Pulsed laser deposition and characterization of TiN/AlN/SiC heterostructures

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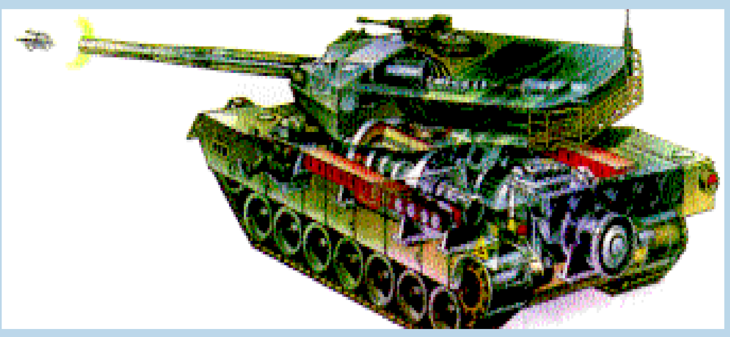
Abstract: Pulsed-laser deposited (PLD) AlN is being investigated as a promising dielectric material for use in SiC high-temperature motor-control electronics. Under this project PLD AlN films were grown, physically characterized, and incorporated into capacitor test structures. Software algorithms were also developed and used for high-temperature (25° to 450° C) electrical characterization of the AlN capacitors.

Introduction: The results of recent Army studies show overwhelming advantages of electric drives over mechanical propulsion systems. But many of these advantages are off-set by having to cool the electronics to 125° C which is a requirement for current state-of-the-art (silicon based) electronics. Since the only available vehicle coolant is 150° C engine oil, an additional cooling system would be required at significant volume and weight penalty. Hence the emerging SiC semiconductor has been targeted as an enabling technology for these future electric drive applications. But at this time there are no high-temperature insulator materials that have been qualified to operate reliably at temperatures of 300° C and under fields of 2 MV/cm.

SiC Targeted as Enabling Technology for the Force XXI Army

High Temp / High Power
Low Specific Resistance
→
200° C Coolant
Smaller / More Efficient Power Modules

Adaptive Suspensions
Track Tension Adjustment
Electronic Clutch Control
On-Engine Monitor / Control
Power Steering
Brake Systems
Electric Drive Systems



Challenges:

- At 1600°C, Si from SiC preferentially evaporates from the surface
- Necessary to encapsulate SiC

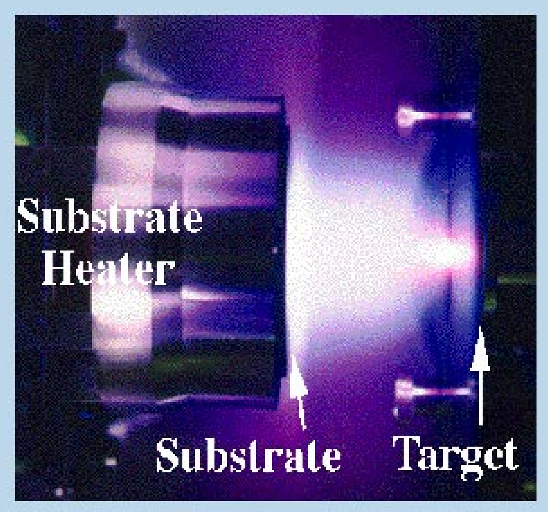
Solution:

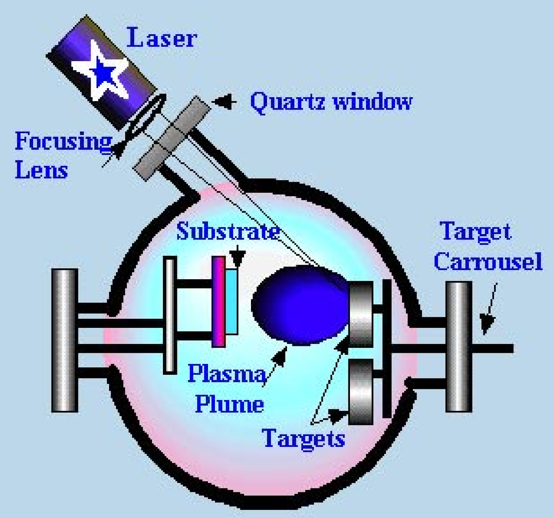
AlN: very stable at high temperatures, no reaction with SiC
Good lattice match between SiC and AlN
AlN is an insulator for Metal-Insulator-Semiconductor (MIS) devices

Growth technique: Pulsed Laser Deposition

Parameters tested and optimized

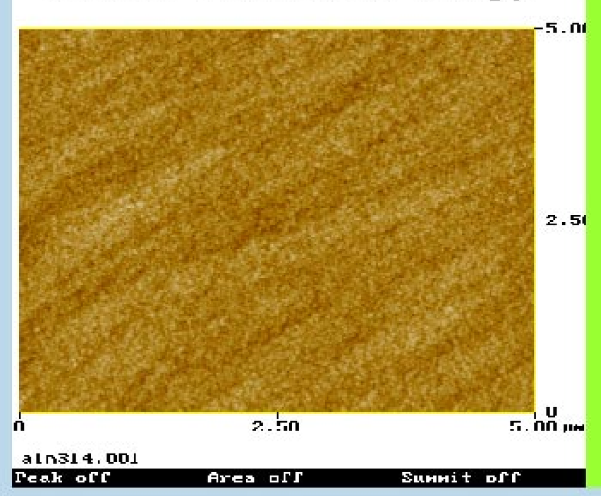
Ablation of AlN target (~2J/cm^2)	Target-to-substrate distance: 10 cm
NH_3/N_2 background pressure: 10^{-5} Torr	Focal lens-to-target distance: 30.5 cm
Substrate temperature: 1000°C	Pulse Repetition rate: 10 Hz



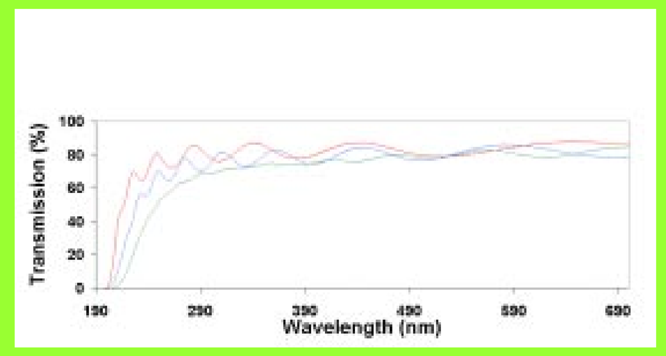


Physical Characterization

Atomic Force Microscopy

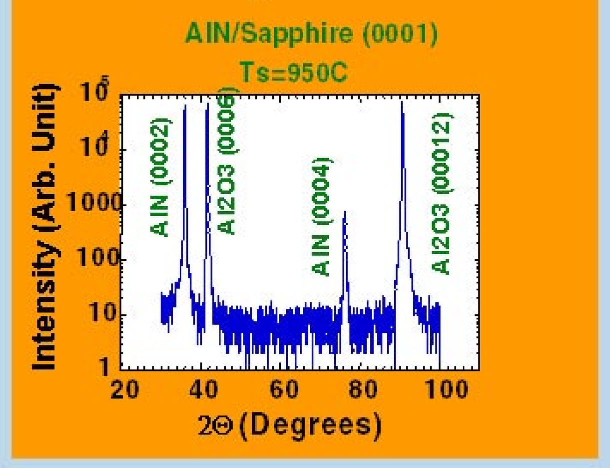


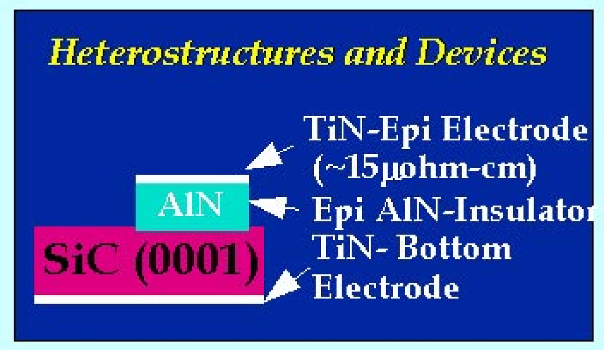
Ultra Violet-Visible Spectroscopy



- Surface roughness: 5 Å
- Energy Band Gap: 6.2 eV
- Highly c-axis oriented
- Epitaxial thin films

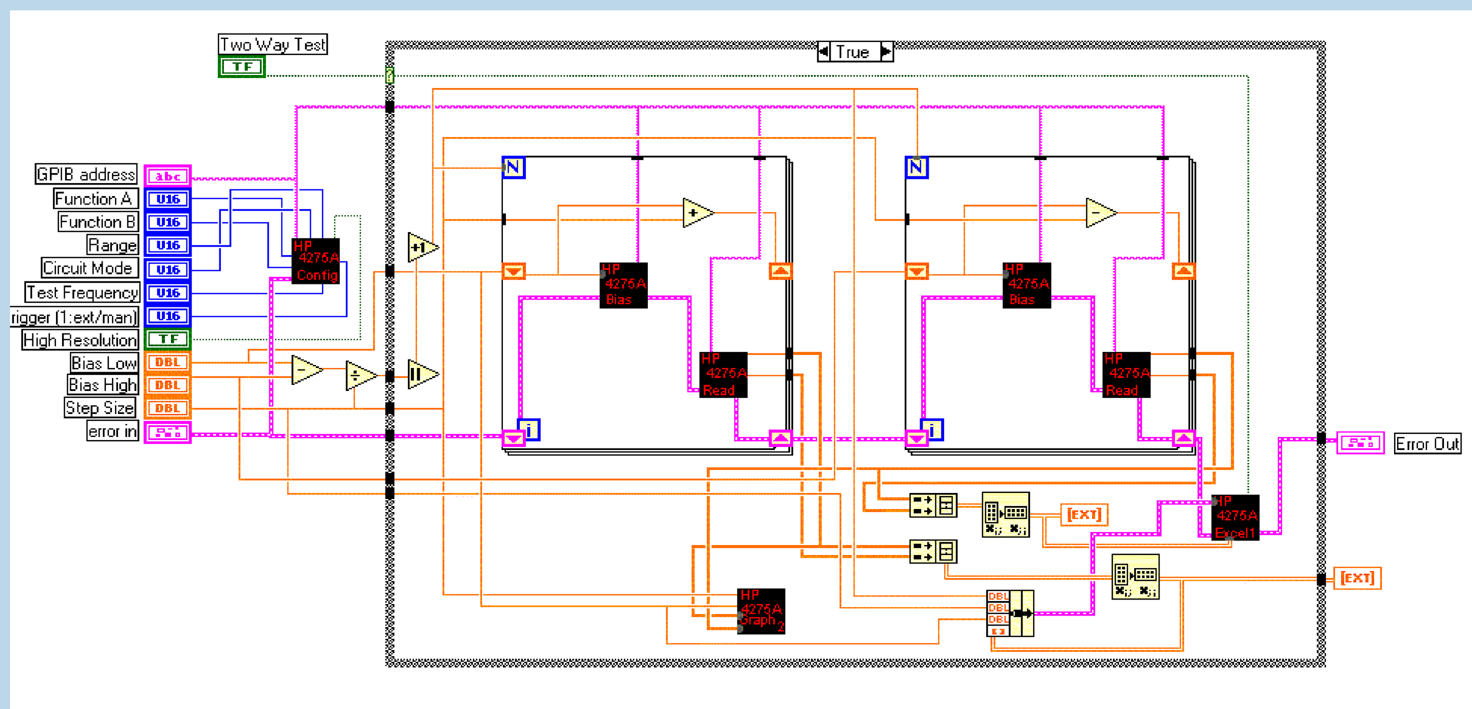
X-Ray Diffraction



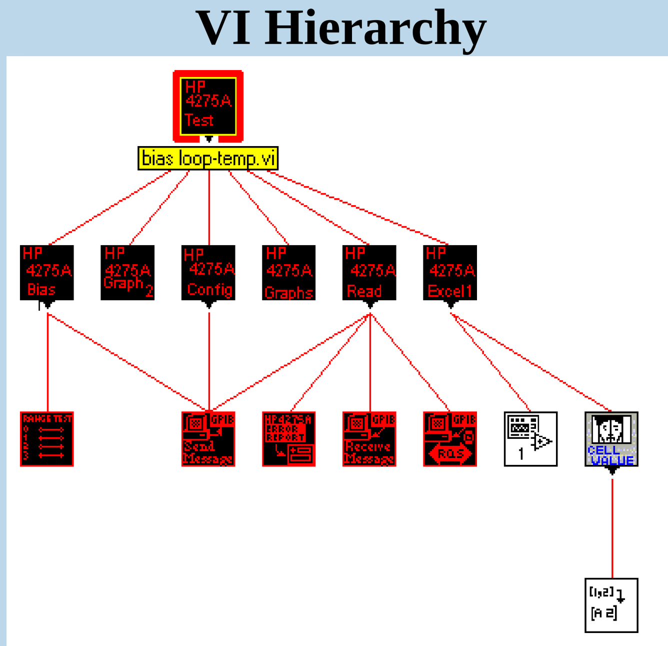


Software Development

Sample Virtual Instrument Diagram



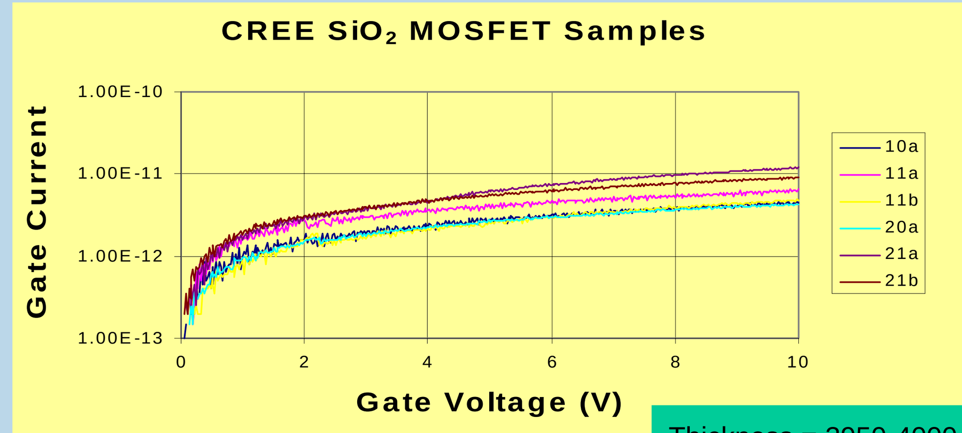
VI Hierarchy



Challenges / Achievements

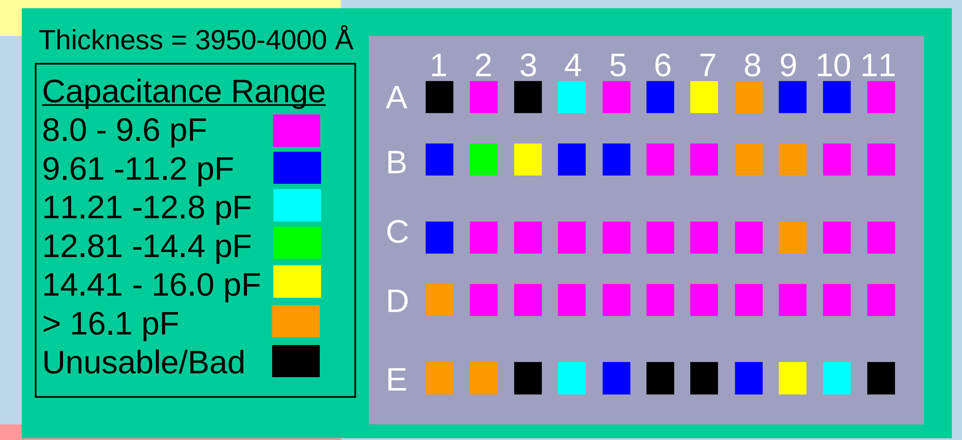
- Procuring Equipment
- Developing Software Interface in both LabVIEW and Interactive Characterization Software
  - HP4145B Parameter Analyzer
  - HP 4275A LCR Meter
  - Tektronix 371A Curve Tracer
  - Keithley 706 Matrix Switch
- Implementing Automated Tasks
- Analyzing Data

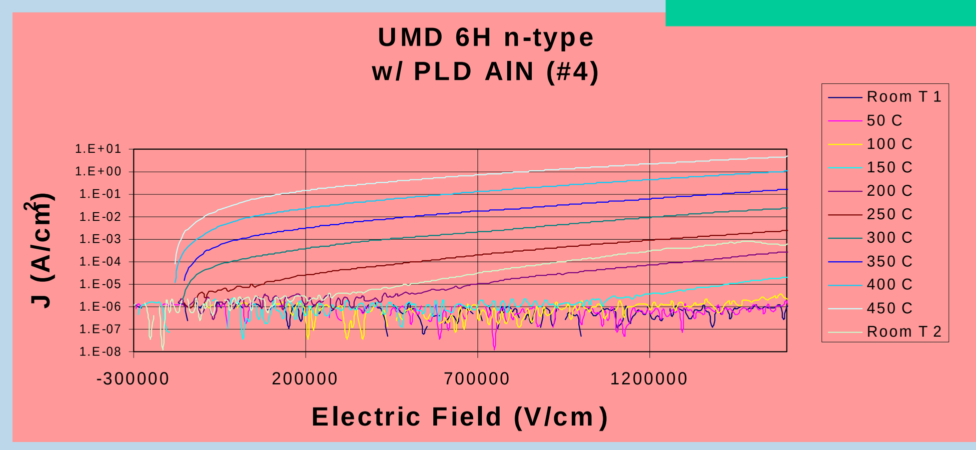
Electrical Characterization



Current versus voltage measurements for several SiO_2 MOSFET gates on a SiC test chip from CREE industry. Collected using HP4145B and Interactive Characterization Software.

Color coded diagram of the capacitance values for AlN/SiC sample chip under varying bias voltage at room temperature. Collected using HP4275B and LabVIEW .





Current density versus electric field for TiN/AlN/SiC capacitor at varying temperatures. Collected using HP4145B and Interactive Characterization Software.

Summary:

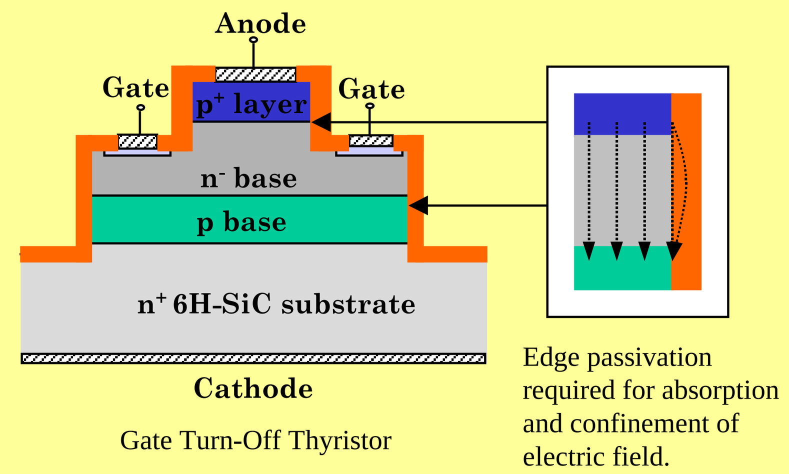
Through our work in collaboration with the Army Research Lab and the University of Maryland we have achieved the following goals:

- Understanding of wide-band-gap semiconductor materials
- Thin film technology: PLD growth of AlN thin films
- Structural and optical characterization via various methods
- Device fabrication
- Electrical characterization using various methods
- Software algorithms and LabVIEW development

Further research must be done to fully evaluate the effectiveness of AlN as both a viable dielectric and passivation layer in more complex power devices such as the GTO thyristor shown below.

Leakage Currents in high quality pulsed-laser deposited aluminum nitride on 6H silicon carbide from 25 to 450 °C
C.J. Scozzie, A.J. Lelis, F.B. McLean, R.D. Vispute, S.Choopun, A. Patel, R.P. Sharma, and T. Venkatesan, Accepted in Journal of Applied Physics (1999).

Pulsed laser deposited AlN films for high-temperature SiC MIS devices,
R. D. Vispute, A. Patel, Kathleen Baynes, Bin Ming, R. P. Sharma, and T. Venkatesan, C. J. Scozzie, A. Lelis, T. Zheleva, and K. A. Jones, Abstract submitted to MRS Fall Meeting, Boston, 1999.



Gate Turn-Off Thyristor

Edge passivation required for absorption and confinement of electric field.

Gauss' Law requires:

$$E_i = \frac{E_s \varepsilon_s}{\varepsilon_i}$$

Material	ε	$E_{Critical}$ (MV/cm) @ 25 °C	$E_{Operating}$ (MV/cm) @ 300 °C	εE_{op} (MV/cm) @ 300 °C
SiC	10	3	3	30
SiO_2	3.9	11	2	7.8
PLD AlN	8.5	10-12	>3	>25