.com*

***Aluminum electrochemistry has been demonstrated to be viable in the ESG system***
***All GaN hardware and electrolyte developments are applicable to large area, high quality bulk AlN development***

## 6. FY13: ESG for Novel High Frequency Transformers






S. Krishnamurthy, Half Bridge AC-AC Electronic Transformer, 6641, 1414 (2012).

- Goal: Based on needs determined by systems engineering models, design and synthesize a new magnetic material for the core in a high frequency transformer DC-DC Link
- Transition metal nitrides have desirable properties but are impossible to synthesize in large quantities by traditional processing methods
- The unique capabilities of ESG likely make development of new magnetic nitrides possible

FY13: Contract let to ASU for systems modeling and determining materials performance parameter requirements

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U.S. DEPARTMENT OF ENERGY

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