GaN Schottky Diodes and Thyristors-The Ultimate in Power Switching Devices

T. C. McGill-Caltech-MS128-95-Pasadena, CA 91125
Email tcm@ssdp.caltech.edu

T. F. Kuech-Dept. ChE -UW-Madison, WI
Email kuech@engr.wisc.edu

J. M. Redwing- MS & E- PSU: University Park, Pa 16802
Email: jmr31@email.psu.edu

P. Chow and J. Van Hove-SVTA, Eden Prairie, MN
Email: chow@svta.com, jvanhove@svta.com

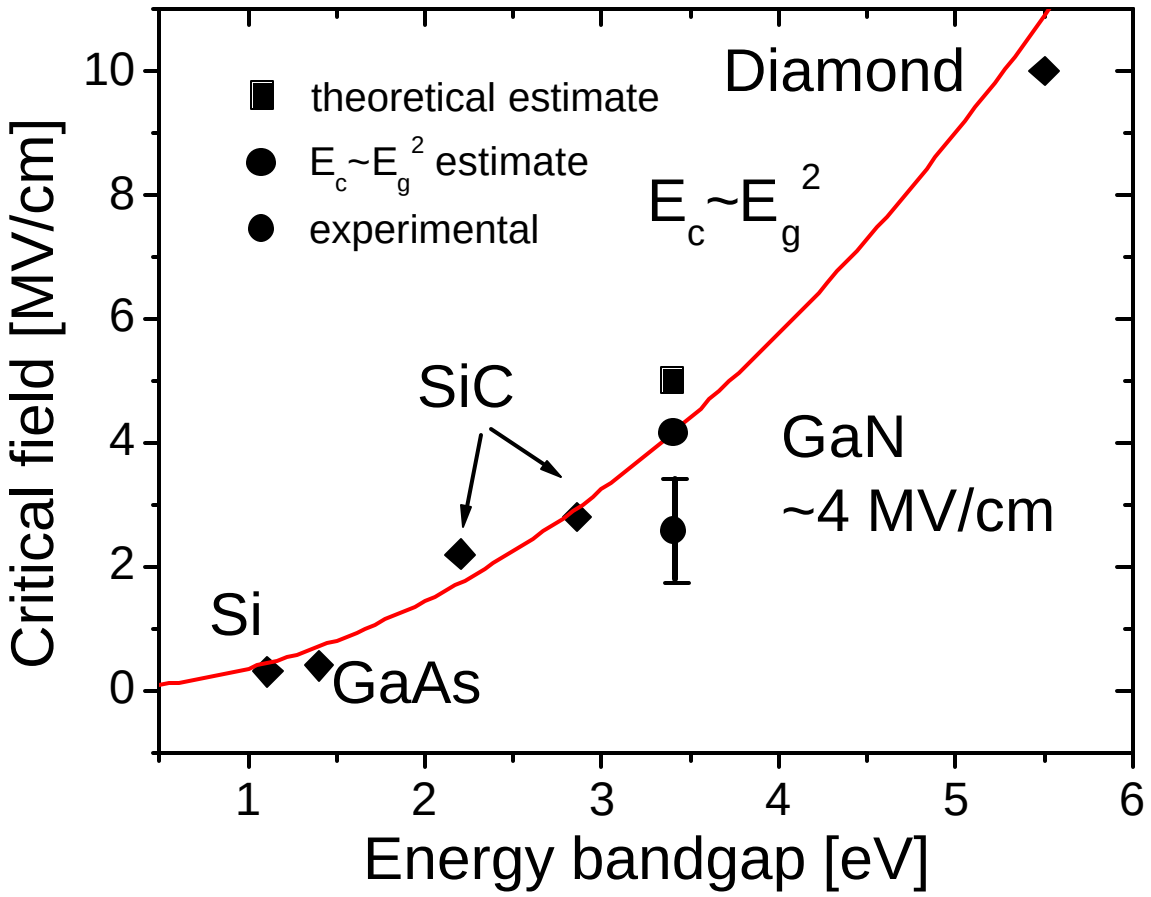
Outline

- Overview and Recent Device Results-Tom McGill (CIT)
- MBE Growth of Nitride for Bipolar Devices
  -Jim Van Hove/Peter Chow(SVTA)
- Developments on Thick Layers for High Standoff Voltages-Tom Kuech (UW)

Why GaAlN for Power Devices

- High Critical Fields
- Heterojunction Technology
- Likely to have Major Tech Base for Light Emitters and Microwave Devices
- Good Bet for CVD technology with both MOCVD and HVPE available for thick layers required
- MBE Structures with Improved p-type Activation in Buried Layers

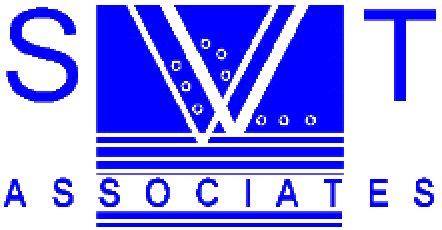
Critical field for electric breakdown



- Critical Fields ~(Energy Gap)^2
- GaN and AlN have very Large Breakdown Fields
- Better than SiC
- Roughly 10 Times Si
- Only Diamond Better

Team Effort

- Develop GaN Power Devices
- Concentrating on Schottky Diodes and Thyristors
- Very Aggressive Goals 25 kV and 200 amp



Participants

- Z.Z. Bandic, Caltech
- E.C. Piquette, Caltech
- P.M. Bridger, Caltech
- R.A. Beach, Caltech
- R. P Strittmatter, Caltech
- O.J. Marsh,Caltech
- J.O. McCaldin, Caltech
- T.C. McGill, Caltech
- V.M. Phanse, ATMI Inc.
- R.P. Vaudo, ATMI Inc.
- J. Redwing, ATMI Inc. (PSU)
- Peter Chow, SVTA, Inc
- Jim Van Hove, SVTA, Inc
- T.F. Kuech, UW-Madison
- Shulin Gu, UW-Madison
- Rong Zhang, UW-Madison

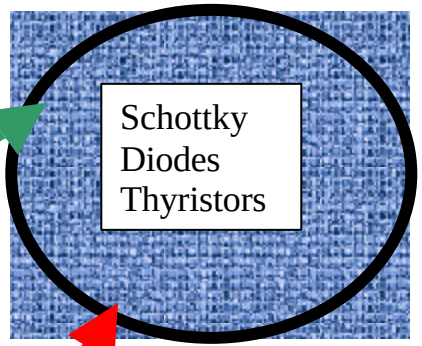
Original Program structure

University of Wisconsin

- Design VPE reactor to grow thick AlGaN layers with low n-type doping
- Assemble VPE reactor to produce thick AlGaN Layers
- Assist Epitronics/ATMI in the production of MOCVD/HVPE layers for our device
- Transfer thick, low-doped HVPE technology to Epitronics/ATMI

Caltech

- Measure Basic Properties of AlGaN Relevant to Schottky Diodes and Thyristors
- Carryout Device Design Simulations and Measurements
- Work with Test Structures Produced by MBE(Caltech) and HVPE/MOCVD (Epitronics/ATMI)
- Intergrate when ready thick HVPE layers from University of Wisconsin



Time

Progress on Program Plan (I)

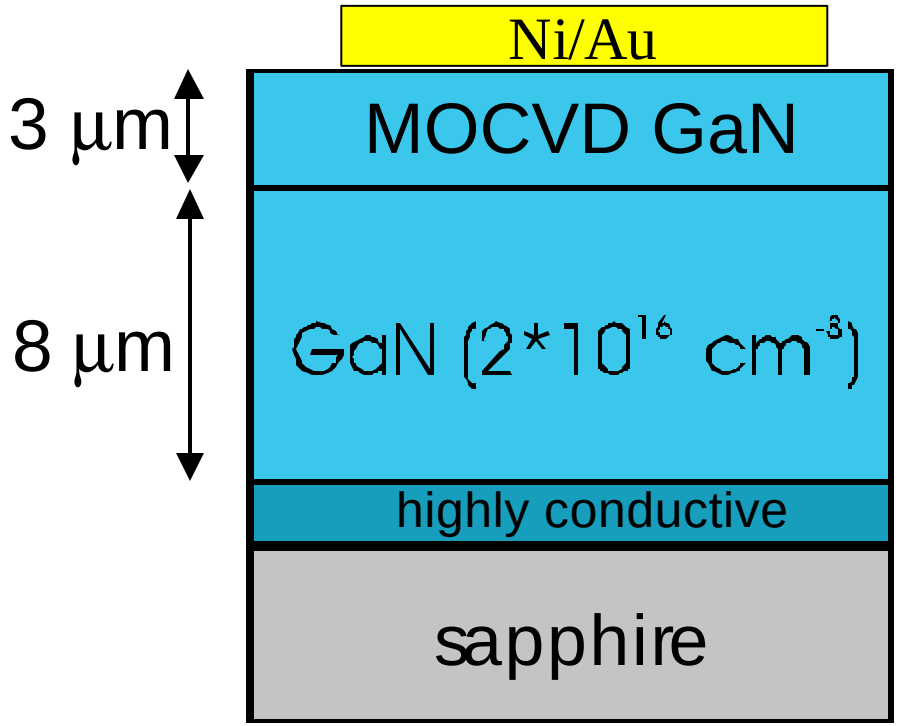
- Device Design for both Schottky and Thyristor in Hand and Presented at A Number of Meetings
- Demonstrated Schottky with High Breakdown Voltage indicating Critical Fields are quite High
- Investigated Contact Properties for Low Resistance Ohmic Contacts
- Measured lifetimes in the Range Suitable for Making High Power pn Junction Based Devices

Progress on Program Plan (II)

- Demonstrated pn Junction Diode
- A Number of Thyristor Structures Grown and Processed with Some Thyristor Like Action Observed
- Developing Thick Layer Growth Technology
- Developing New Fabrication Technologies for Power Devices and Other Applications

Schottky rectifier

- Built Two Devices with Differing Layer Thickness
  - 450 V Stand Off Voltage
  - 750 V Stand Off Voltage



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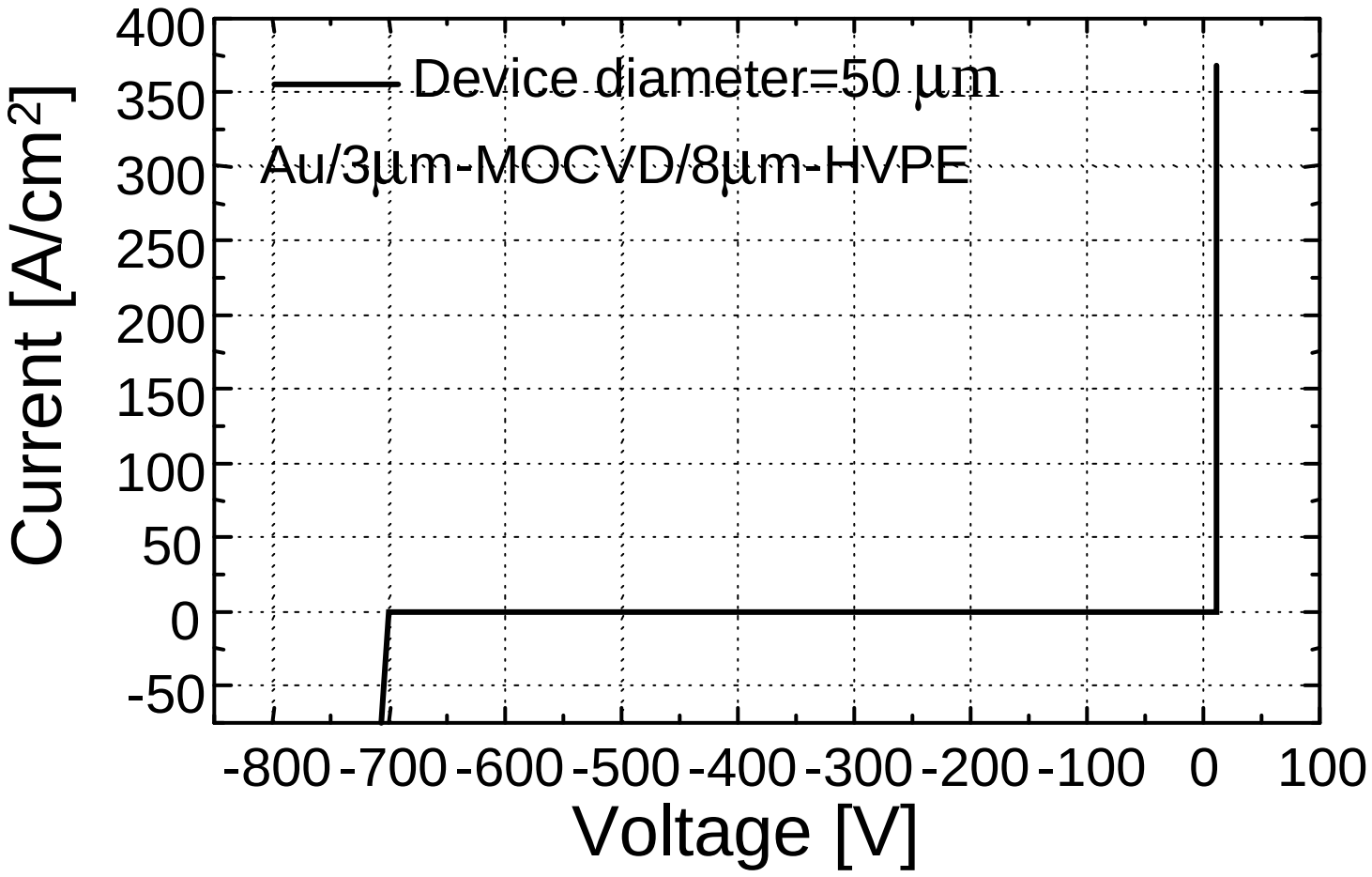
750 V Schottky rectifier



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Critical Field Estimate

- Using:

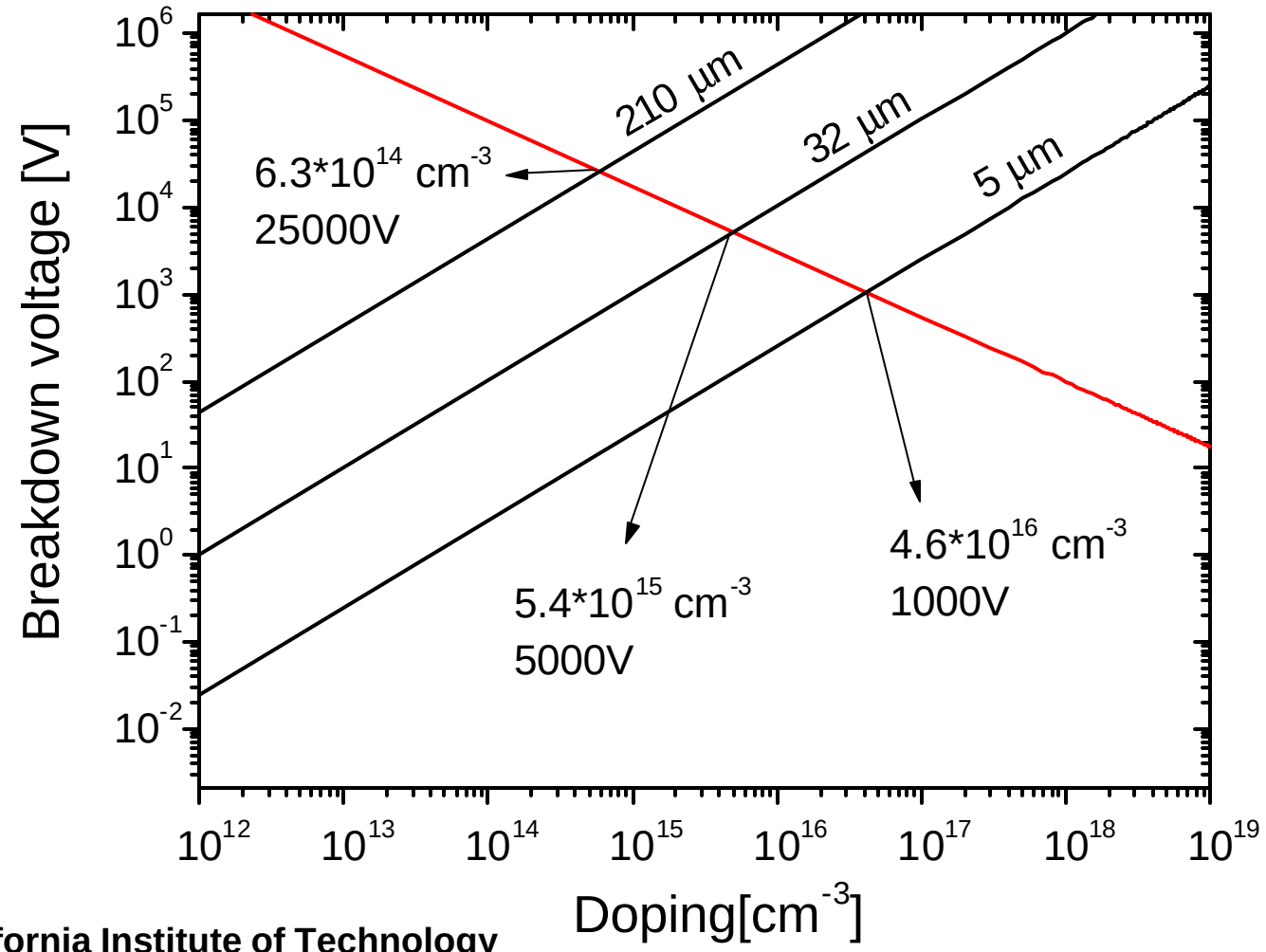
$$V_B = \begin{cases} \dfrac{e_0 e_r E_{CR}^2}{2qN_d}, & W \geq \sqrt{2e_0 e_r V_B / qN_d} \\ E_{CR}W - \dfrac{qN_d W^2}{2e_0 e_r}, & W < \sqrt{2e_0 e_r V_B / qN_d} \end{cases}$$

- We obtain:

  Ecr¤ 1.8⊕0.5 MV/cm for 450V devices

  Ecr¤ 2.3⊕0.5 MV/cm for 750V devices

GaN Schottky diodes



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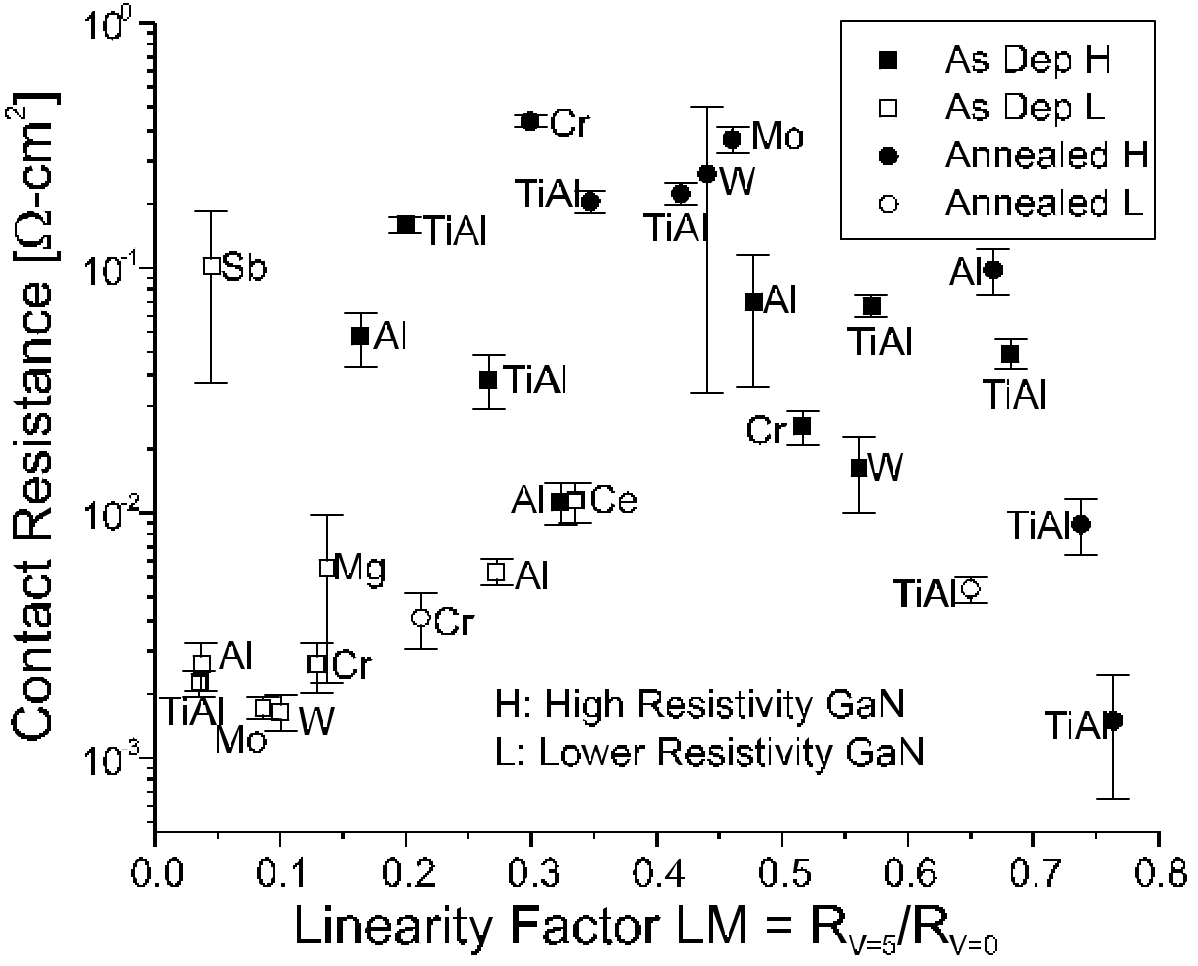
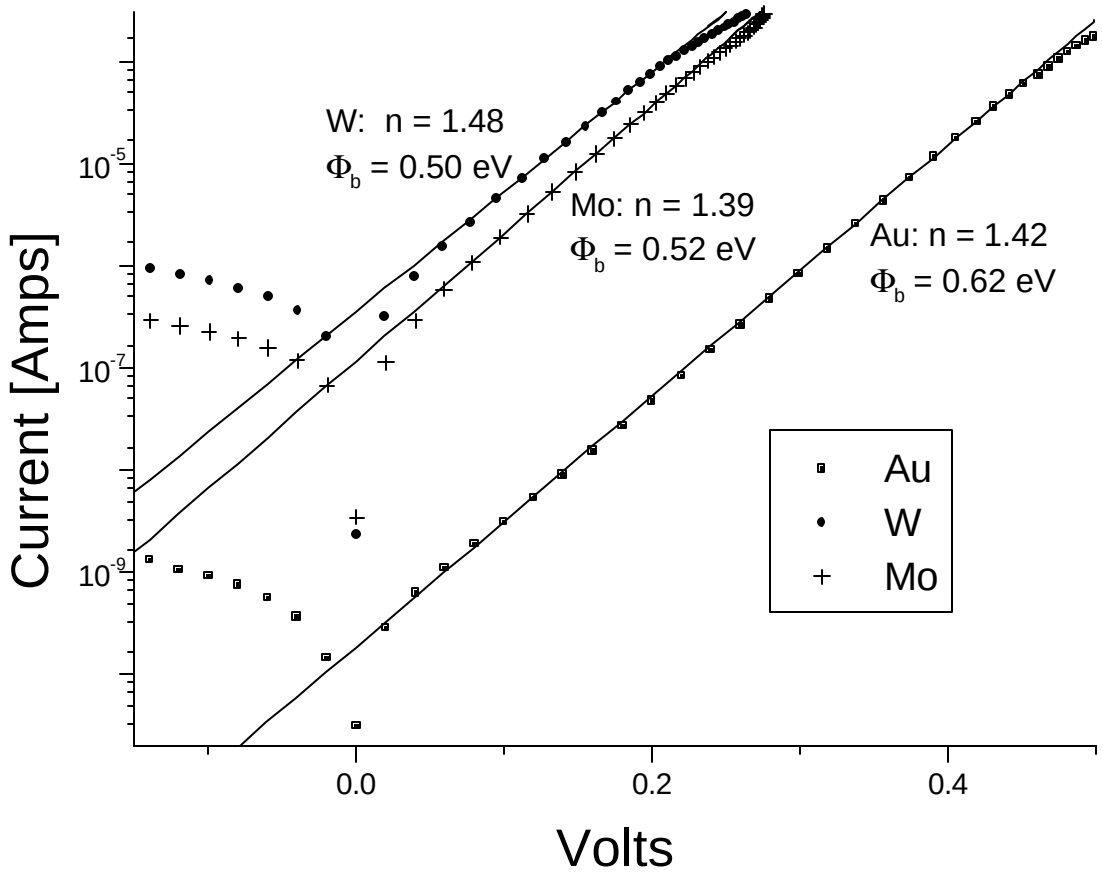
Contact Resistance



Schottky Barriers: I-V Analysis



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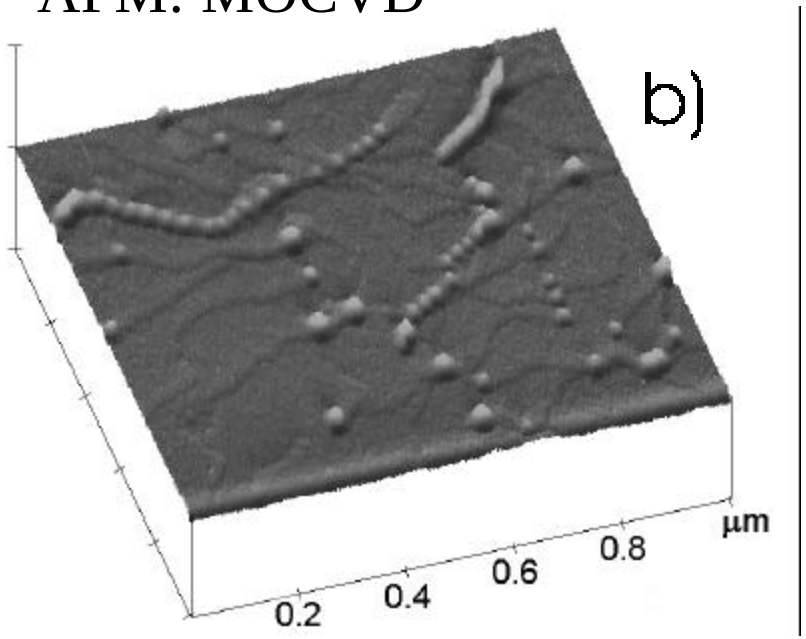
Diffusion Length and Lifetime

AFM: MOCVD



L_e=0.2 µm, τ_e=0.1 ns L_h=0.28 µm, τ_h= 7 ns

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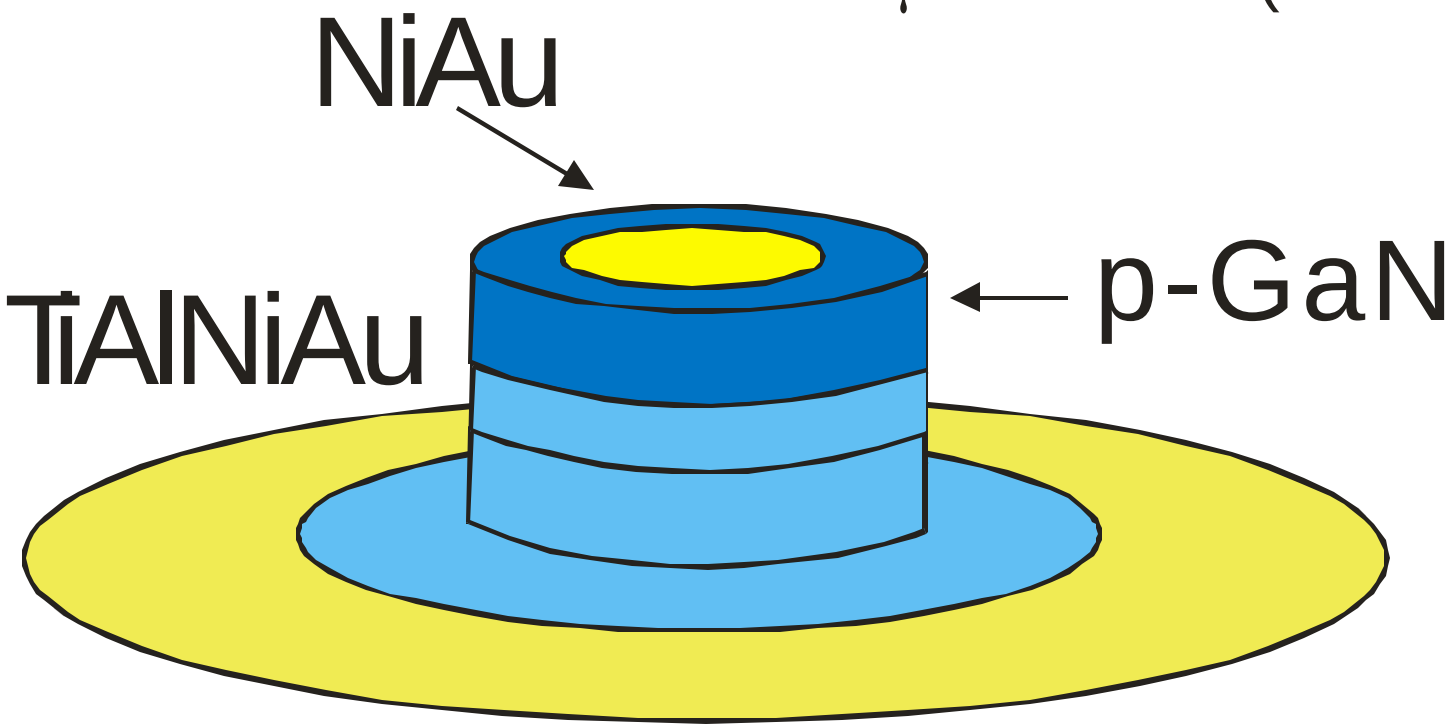
450 V p/n diode by MOCVD/HVPE

0.75 μm p-GaN (MOCVD)
0.75 μm n-GaN (MOCVD)
8 μm n-GaN (HVPE)



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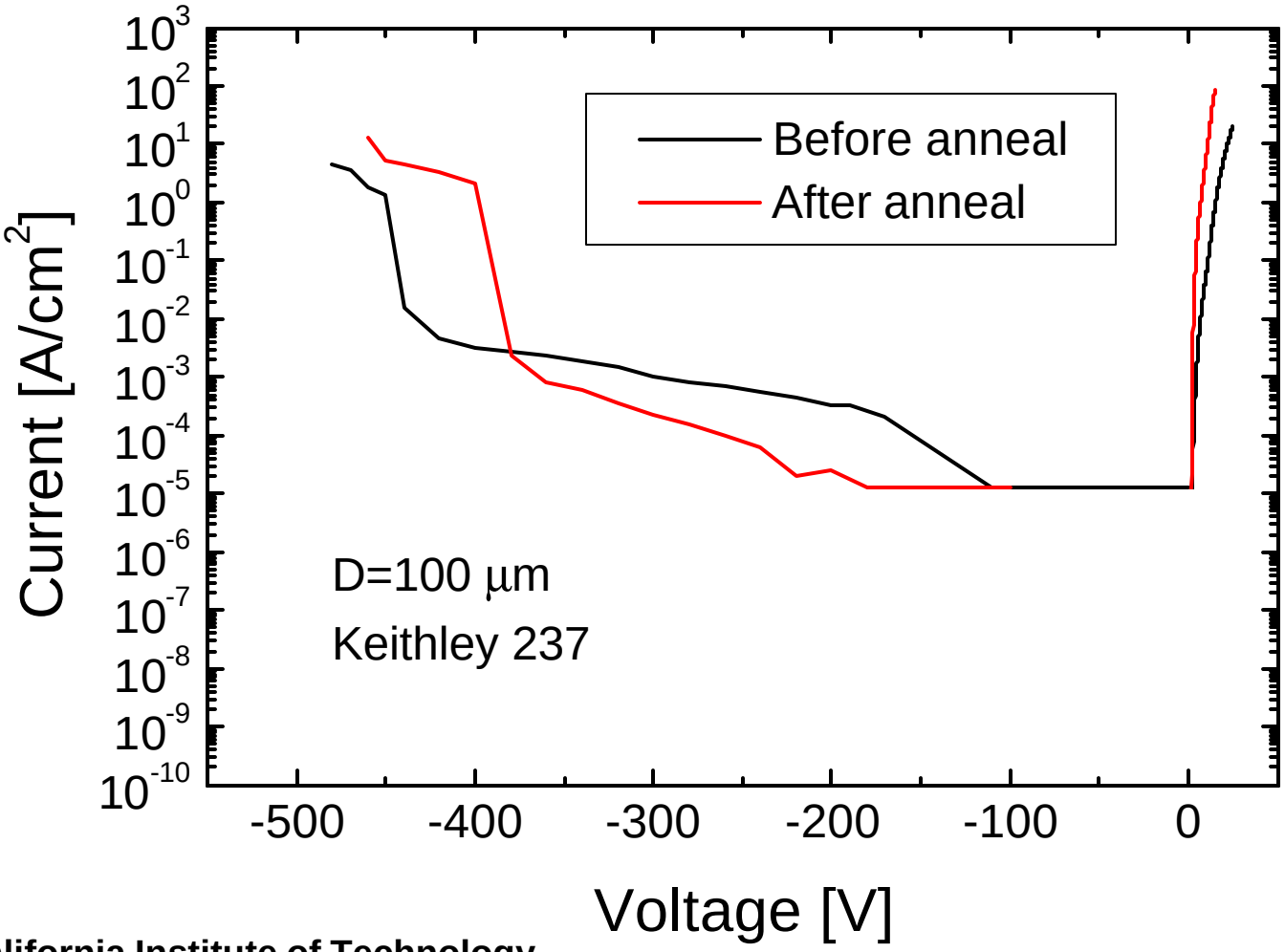

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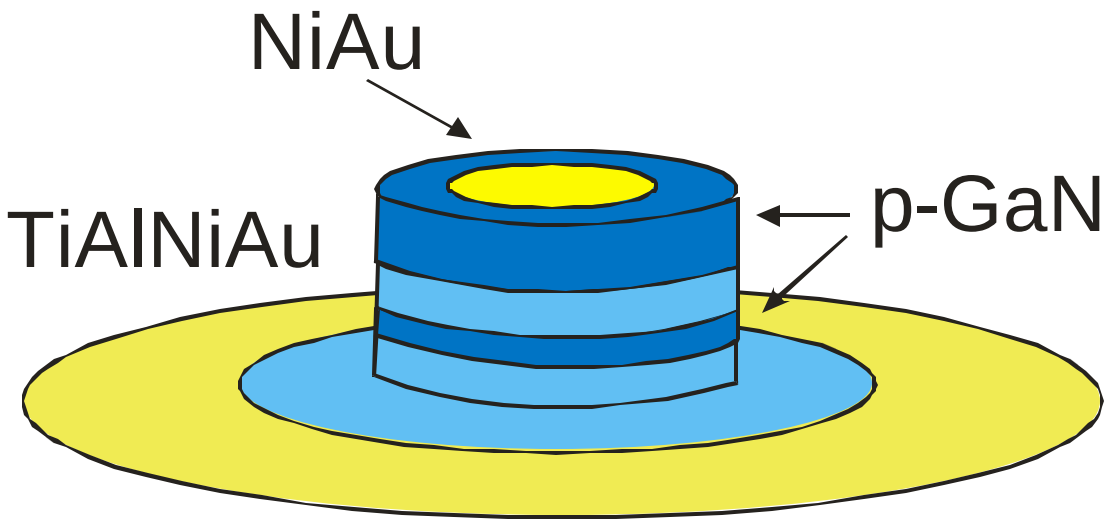
Thyristors

- Various Growth Techniques Employed
  - MOCVD, MBE/MOCVD, MBE/HVPE
- Thyristor like Behavior Observed



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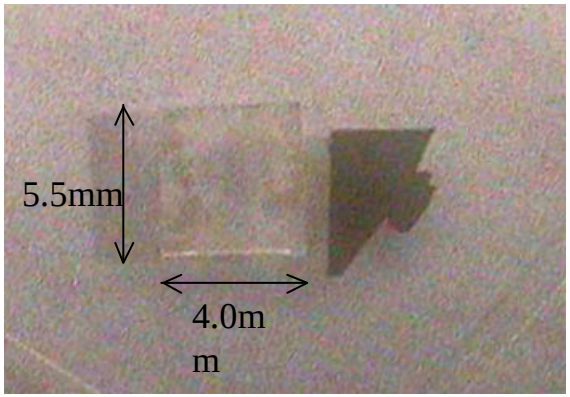
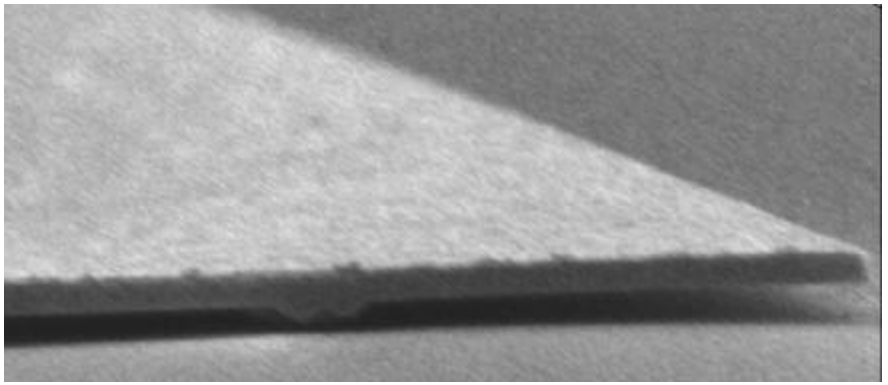
Selective Etching

- Developed Photo-Electro-Chemical Etching for Low Damage Contacting
- Investigated PEC Lift Off for Backside Contacting and Thermal Management
- Have Removed 0.5cm p-type Sample





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Overall Conclusions

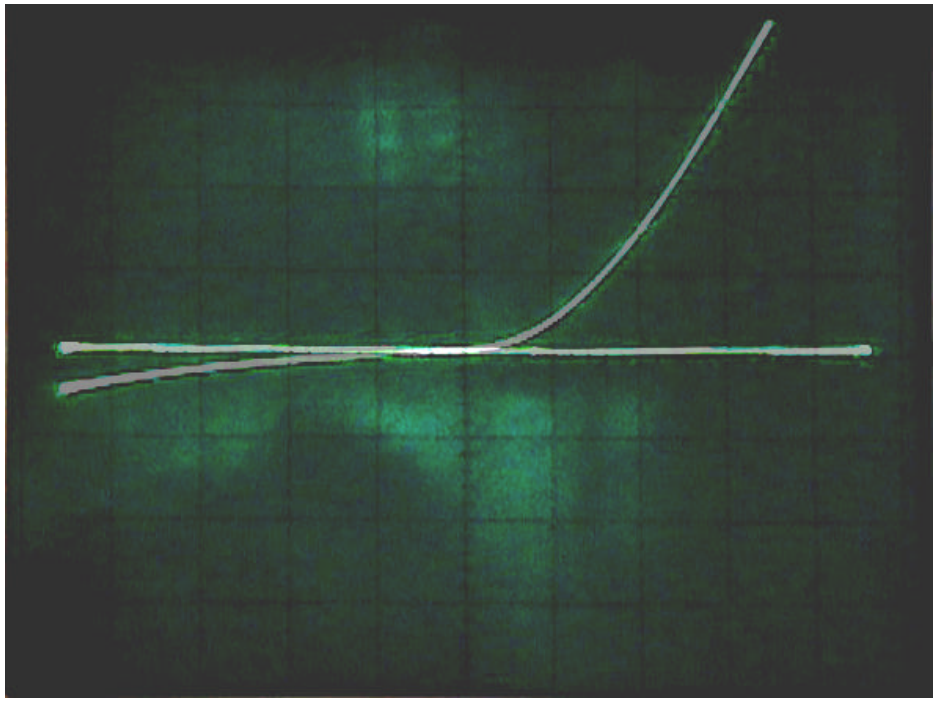
- Program To Date Major Success
  - Demonstrated That GaN has Basic Properties that for a Major New Set of Power Devices
  - Original Basis for Proposal Fully Verified
- Major Issues in Development of Materials and Processes
  - New Process Technologies including contacts, etch and liftoff and associated structures (CIT)
  - Substrates-worldwide effort
  - Control of p-type buried layers (SVTA)
  - Thick layers of AlGaN (UW)
- Have Set the Basis for Power Device Technology Based on Nitrides

General Characteristics

- Low initial switching voltage ~5V
- Persistent on state
  - Breakdown induced conductive paths
  - Trap states in base (persistent conductivity)
  - Surface flashover on mesa walls
- Surface sensitivity
- Annealing improves switching to ~20V
- Repeated cycling improves voltage

Stable states for GaN switch

- Requires heating to return to off state



Current (1mA/Div)

Voltage (.5V/Div)

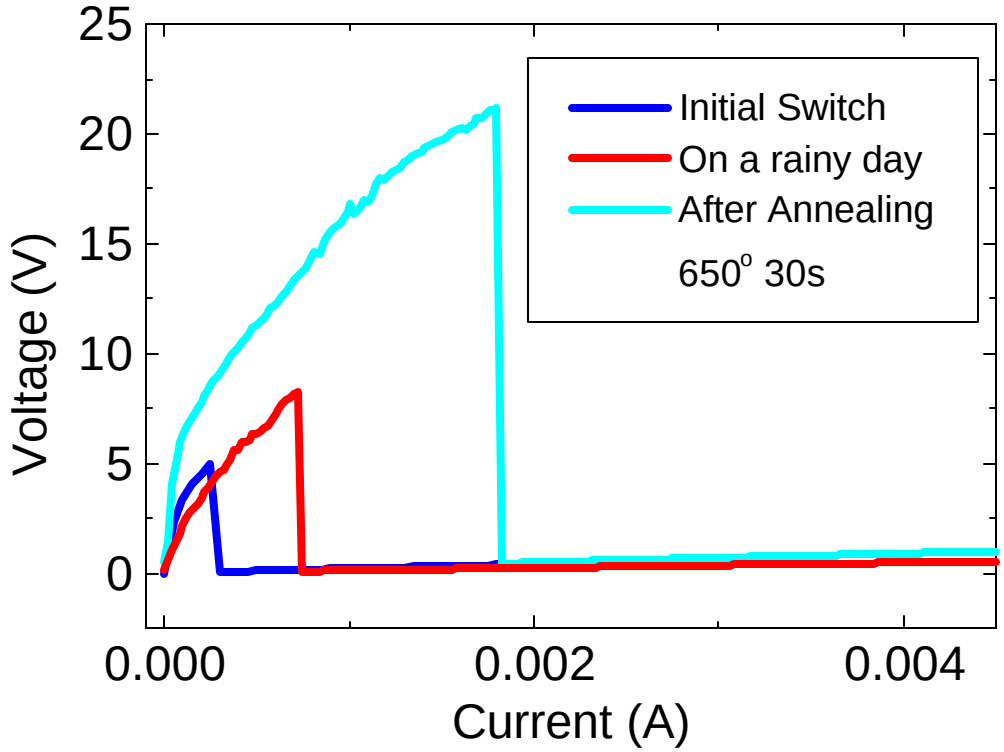
On State

$\frac{I(on)}{I(off)}$ =373@1.5V

Off State

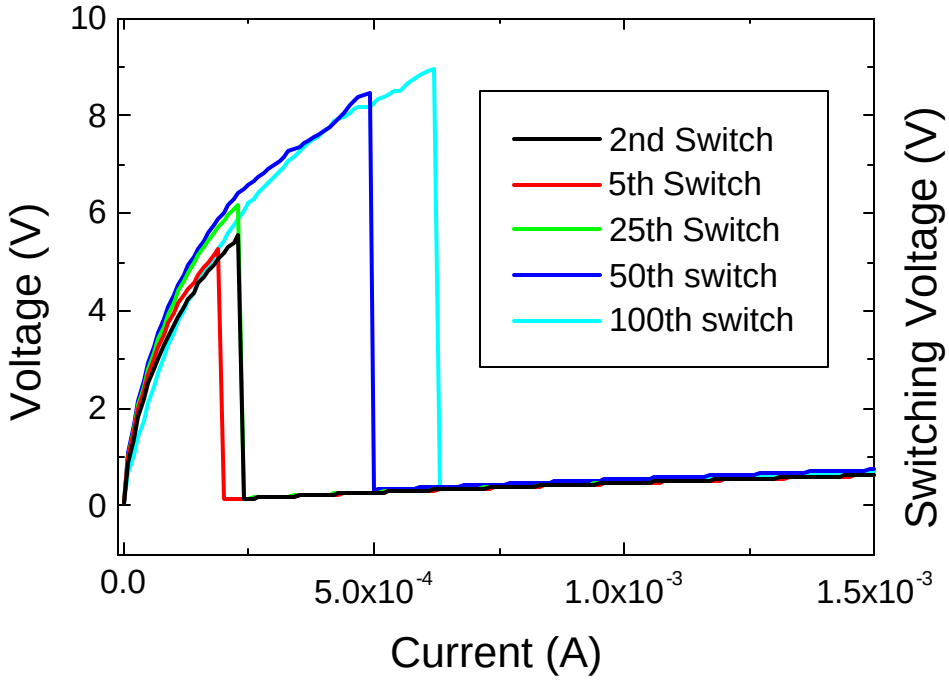
Surface Sensitivity

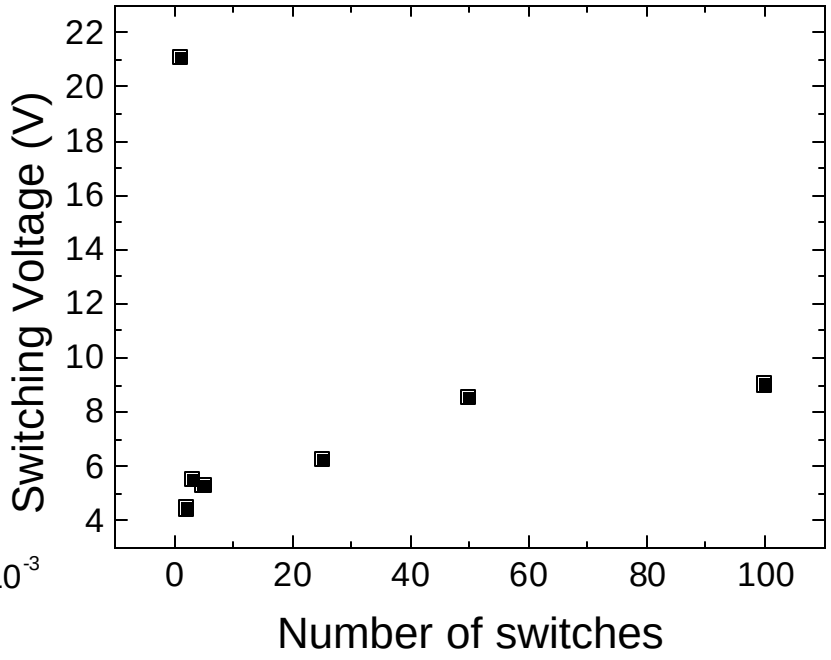
- Low initial forward blocking voltage
- Humidity increases turn on voltage



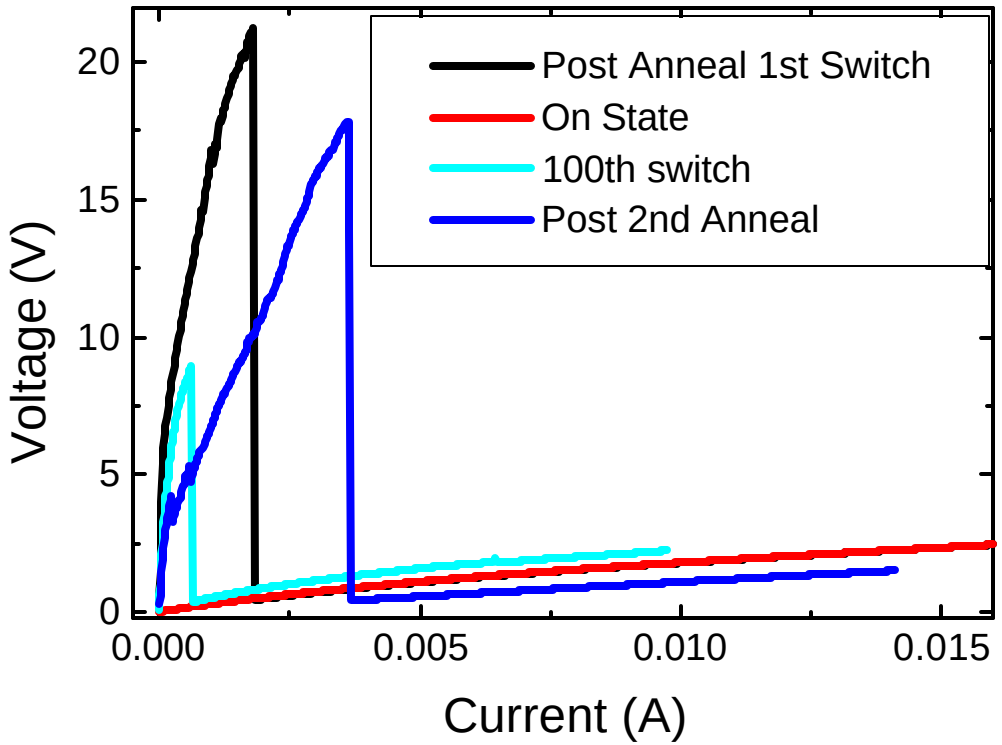
Switching voltage progression

- Significant change after first switch
- Switching voltage slowly improves





Second Anneal



Conclusions

- Have shown switching behavior in a GaN thyristor structure with 21 V forward blocking
- Forward blocking appears limited by surface or defect related breakdown
- Breakdown is associated with significant changes in device characteristics
- Thermal cycling or annealing improves device performance

Directions

- Determine source of persistent conductivity
- Investigate surface passivation for increasing forward blocking and reducing leakage current
- Fabricate three terminal thyristor for improving control of switching behavior
- Improve growth and processing of devices for larger standoff voltages