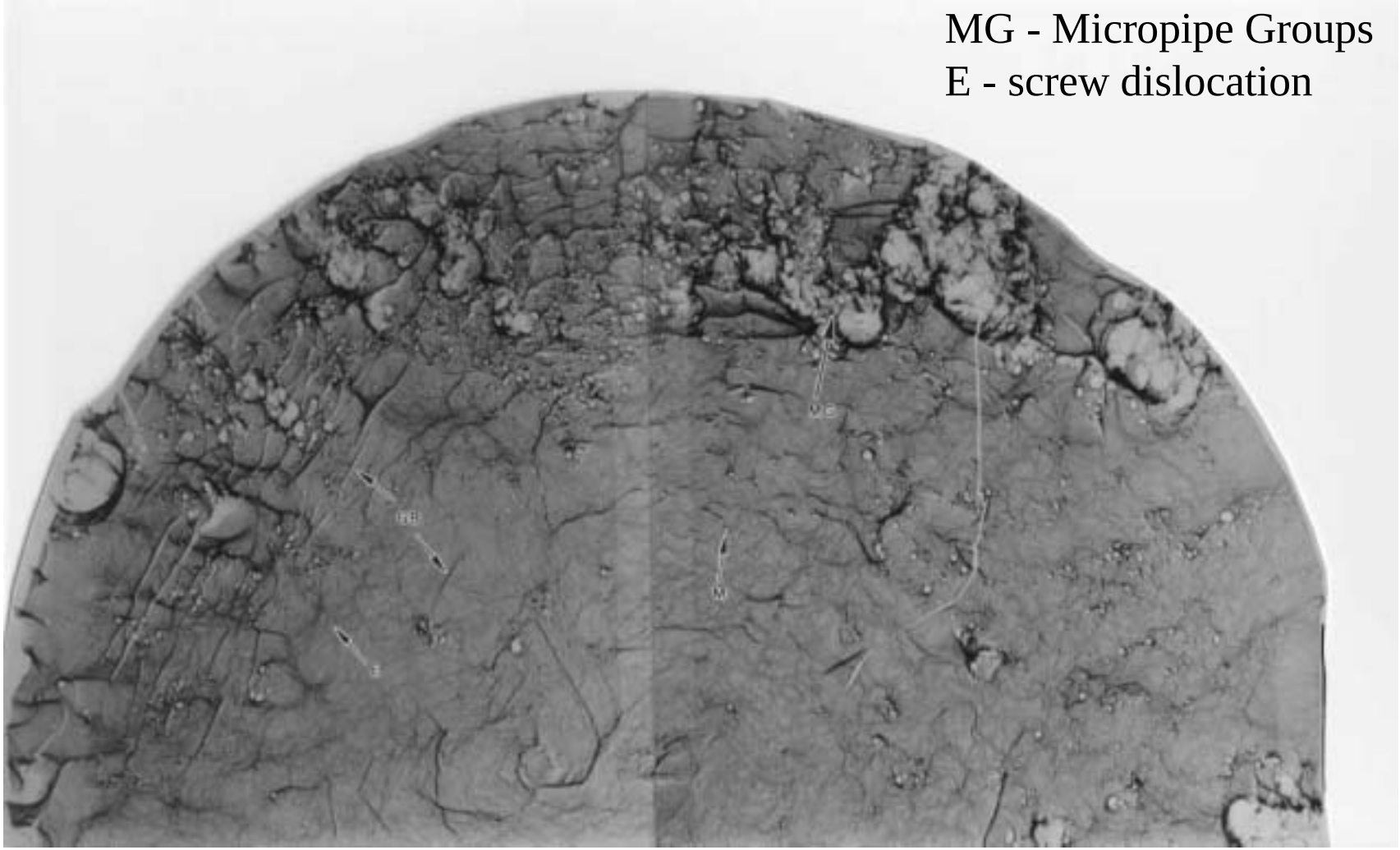
Background

- Large-area GaN and SiC substrates required for next-generation high power/high frequency applications (e.g., RF power amplifiers) in critical Navy systems.
  - 2-3″ SiC wafers commercially available.
  - 4″ SiC wafers under development.
  - 2″ GaN wafers under development.
- Structural defects (dislocations, micropipes, etc.), lattice imperfections (vacancies, interstitials, antisites), residual impurities (Si, O, C, B, N, etc.), and dopants (Si, Mg, V, etc.) play significant roles in **electronic properties** of wide bandgap semiconductors.
- Need to develop contactless methods to screen/assess wafers for crystalline quality and conductivity-type in a production line environment.

Structural Characterization

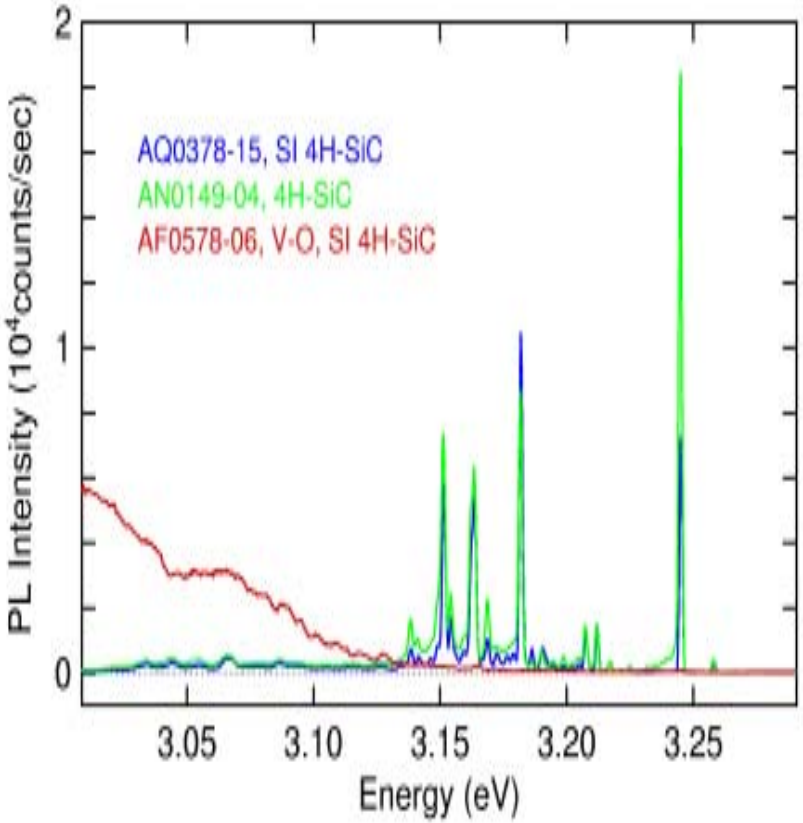
X-ray Topograph (M. Dudley, SUNY Stony Brook)

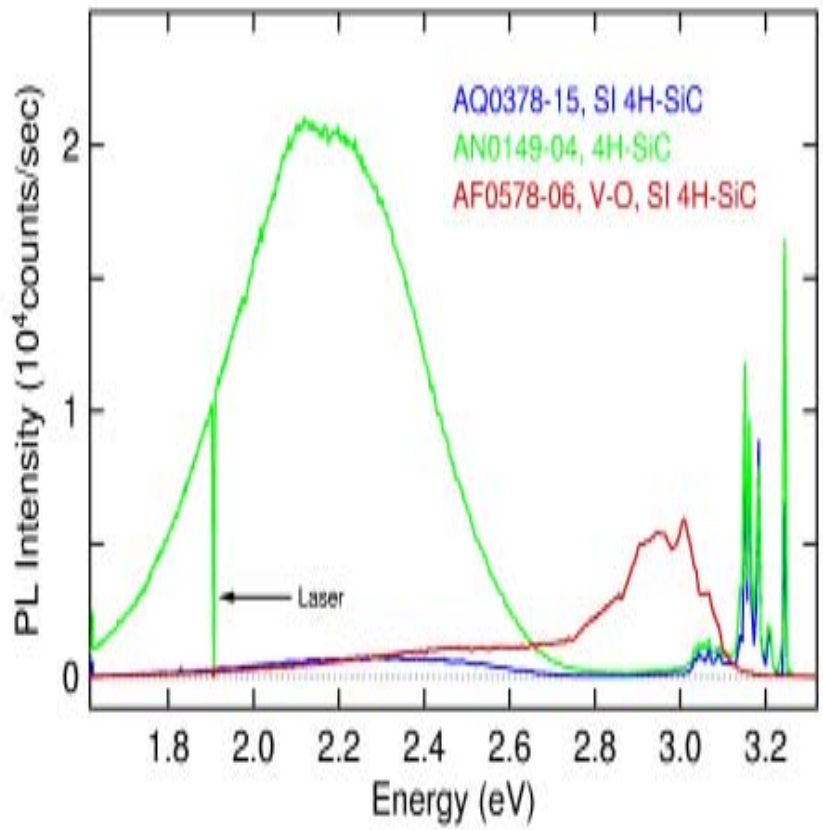
GB - Grain Boundary
M - Micropipe
MG - Micropipe Groups
E - screw dislocation



SiC PROPERTIES

Low Temperature Photoluminescence

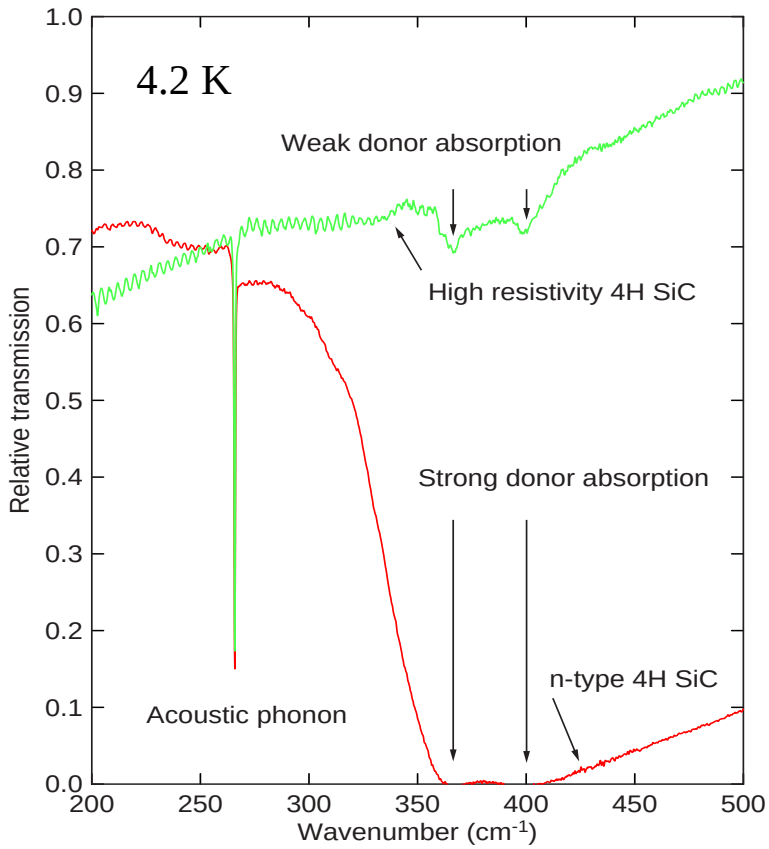


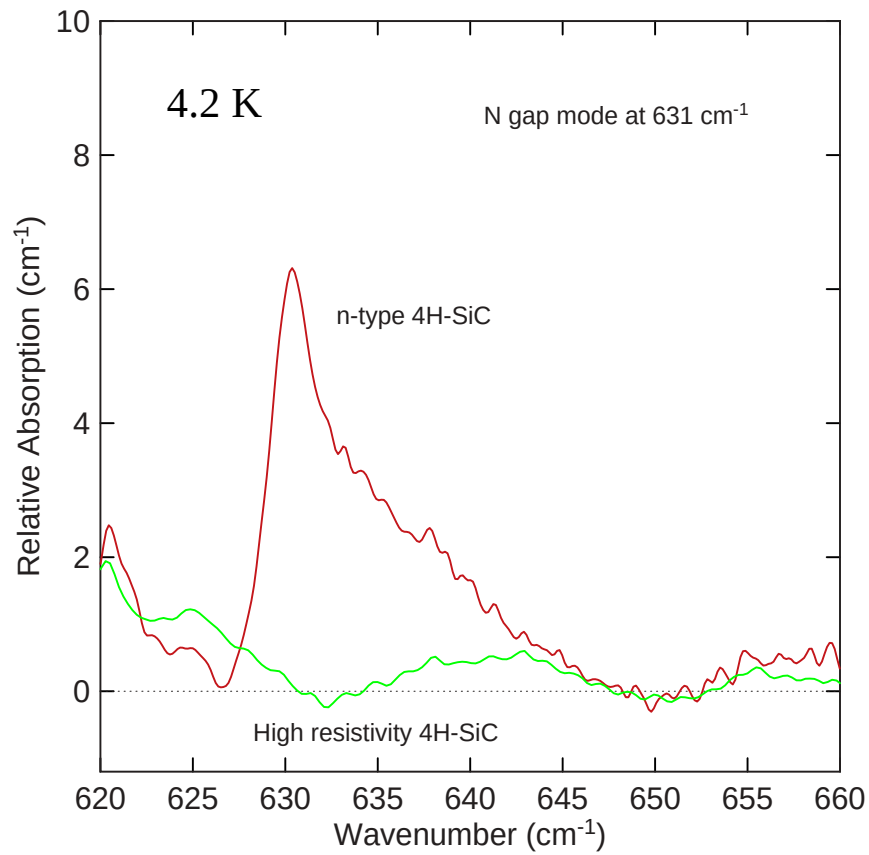


- Emission near 3.2 eV due to N-bound excitons.
  - Narrow linewidths reflect high crystallinity of samples.
- Strong for n-type and undoped (SI) samples; weak for V-doped sample.

- Different deep emission bands.
  - Strong band near 2.2 eV from n-type sample (green).
  - Weak band near 2.3 eV from undoped (SI) sample (blue).
  - Strong structured band from V-doped sample (red).

Non-destructive Infrared Assessment of Impurities

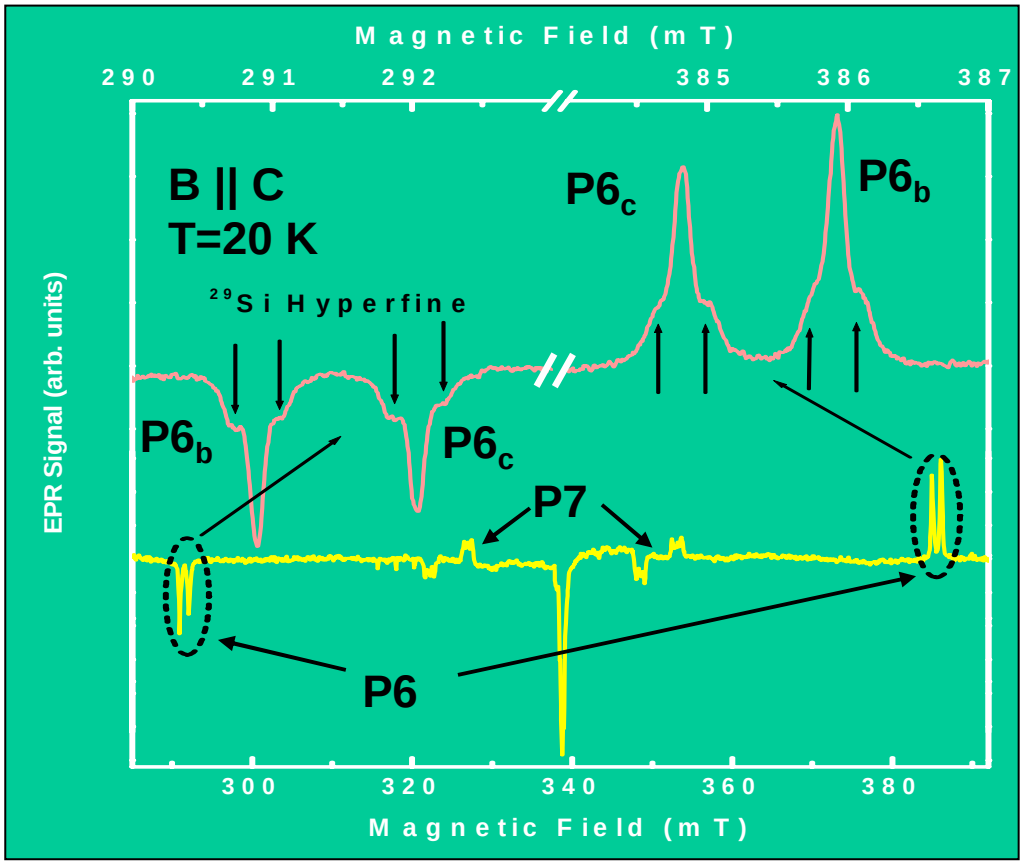


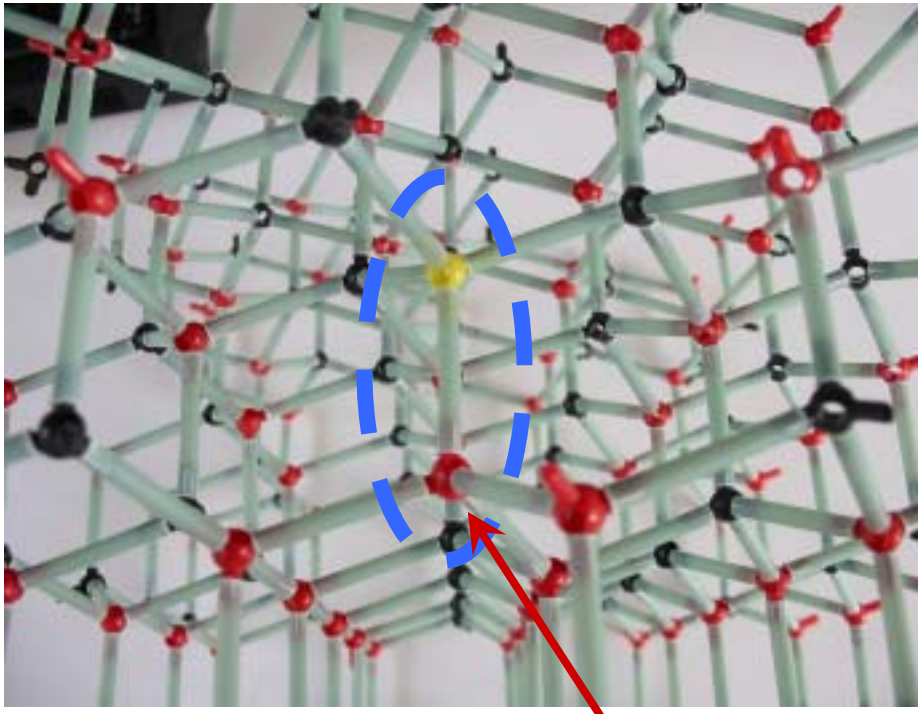


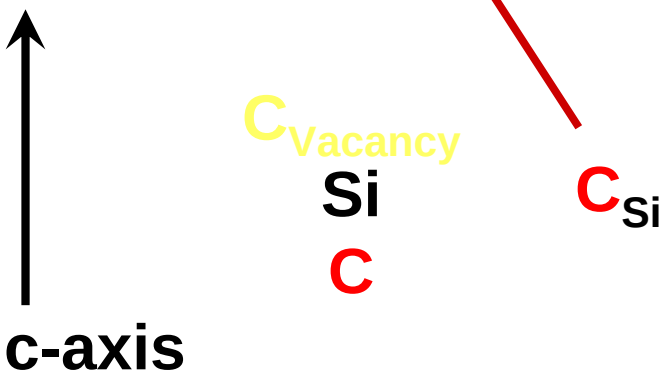
- n-type sample absorbs strongly in region of 1s-2p (N donor) electronic excitation transitions.
- High-resistivity sample absorbs only weakly.

- Feature near 631 cm^{-1} due to N localized gap mode.
  - intensity proportional to N concentration on C site.
  - work underway to obtain calibration standard.

The Possible Source of SI SiC: C Vacancy – C Antisite Defects



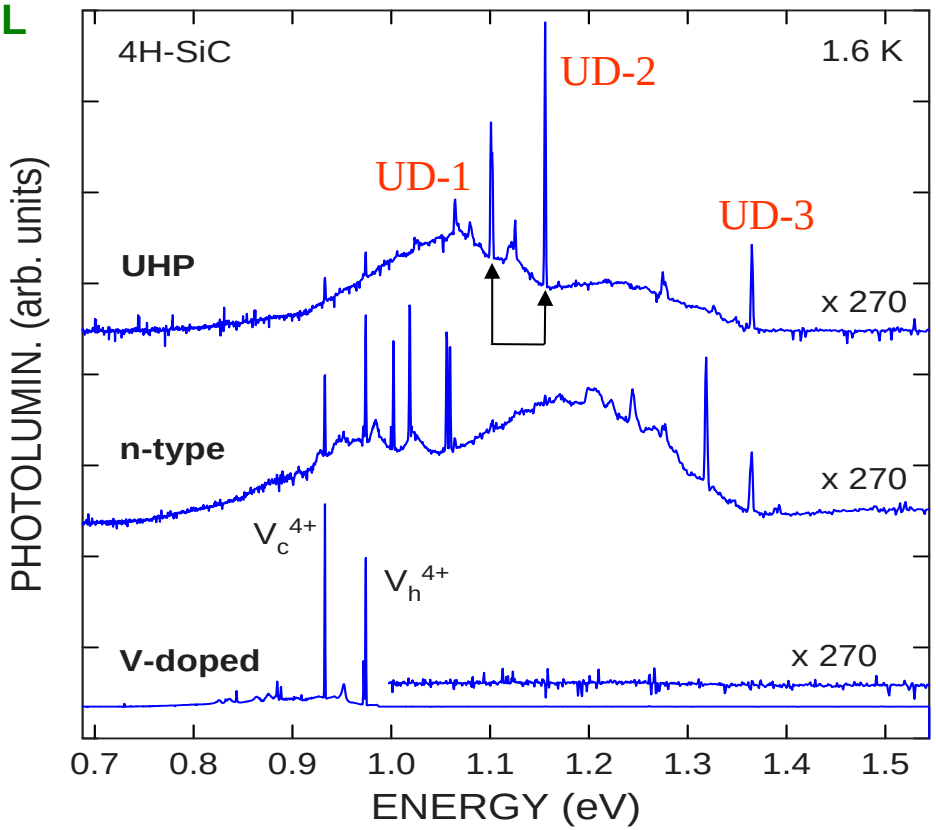




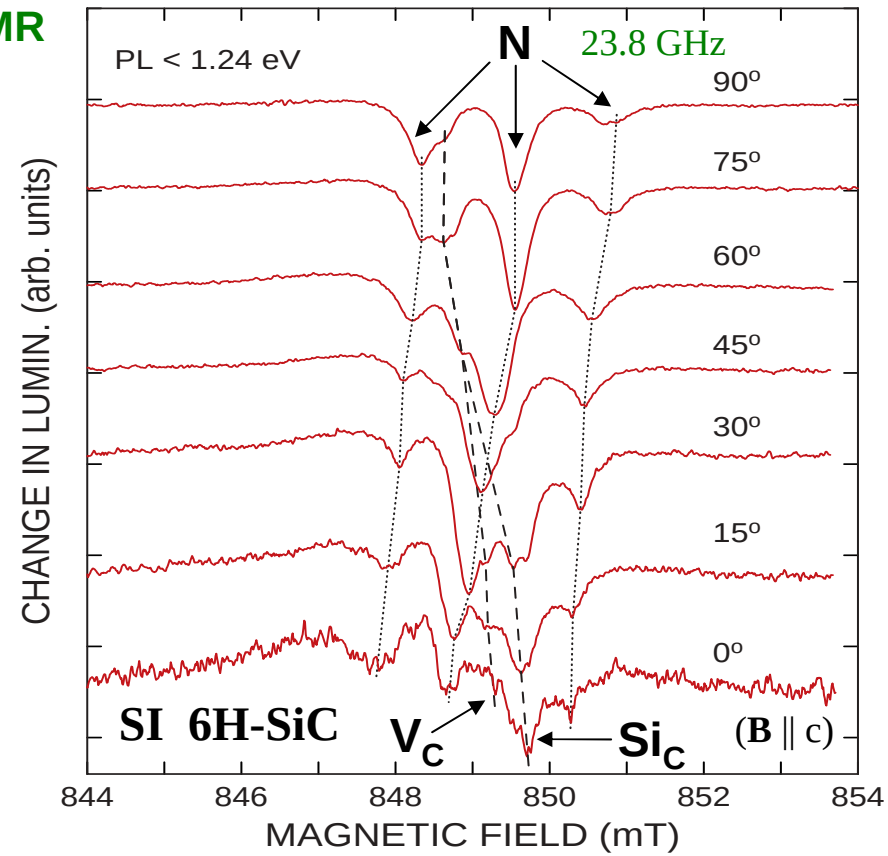
- Photo-EPR reveals C Vacancy – C antisite defects in semi-insulating ("Vanadium-free") 4H-SiC.
- Concentration of V_C-C_{si} relative to residual B and N levels must still be determined.
- Control of Si/C stoichiometry should govern conc. of these centers and SI character of the SiC boules.

Infrared PL/ODMR of Large-Area SiC Substrates

PL



ODMR



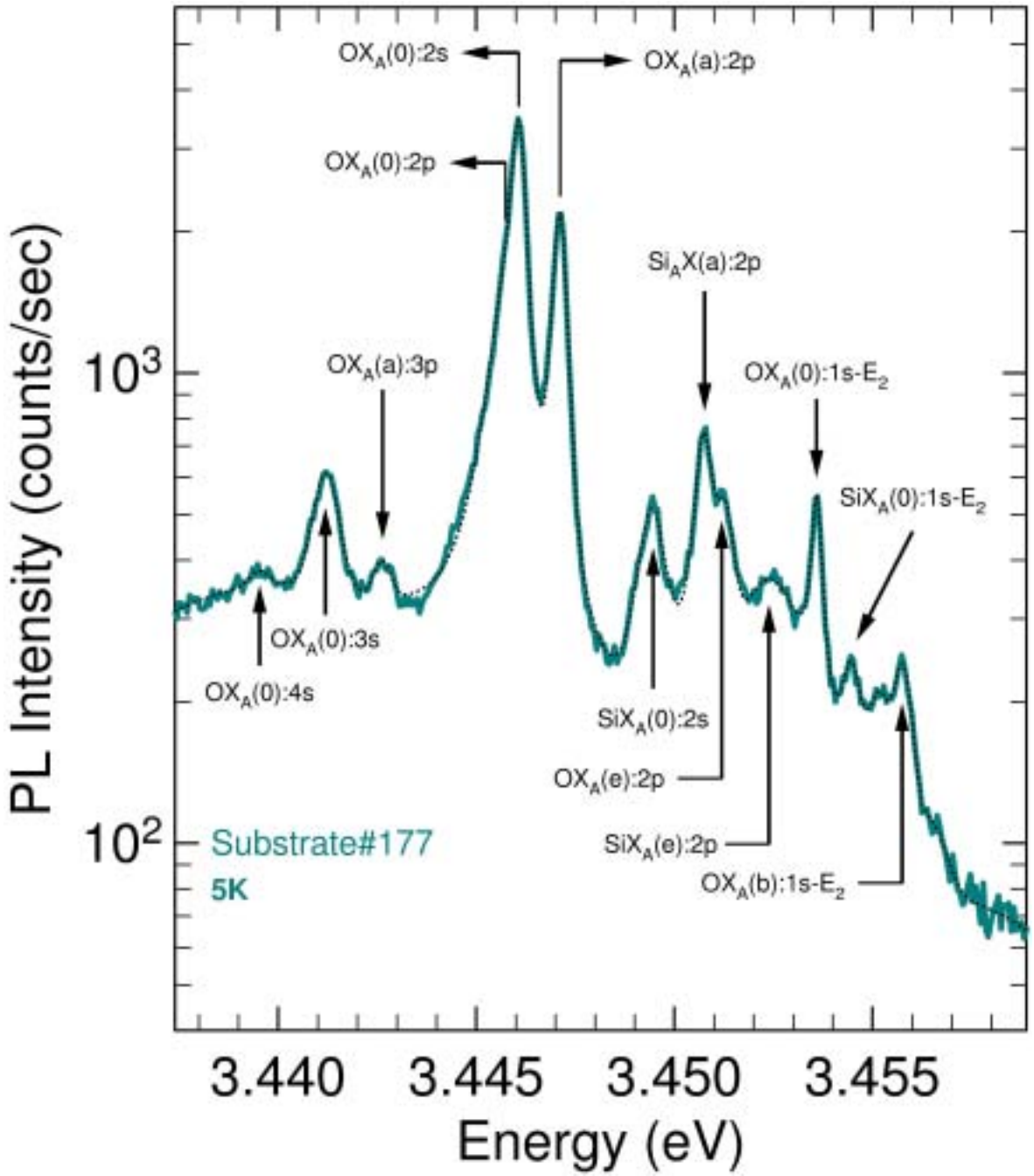
Ultra-High Purity (UHP) SI 4H-SiC:

- Several sharp lines + broad phonon sidebands between 0.9 and 1.4 eV.
- Strong lines ("UD-2") between 1.10 and 1.15 eV not observed in n-type and V-doped substrates.
  - PL at 1.10 eV similar to ZPL observed in EPR excitation spectrum of V_C-C_{si} pair defect.

- Three defects identified in as-grown semi-insulating 6H-SiC wafer.
  - N donors on hex. + two cubic sites.
  - C vacancies + Si_C anti-sites (as reported from EPR of e^--irradiated 6H-SiC).

GaN PROPERTIES

High-Resolution PL of Free-Standing HVPE GaN

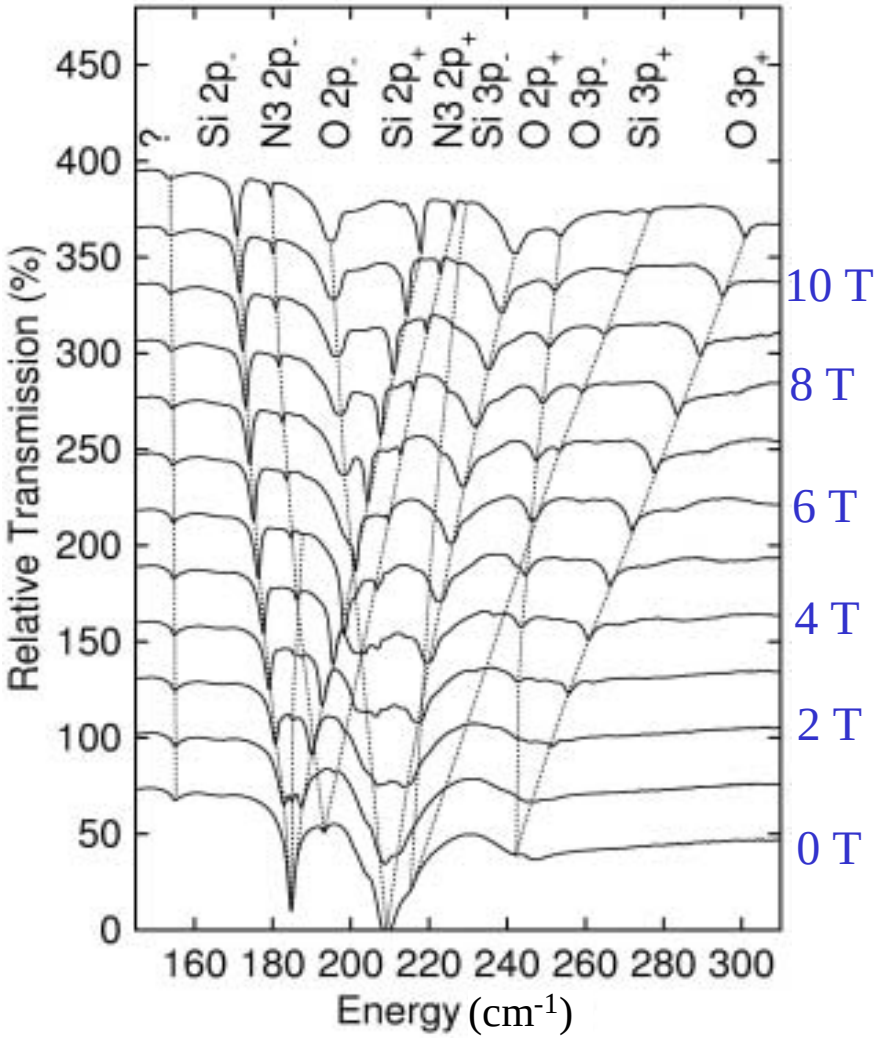


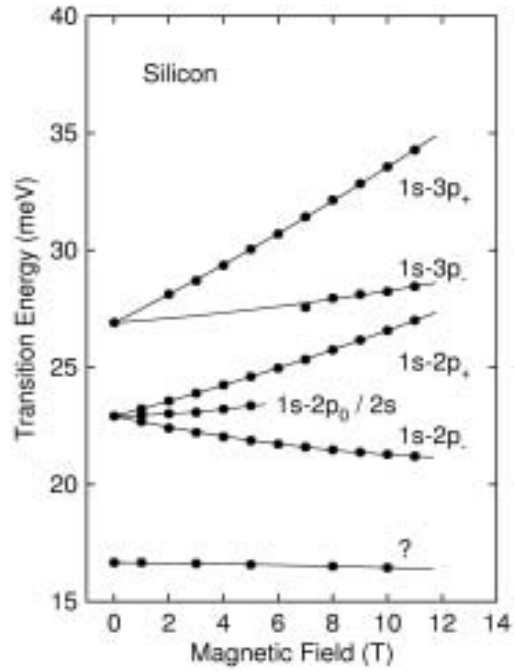
Two-Electron Satellite Region at 5K:

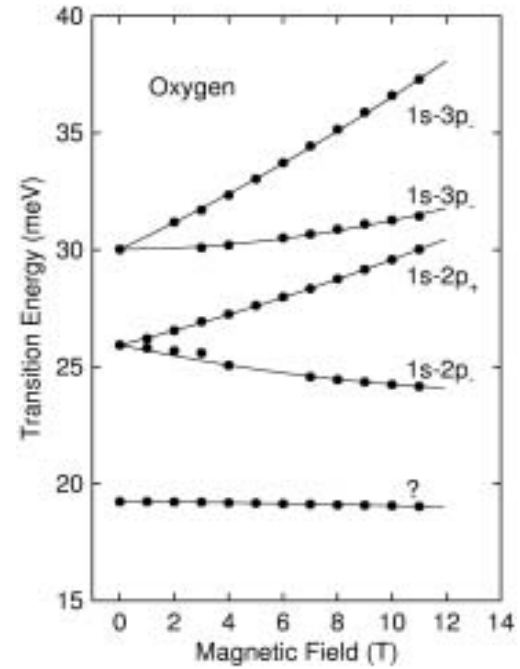
- Transitions associated with 2s,2p, 3s, 3p, and 4s of Si and O shallow donors have been identified.
- Excited states (a,b,e) of the complex D^oX_A are observed.

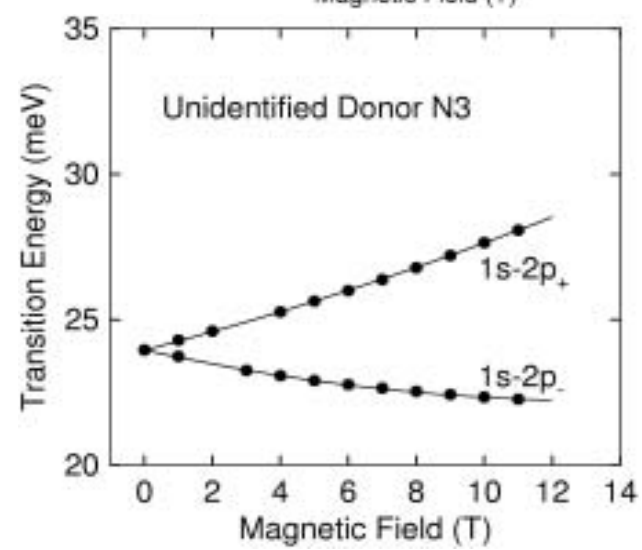
Non-destructive Infrared Assessment of Impurities

HVPE GaN



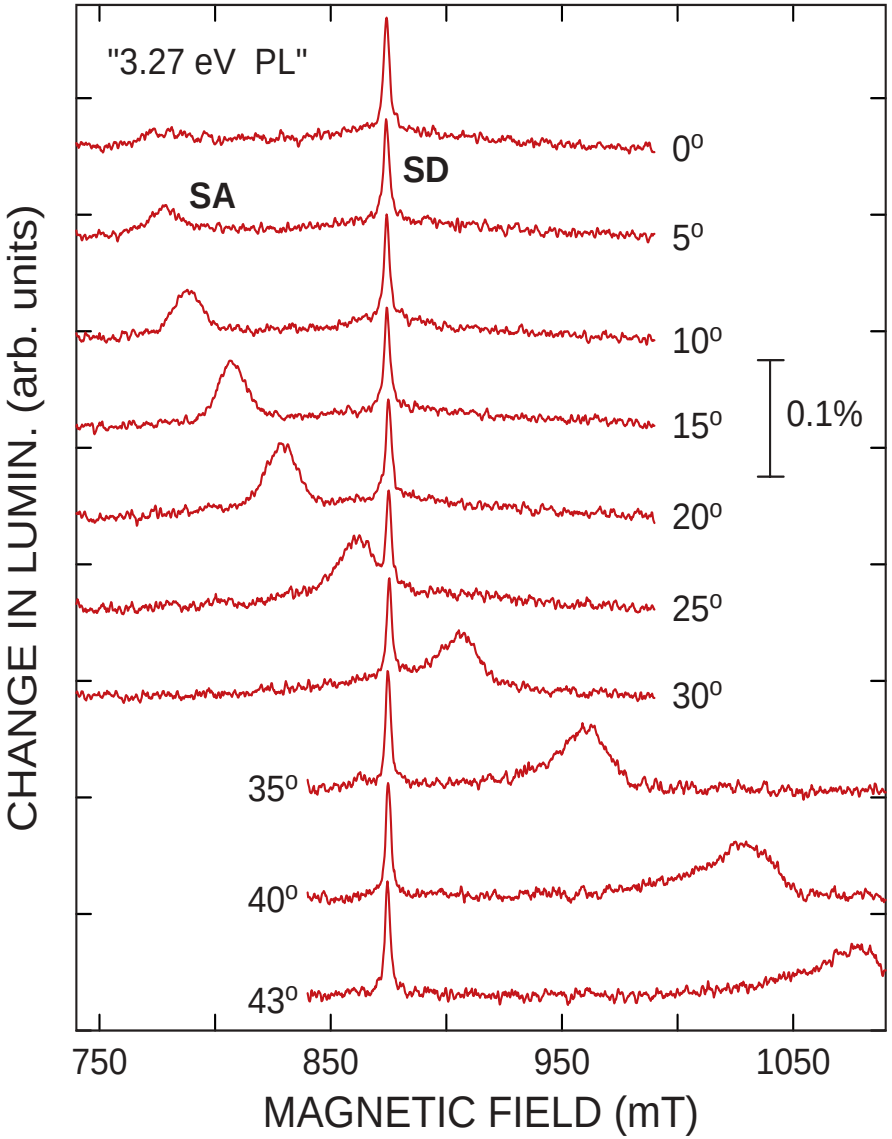






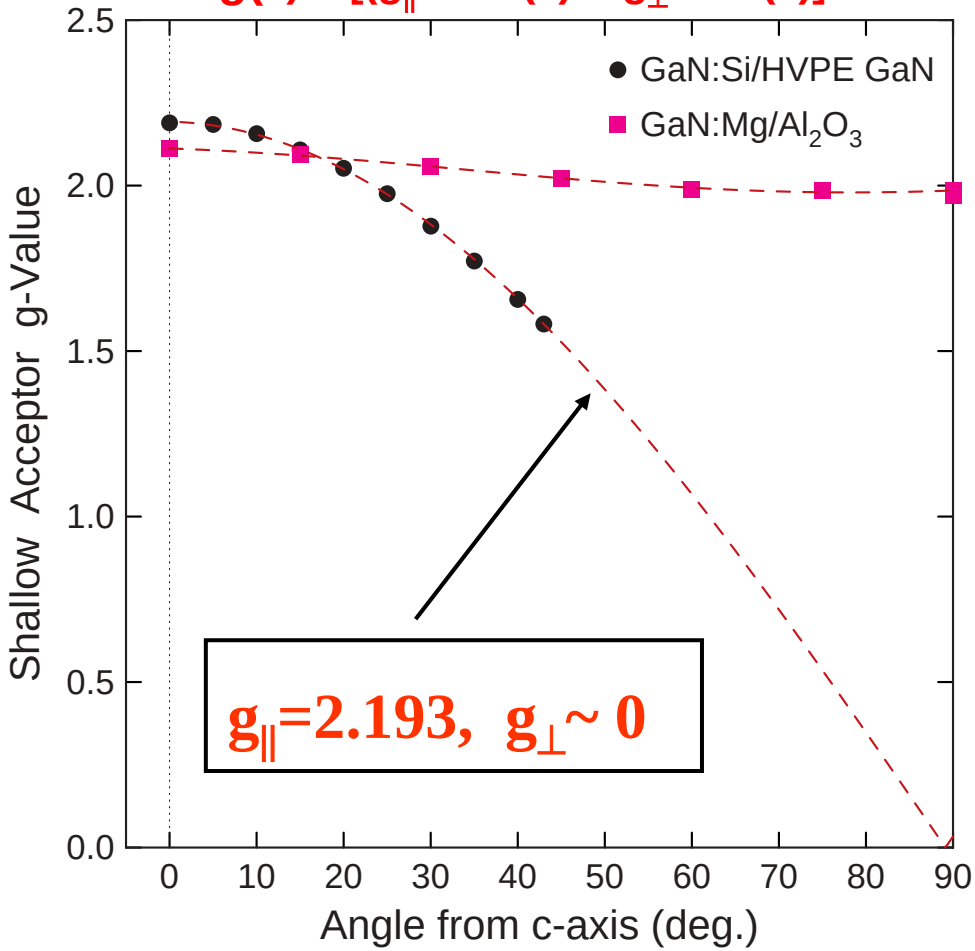
From the magnetic field splitting we find the GaN electron effective mass = $0.22m_o$

ODMR of Si-doped Homoepitaxial GaN Layers



MOCVD GaN:Si/HVPE GaN

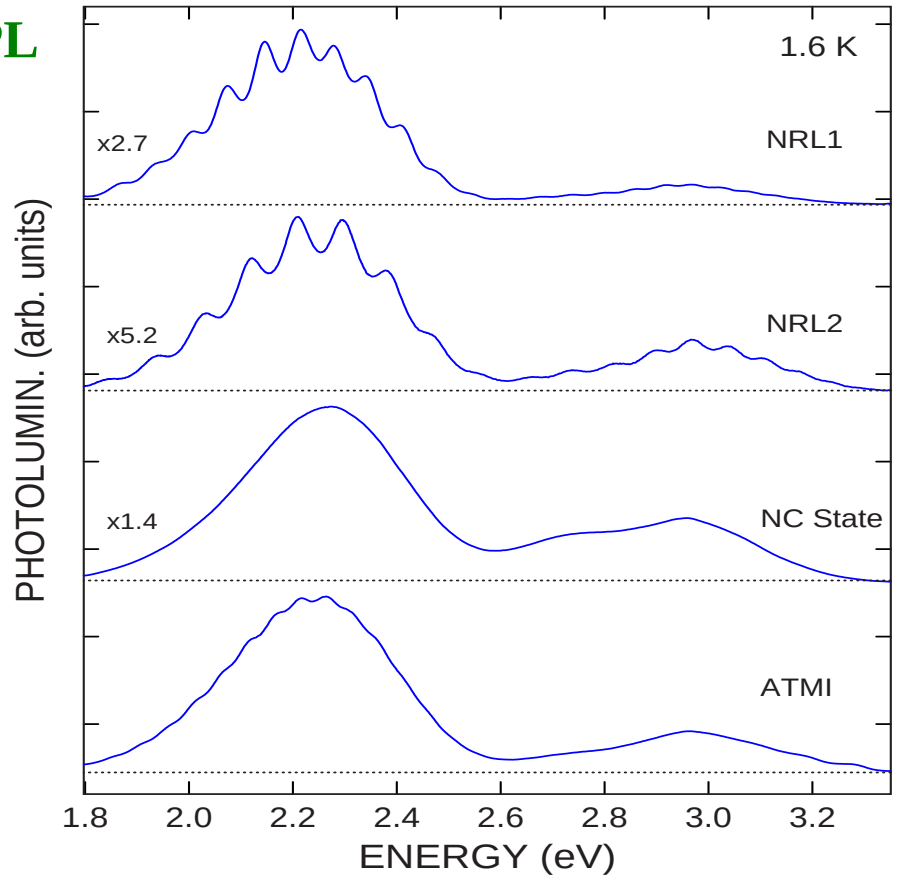
$g(\theta) = [(g_{\parallel}^2\cos^2(\theta) + g_{\perp}^2\sin^2(\theta)]^{1/2}$



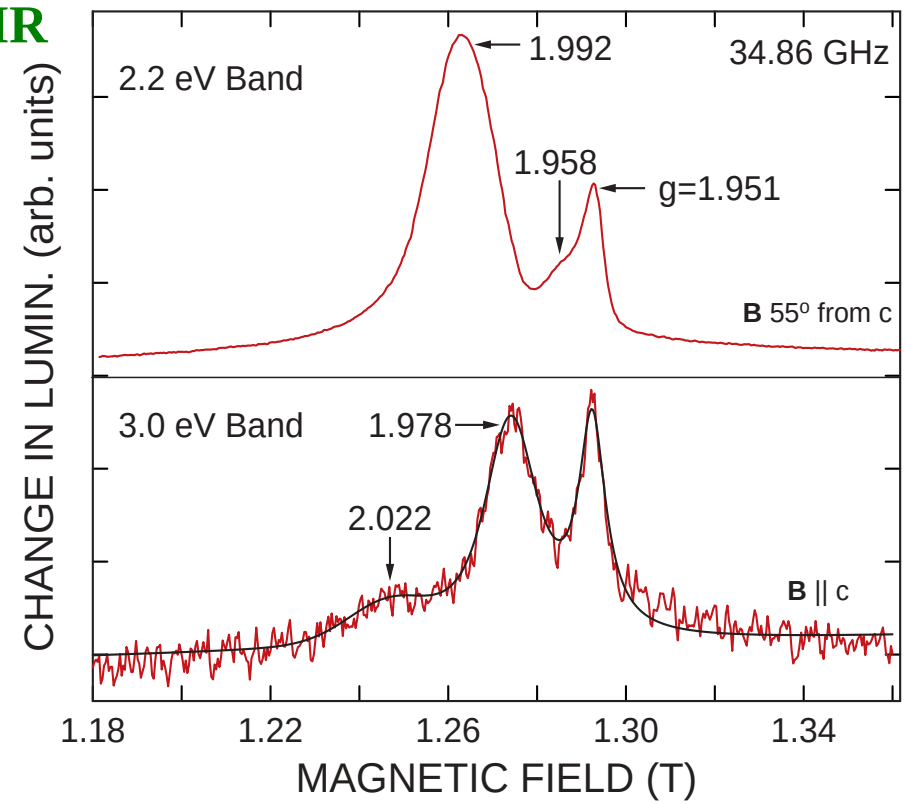
First observation via magnetic resonance of highly anistropic g-tensor predicted for shallow acceptors ("SA") in wurtzitic GaN

Optically-Detected Magnetic Resonance of High-Resistivity GaN

PL



ODMR



- In addition to sharp band-edge (excitonic) emission, two broad PL bands at 2.2 and 3.0 eV (**"optical signature"**) are observed from HR GaN.

- ODMR reveals that shallow donors (g=1.951) are active in both 2.2 and 3.0 eV bands.

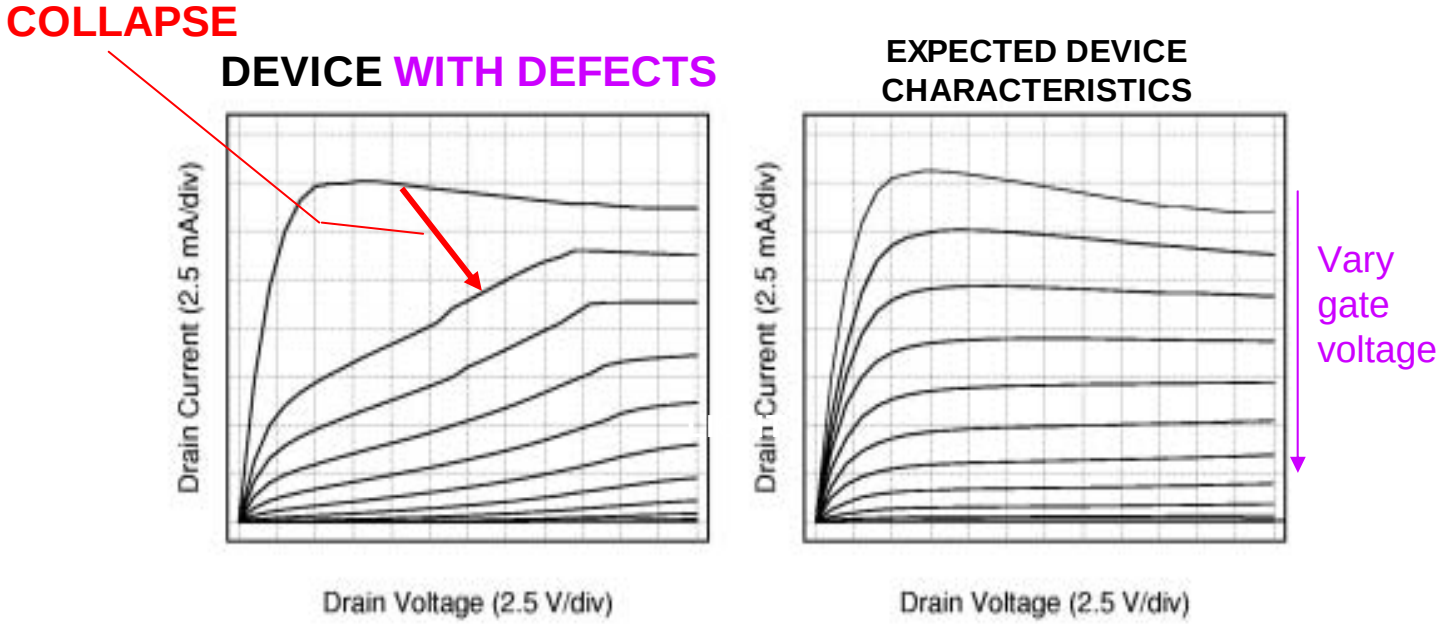
- Four additional defects (g=1.958, 1.978, 1.992, and 2.022) attributed to residual donors and acceptors are also found.

PHOTOIONIZATION SPECTROSCOPY OF DEFECTS IN WIDE BANDGAP ELECTRONIC DEVICES

CURRENT COLLAPSE IN WIDE BANDGAP DEVICES

- **SOME DEVICES EXHIBIT OUTPUT DEGRADATION AFTER TURN-ON.**
  - **Due to MATERIAL DEFECTS.**
- **DEFECTS CAUSE** "Current Collapse".
  - **Defect** traps **mobile charge carrier -** reduces device current & power.

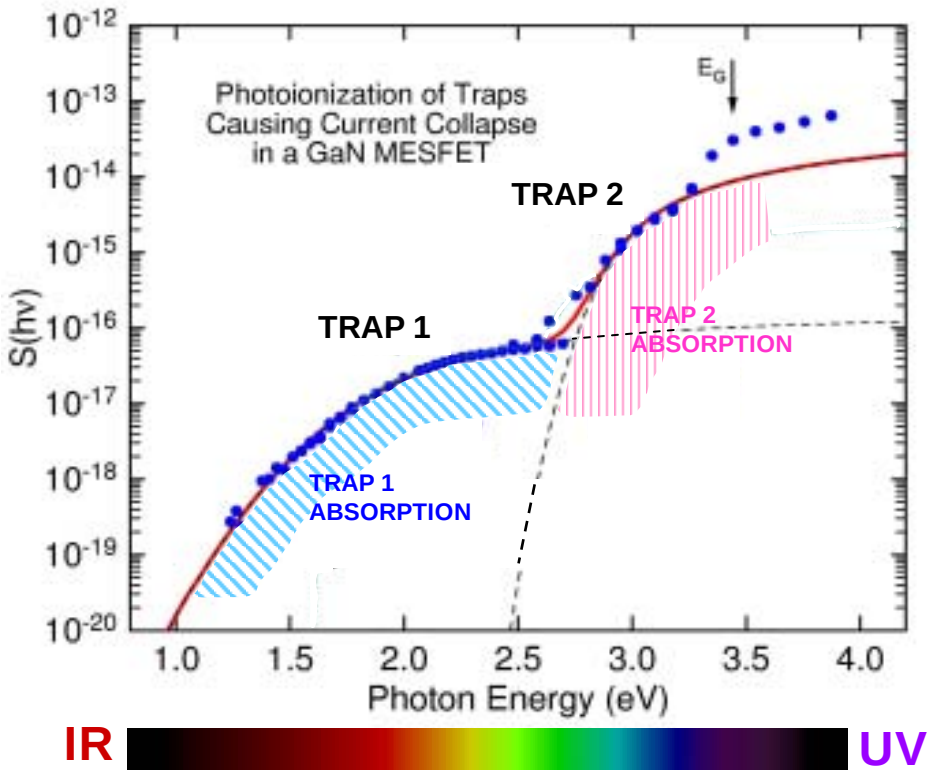
Device Drain Current vs. Drain Voltage

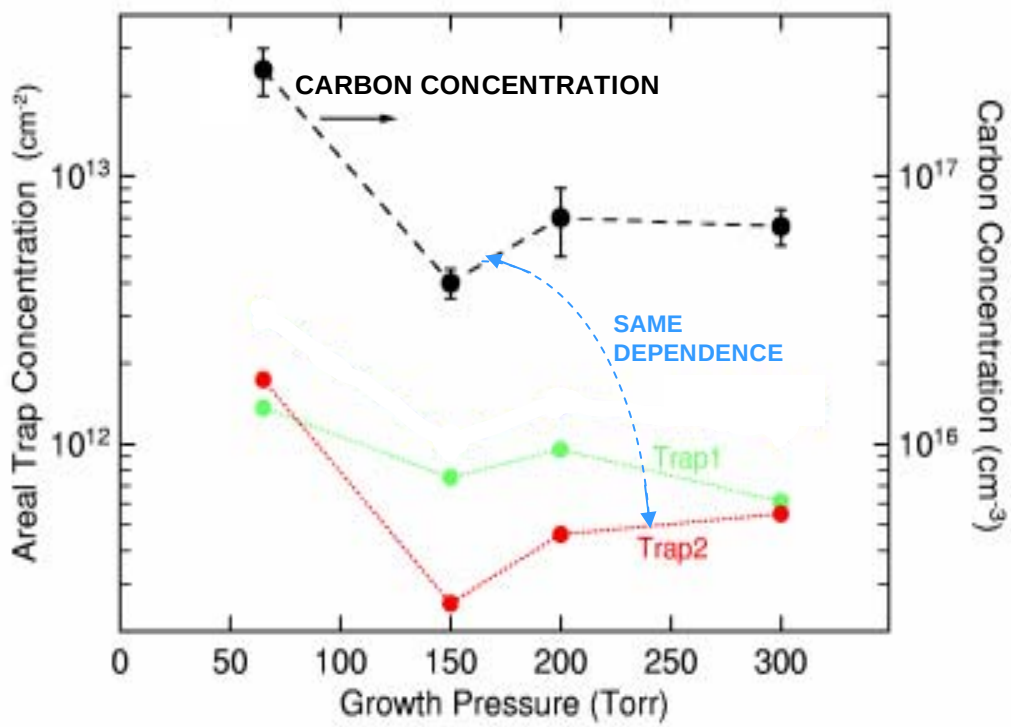


- LIGHT **WILL FREE (PHOTOIONIZE) CARRIERS FROM TRAPS AND** RESTORES DEVICE PROPERTIES.
- ⇒ **USE LIGHT ABSORPTION PROPERTIES OF DEFECTS TO** IDENTIFY **&** QUANTIFY **DEFECTS.**

Photoionization Spectroscopy of Defects (Traps)

- **NEW technique developed at NRL**
  - **Dependence of defect light absorption on wavelength (color).**
  - **Spectrum determines** unique fingerprint of each defect.
  - **Provides method to determine** concentrations of defects.
  - **Leads to method of** defect identification.
  - **Essential information for defect** elimination.



Defect Identification from Photoionization Spectroscopy

- **Defect incorporation affected by material growth conditions.**
- **Variation of Trap1 & Trap2 concentrations with material growth pressure:**
  - **Concentration of Trap2 TRACKS concentration of** CARBON**.**
    - Trap2 is carbon-related defect**.**
    - **Reduction of carbon expected to reduce this effect.**
  - **Trap1 concentration varies similar to** structural defects.
    - **Current studies probing this relationship.**