Single Event Effects in $Al_{1-x}Ga_xN/GaN$ HEMTs

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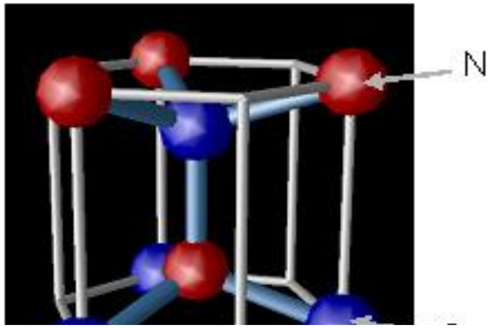
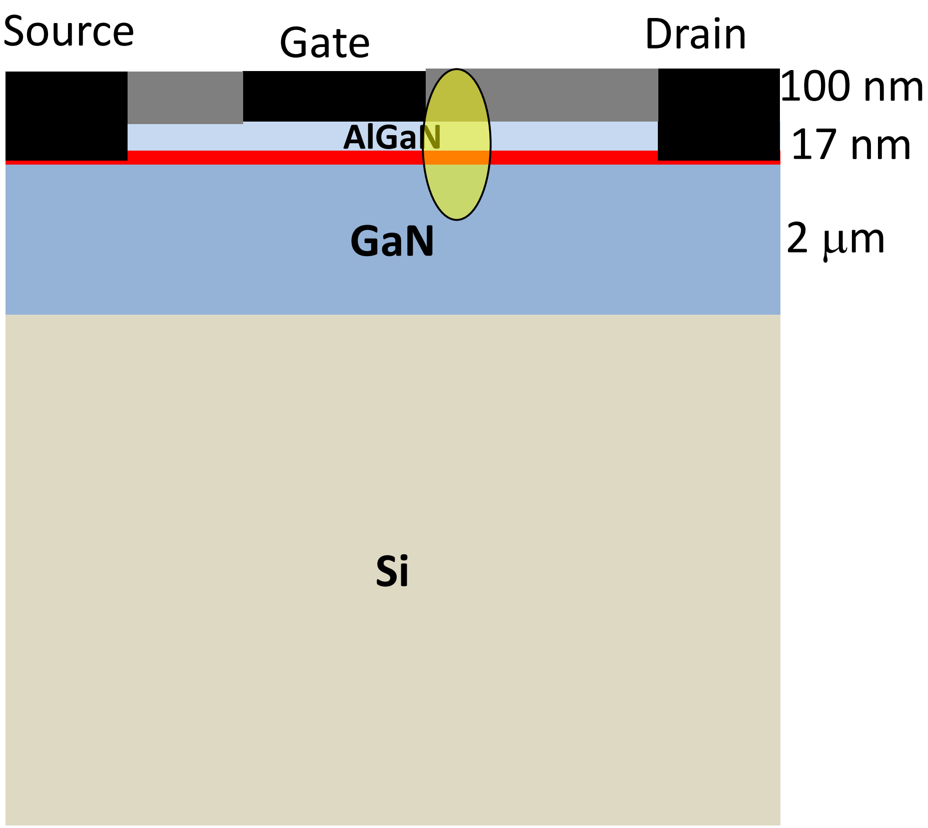
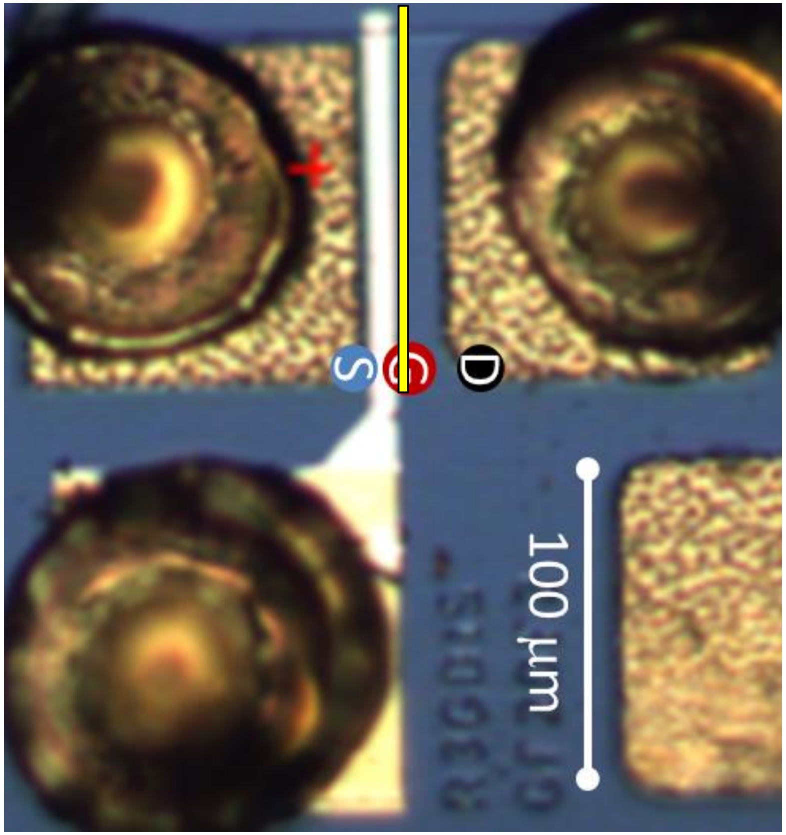
Introduction GaN HEMT

- Material structure
  - Hexagonal (Wurzite)
  - Polar in (0001) direction
  - Ga and N form layers
- E_g = 3.4 eV
- E(crit) = 3×10^6 V/cm
- μ_e = 900 $cm^2/V.s$
- High temperature operation.
- 2D electron gas without doping.
- Small footprint makes it **attractive for space**

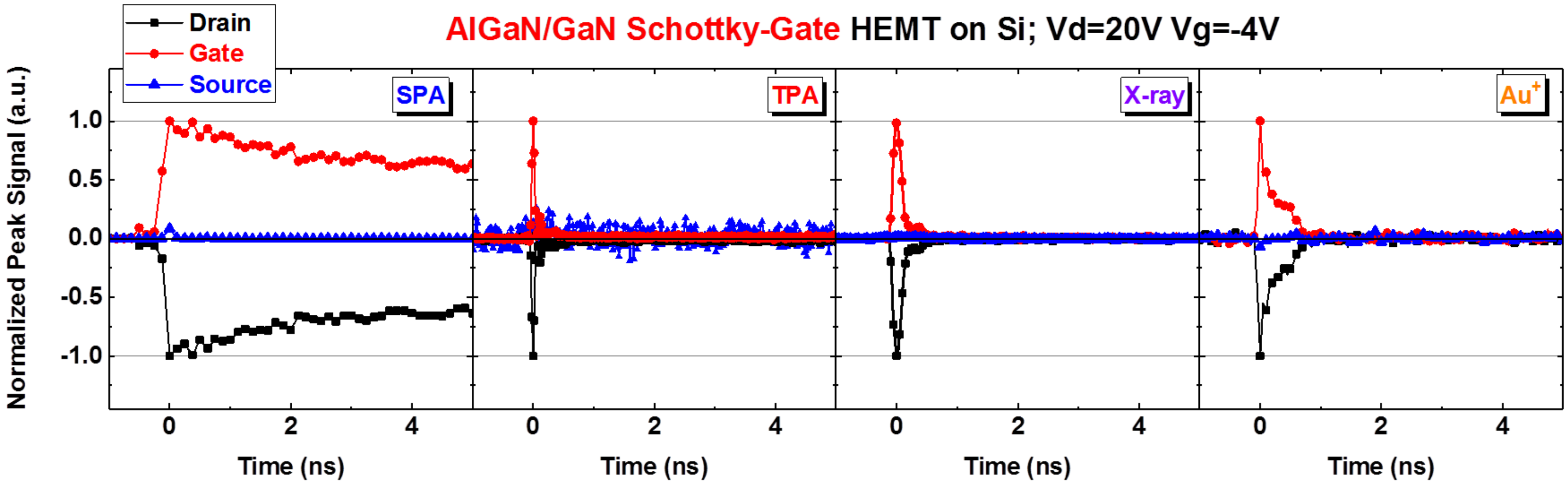


AlGaN/GaN HEMT Structure

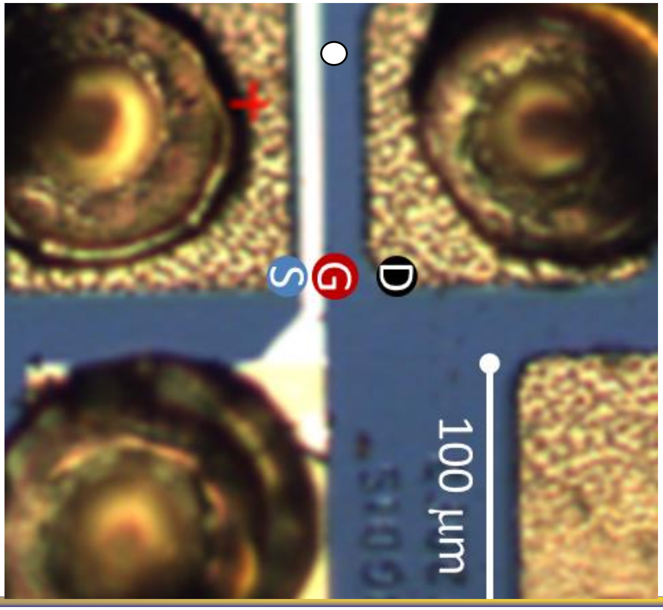




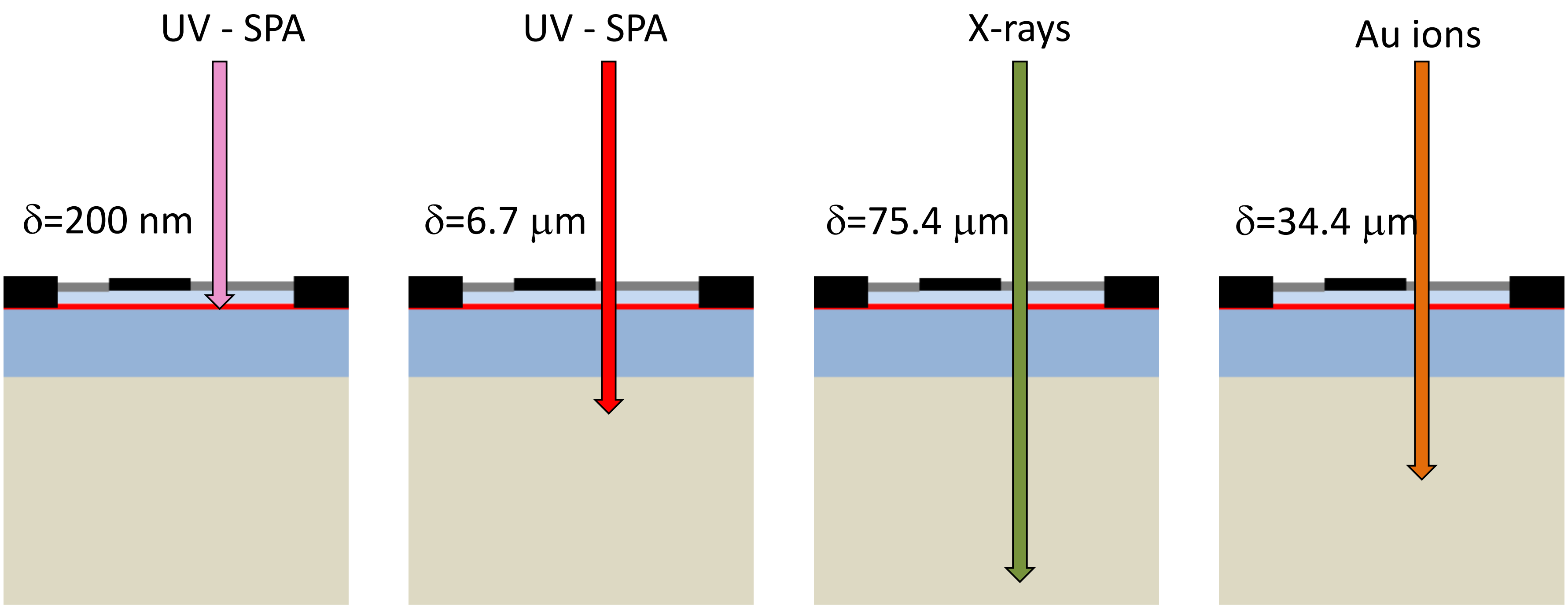
SETs From Four Radiation Sources



- Beam focused on:
  - ❑ Same HEMT
  - ❑ Same location



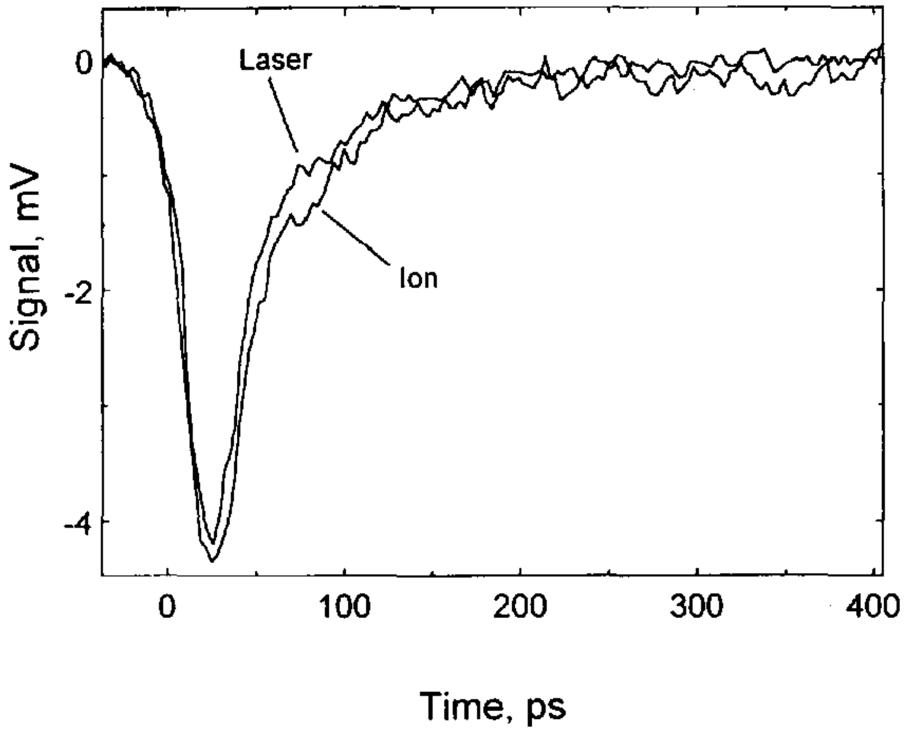
Relative Penetration Depths



Goals

1. Can pulsed lasers be used to ***simulate*** SETs generated by heavy ions?
2. What are the ***mechanisms*** responsible for SETs in GaN HEMTs?

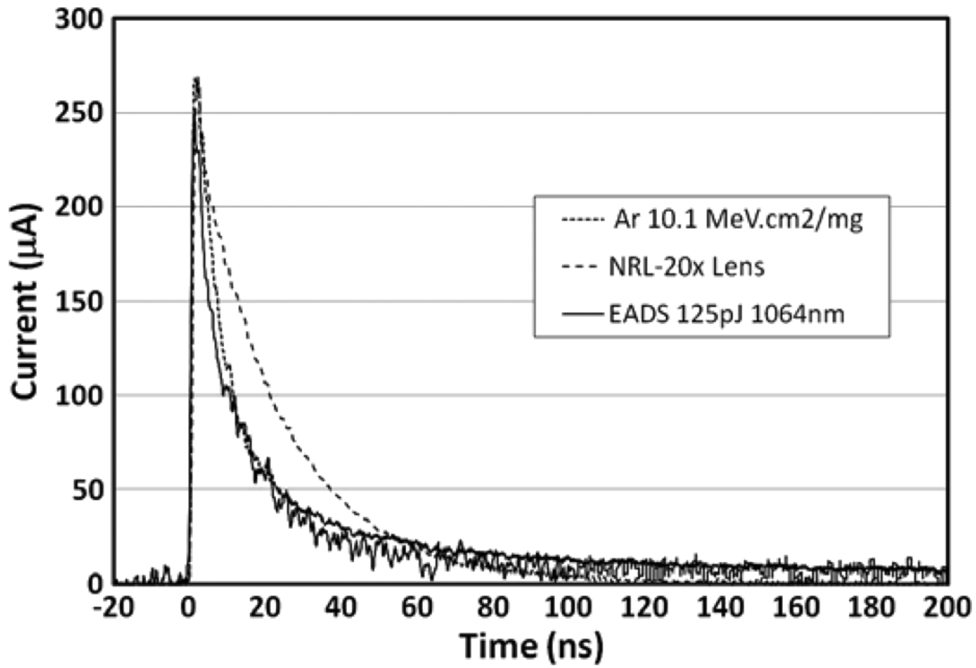
3 MeV ^{4}He ions and pulsed laser light



- δ(1/e)=**0.21 µm** for λ=620 nm
- Range for He ions = **9.2 µm**
- Charge Collection Depth = **0.8 µm**

D. McMorrow *et al., IEEE TNS, vol. 40, no. 6, pp. 1858-1866, 1993*.

10 MeV Ar ions and pulsed laser light



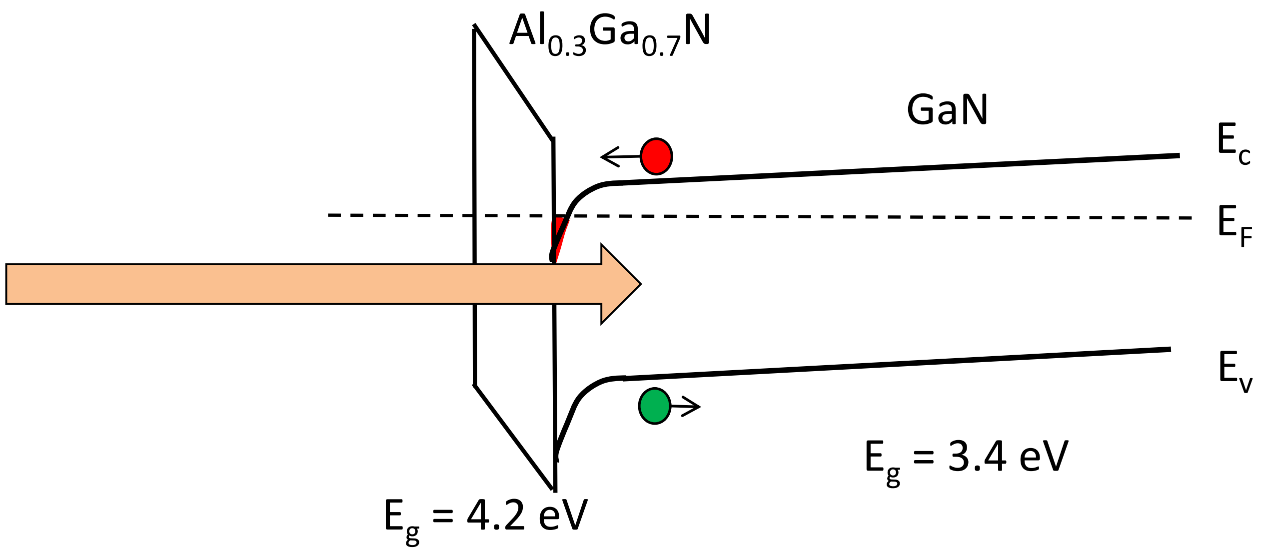
- δ(1/e)=**1.7 μm** for λ=590 nm
- δ(1/e)=**676 μm** for λ=1064 nm
- Range for Ar ions = **120 μm**
- Charge Collection Depth = **19 μm**

S. Buchner, *et. al.*, *IEEE TNS,* vol. 59 (4), pp. 988-998, 2012.

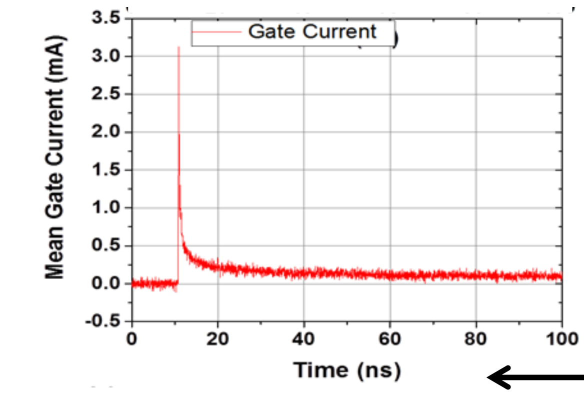
Single-Photon Absorption

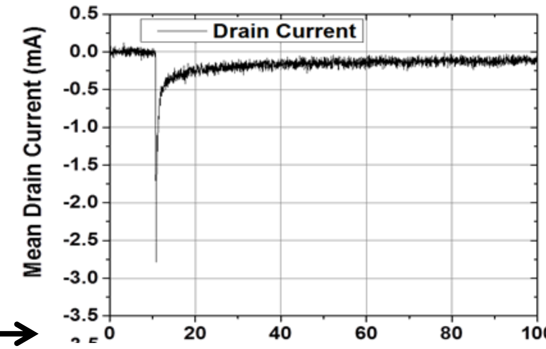
Single-Photon Absorption

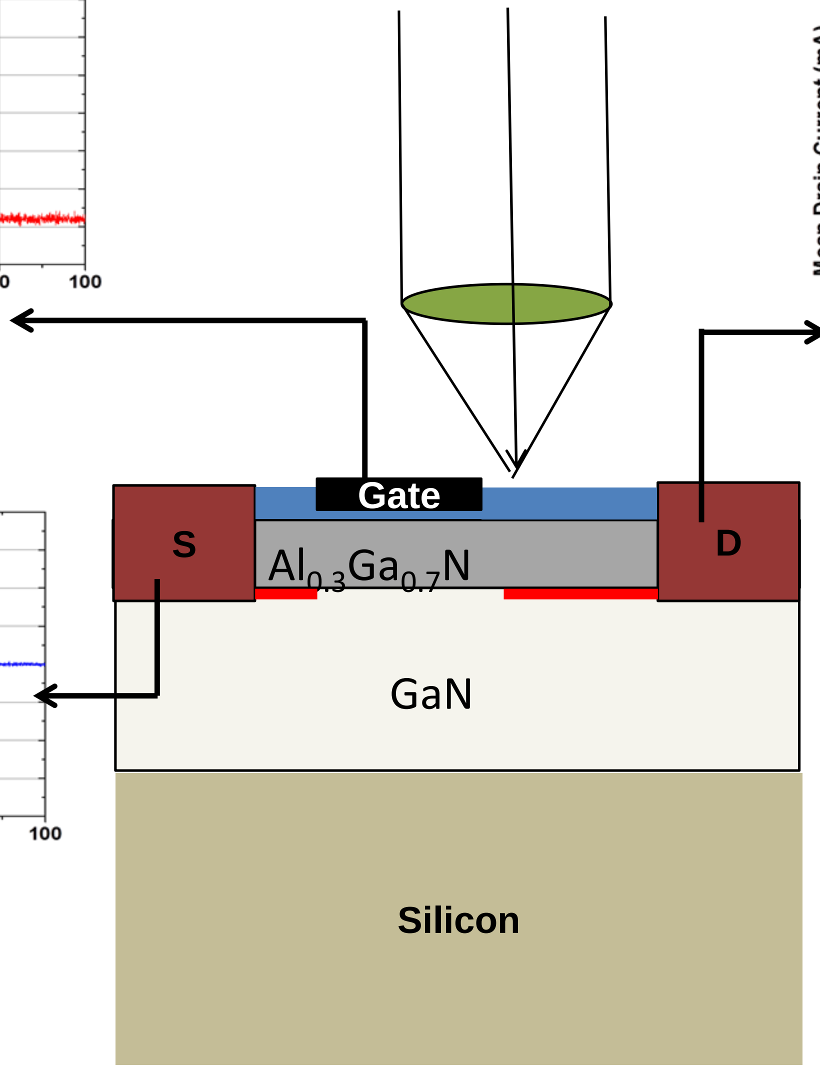
- Photon Energy = 4.2 eV (UV)
- Spot size = 0.3 μm
- Pulse width = 1 ps
- ***Short penetration depth in GaN = 200 nm***

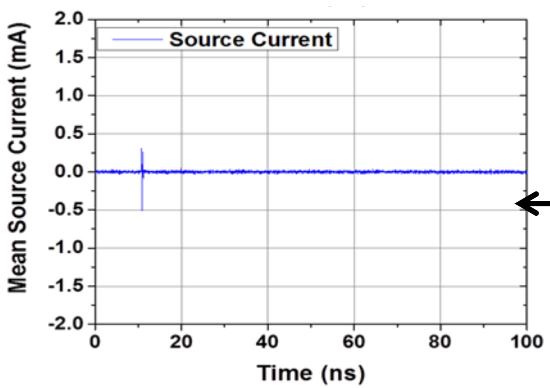


Experimental Setup



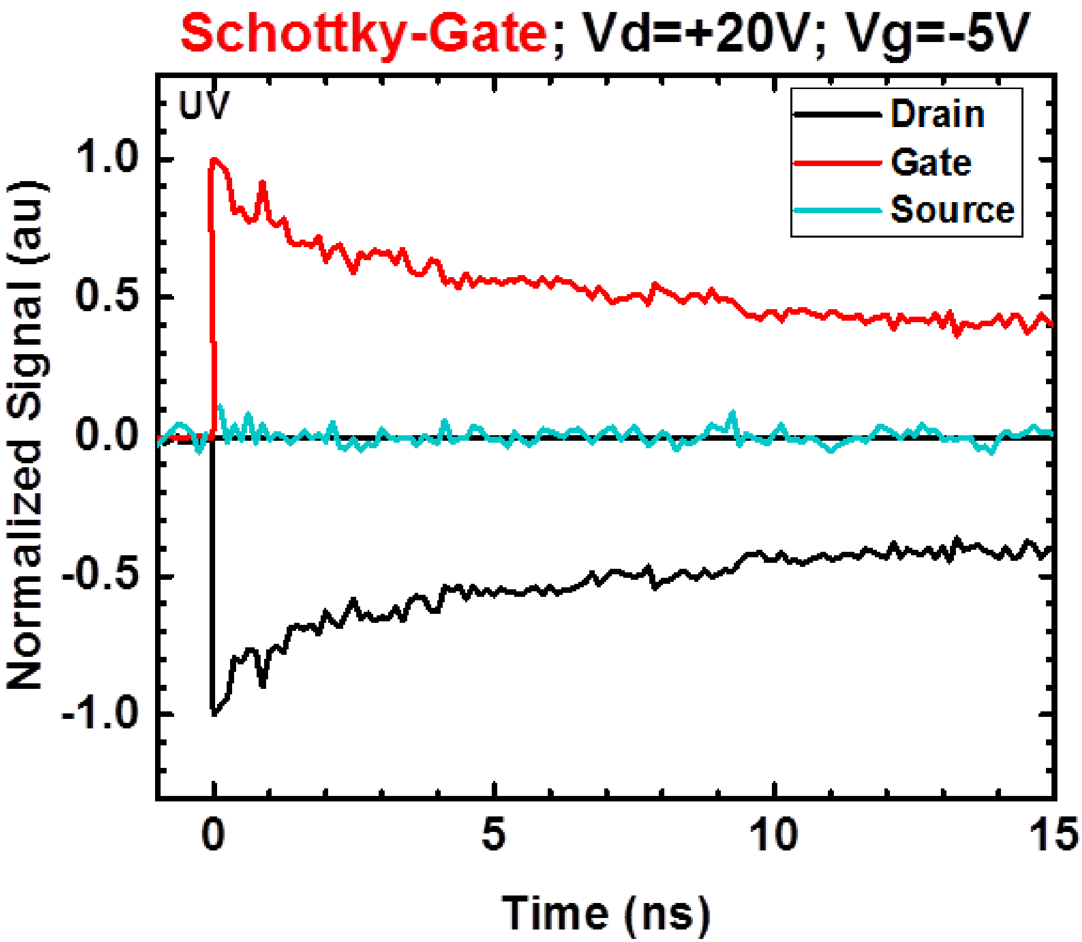






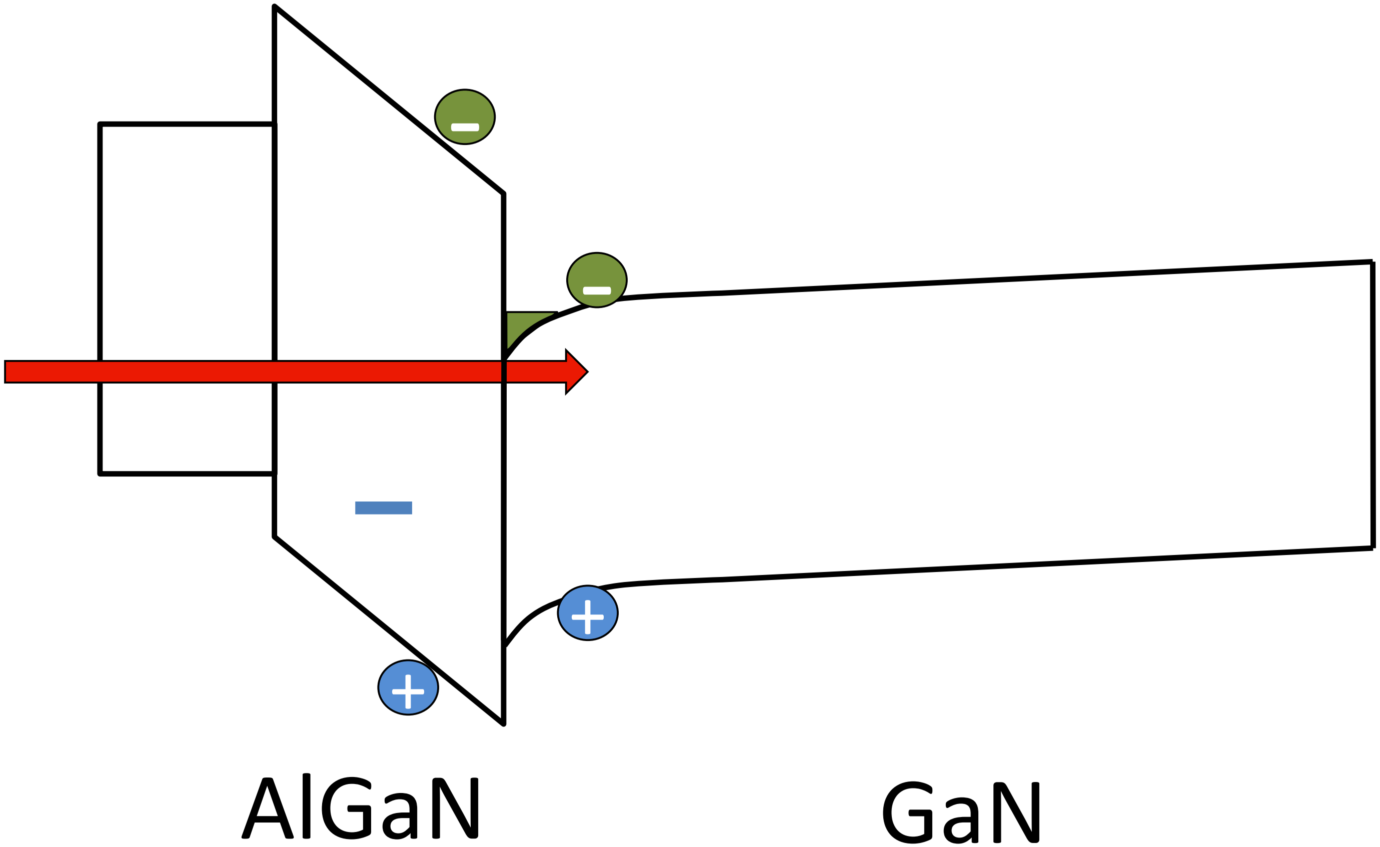
Bias Tees used to isolate signals from biases

SETs Induced by SPA

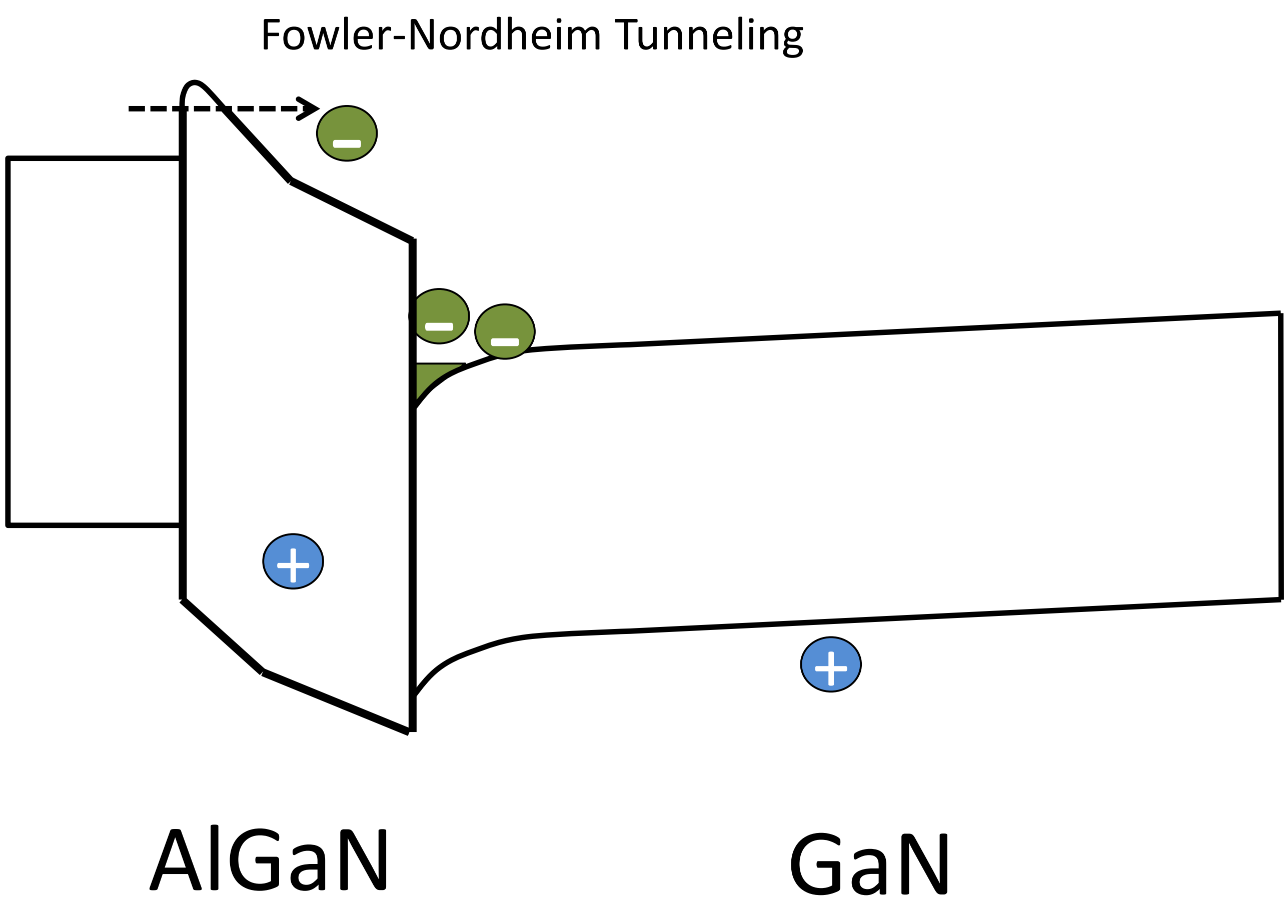


- Unique mechanism:
  - *Electrons to drain*
  - *Holes to gate*
- Long tails imply more charge collected than deposited 1800X
- Suggest traps play a role

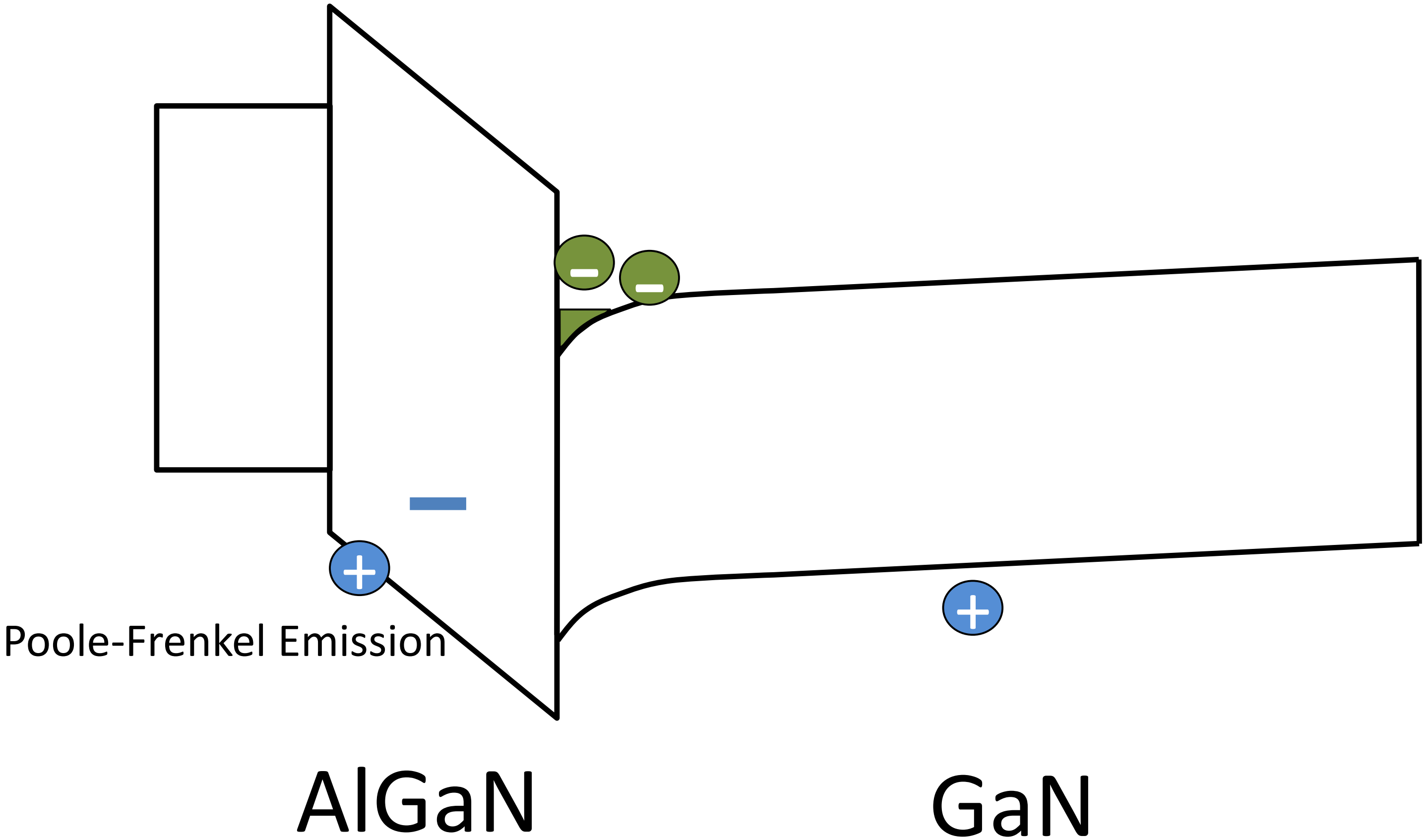
Mechanism for SPA Induced SETs



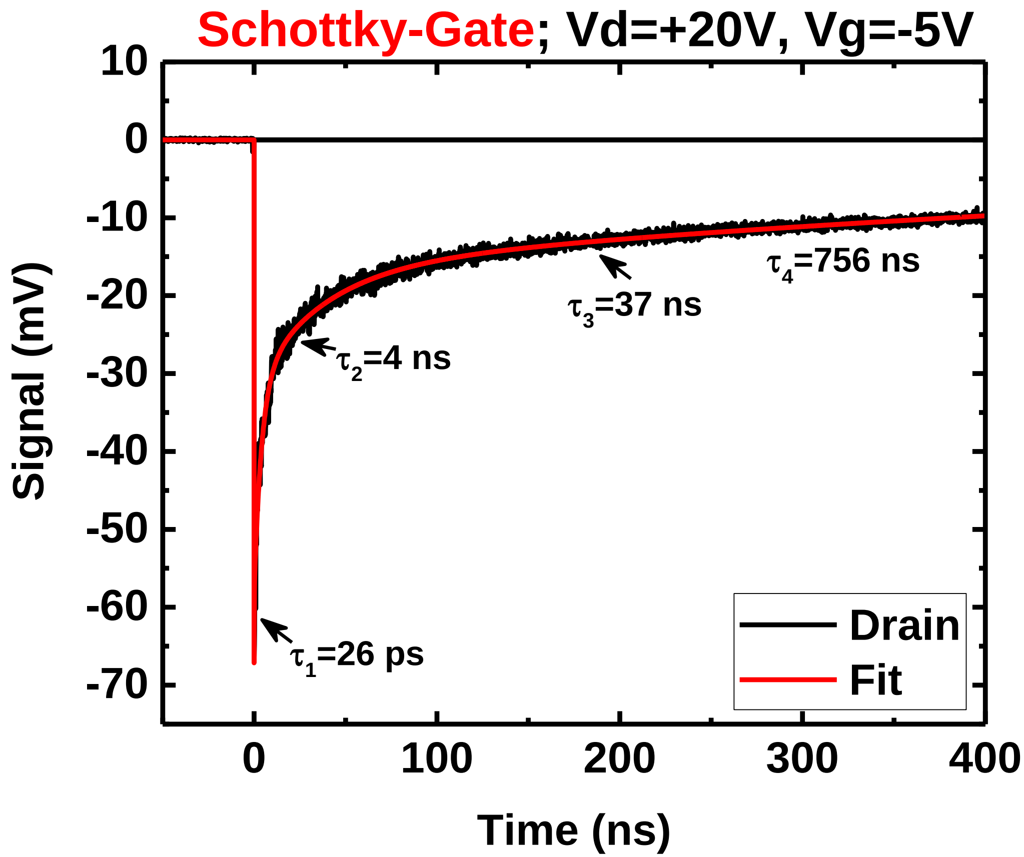
Mechanism for SPA Induced SETs



Mechanism for SPA Induced SETs

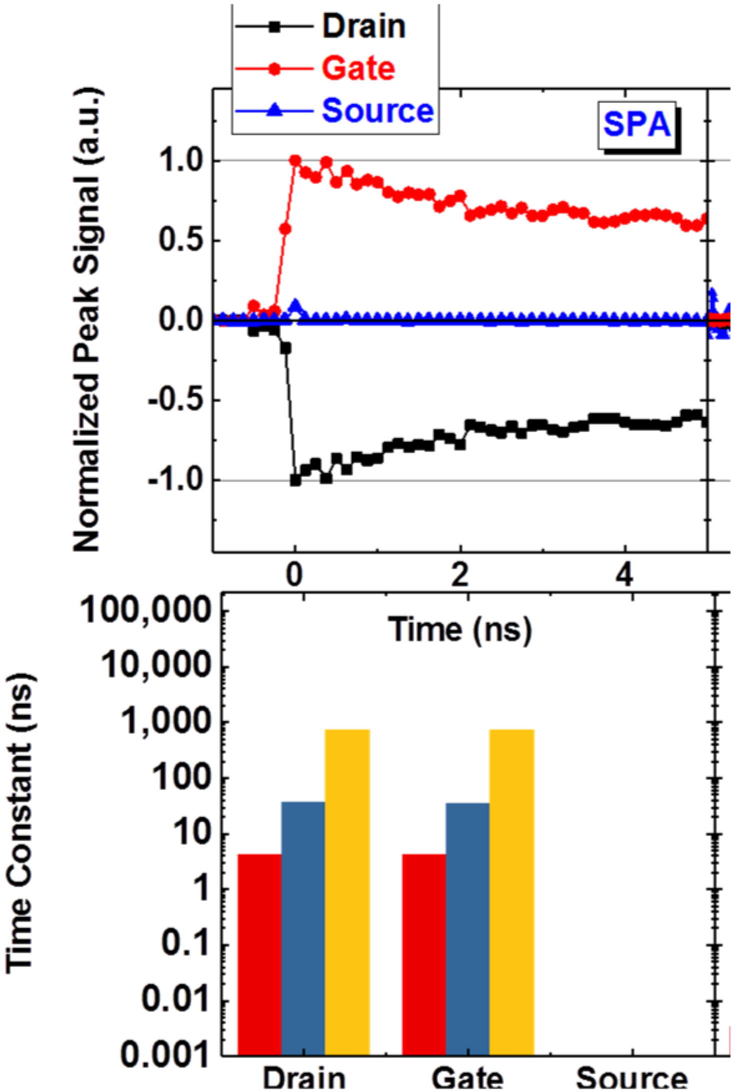


SET Analysis to Obtain Trap Lifetimes



$$y(t) = \int_{-\infty}^{+\infty} e^{\frac{-(t-t')^2}{2\cdot w^2}} \cdot \sum_{i=1}^{n} A_i \cdot e^{\frac{-t'}{\tau_i}} dt'$$

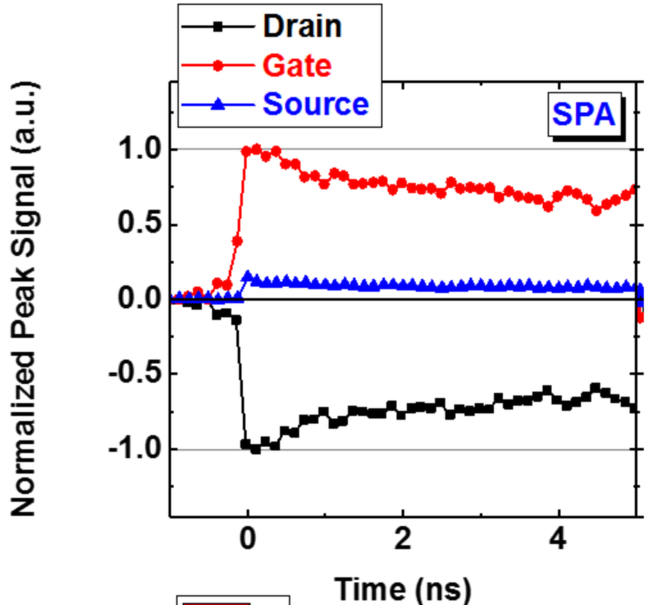
Analysis of SPA SEEs– biased OFF

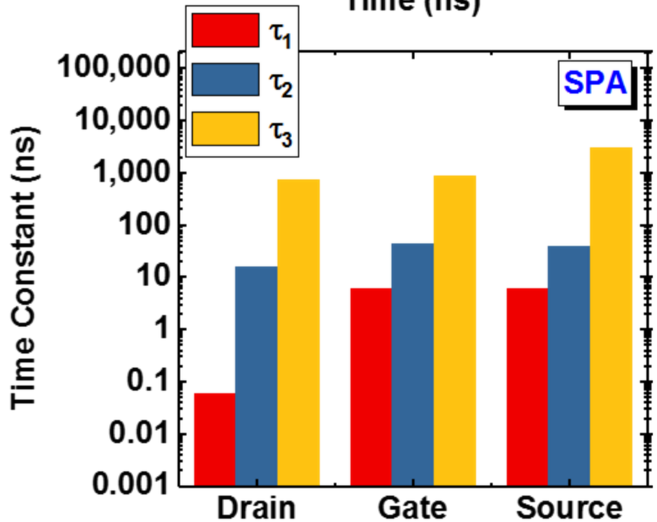


V_s = 0V
V_g = -4V
V_d = 20V

Source SET is absent

Analysis of SPA SETs – biased ON

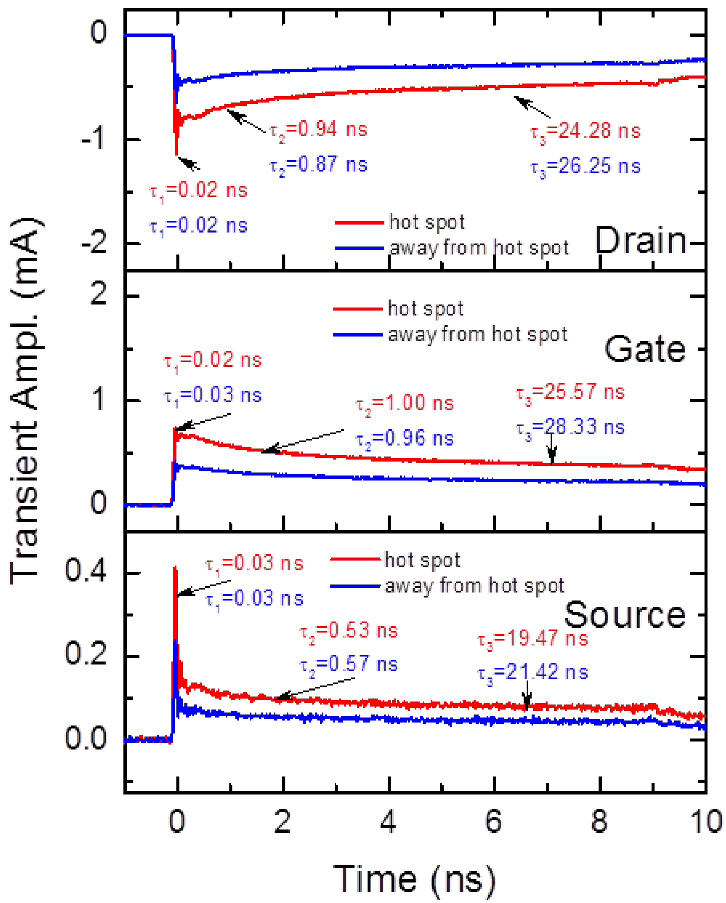




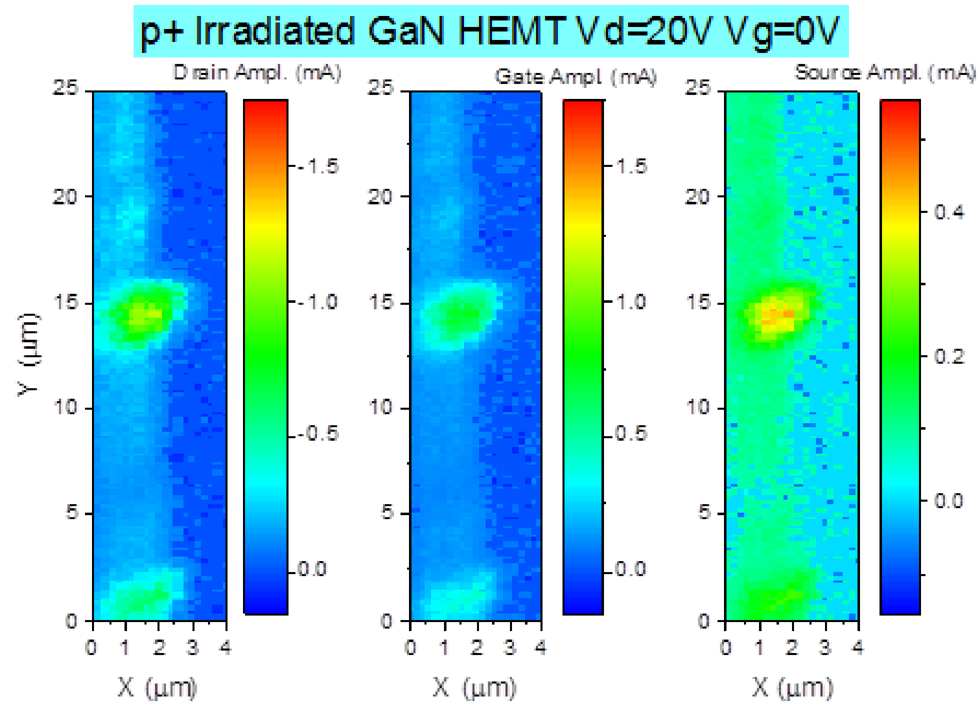
$V_s = 0V$
$V_g = +1V$
$V_d = 20V$

Source has a small but long lasting tail

SET Amplitude Maps – Proton Irradiated



- *Vg = 0 V; biased "on"*

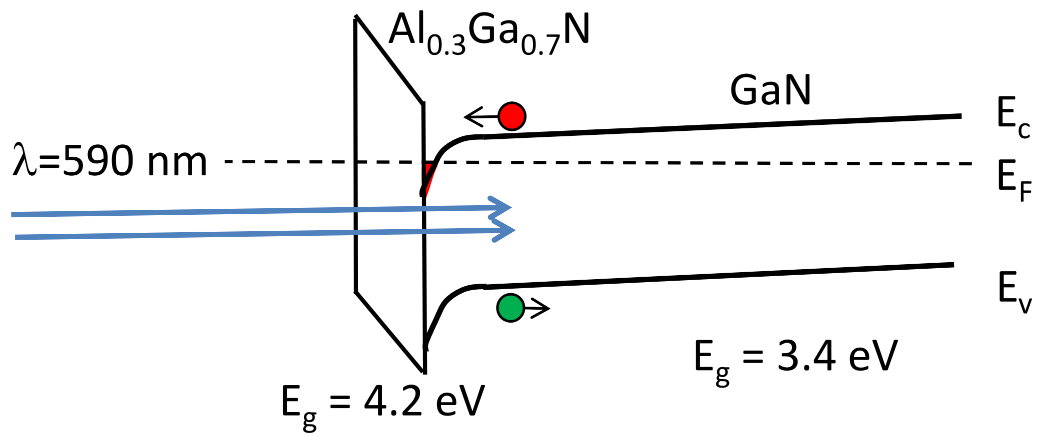


- The shapes of the transients provide insights into the nature and density of defects
- Analysis of the transients is consistent with traps with lifetimes ranging up to 30 ns
- Consistent with *radiation-induced Nitrogen vacancies*

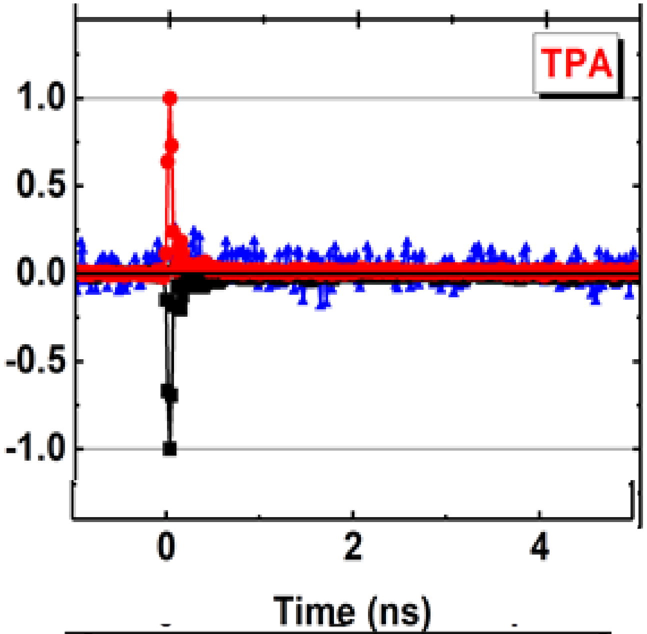
Two-Photon Absorption

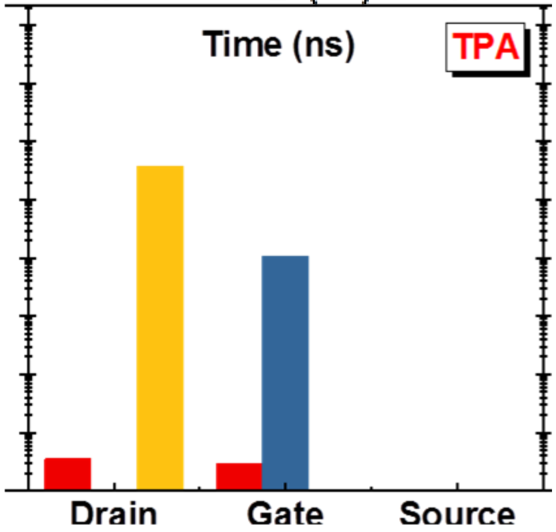
Two-Photon Absorption

- Photon Energy = 1.96 eV (visible)
- Spot size = 1.0 μm
- Pulse width = 150 fs
- Penetration depth depends on beam optics ~ 6.7 μm



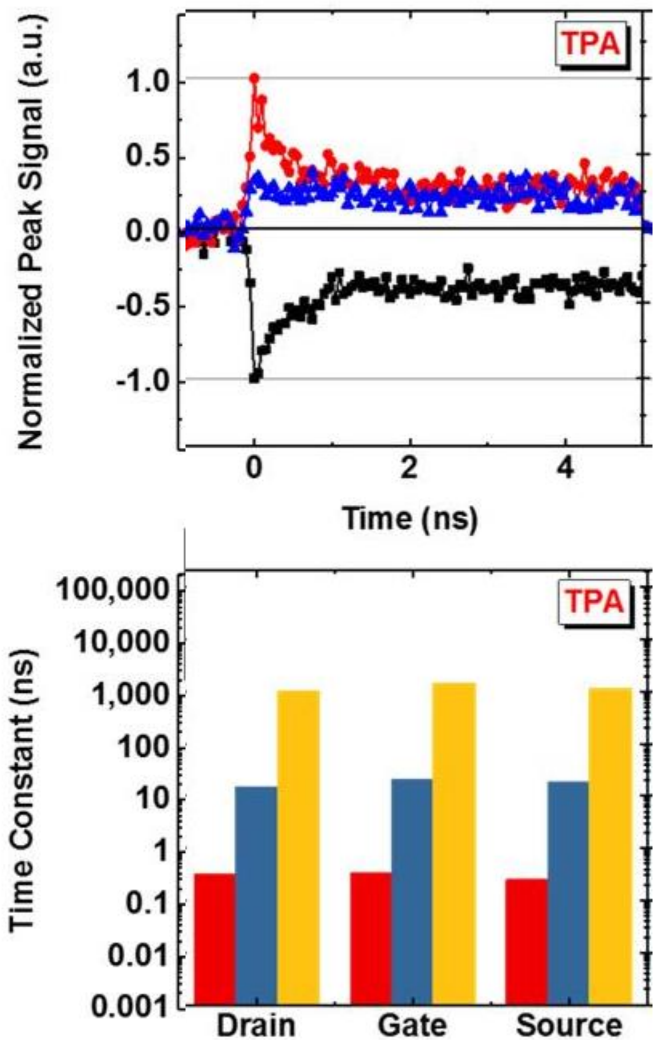
SETs for HEMT Biased OFF





- Electrons collected at drain
- Holes collected at gate
- No signal on source
- Much smaller tail

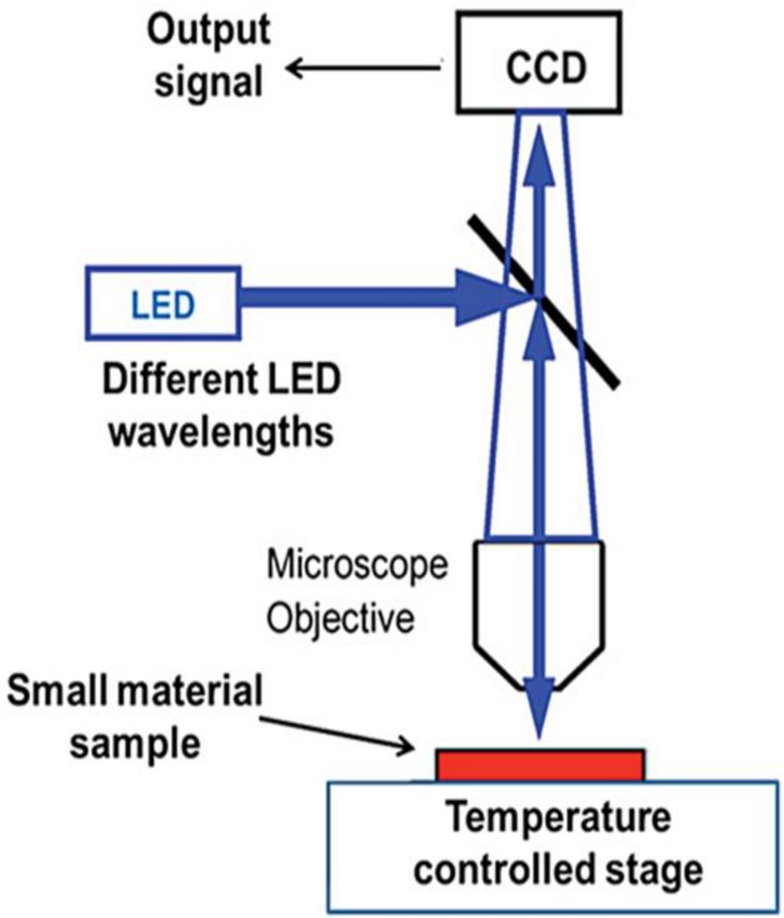
SETs for HEMT Biased ON



- Electrons collected at drain
- Holes collected at gate and source
- Much longer tail

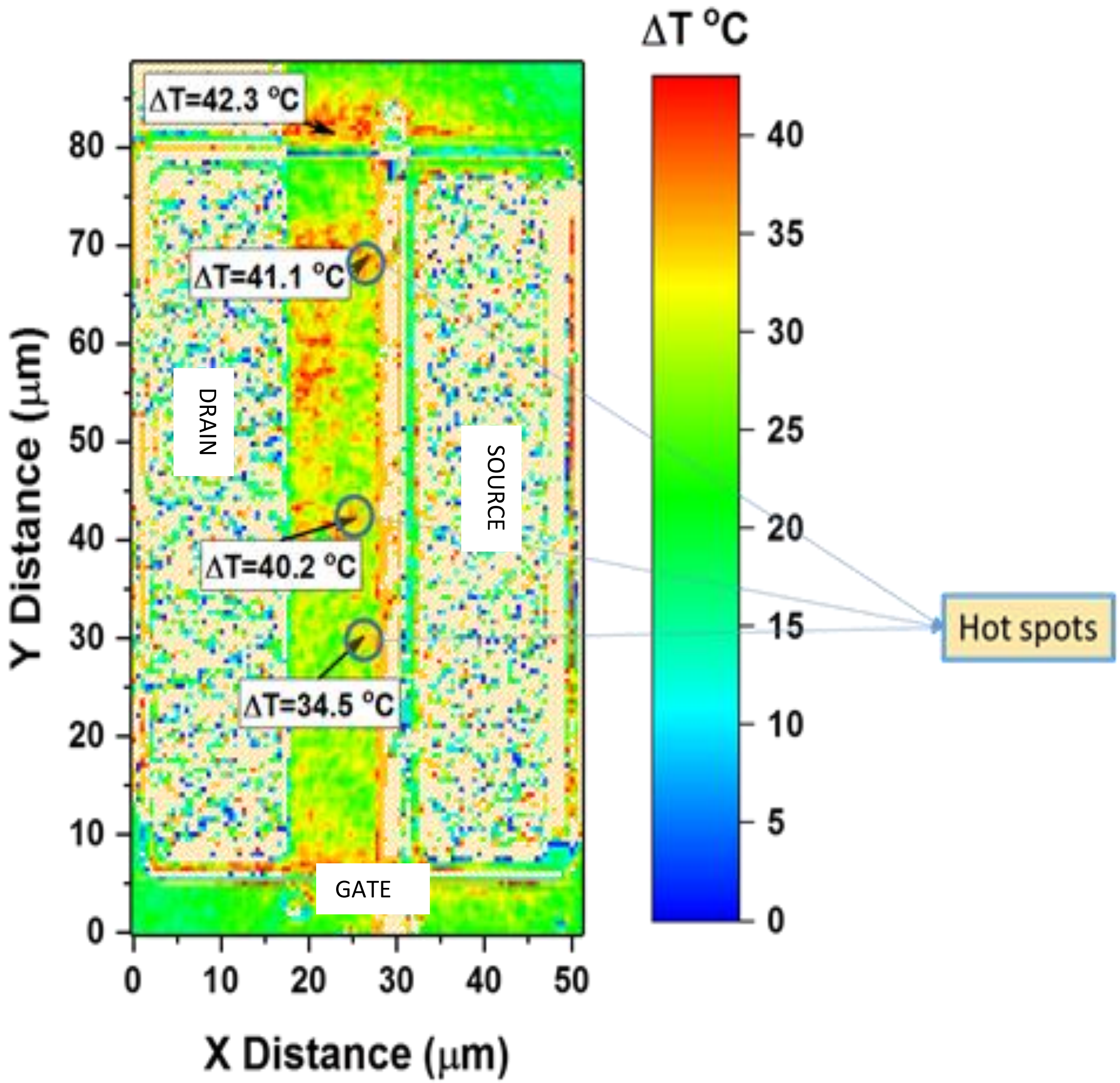
Thermo-Reflectance Thermography

Thermo-Reflectance Thermography

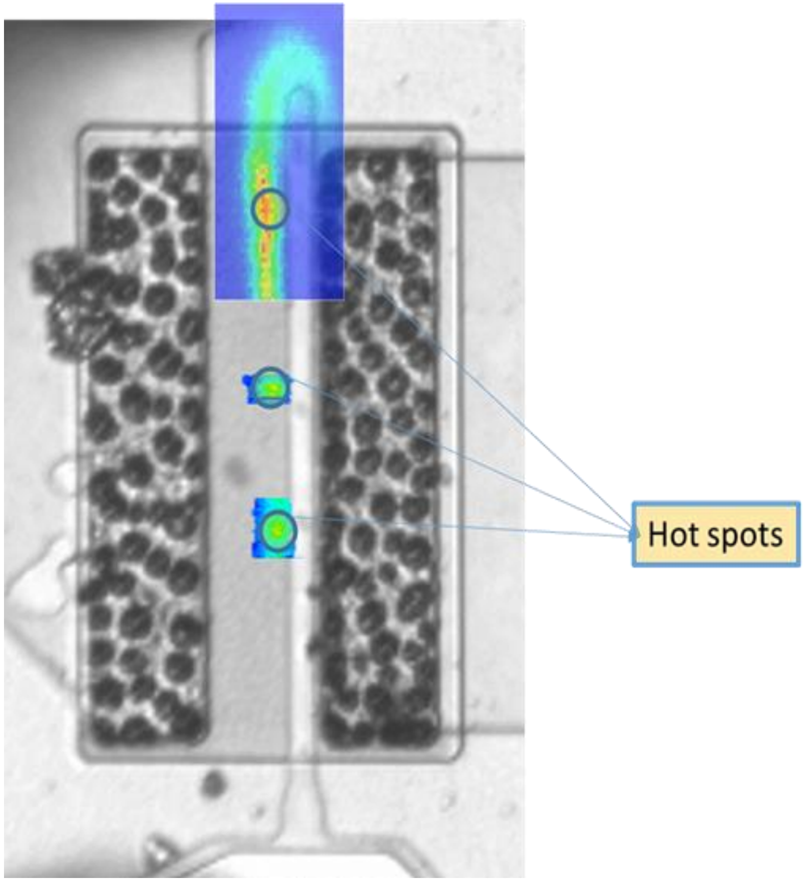


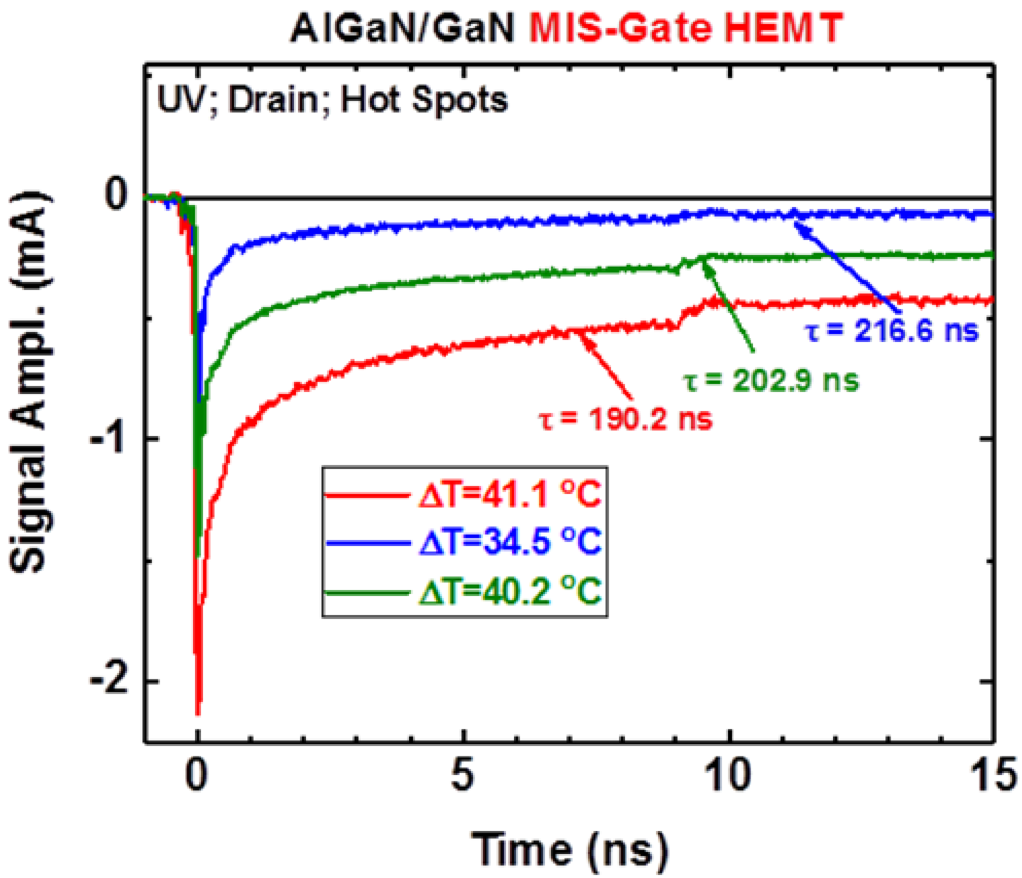
- Select optimum wavelength for largest DR
- Bias HEMT on so current can flow
- Apply square wave to drain (0V – 20 V)
- Measure difference in reflectivity DR
- Calibrate by heating HEMT and measuring DR/R
- Micron resolution for DT

Thermo-Reflectance Thermography



Relationship between TRT and SET





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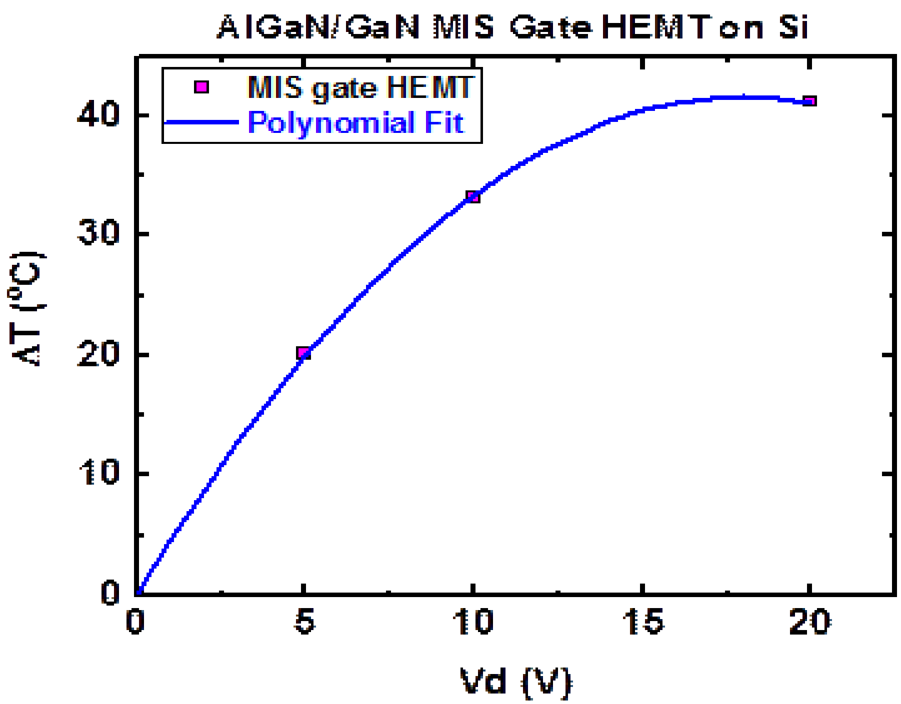
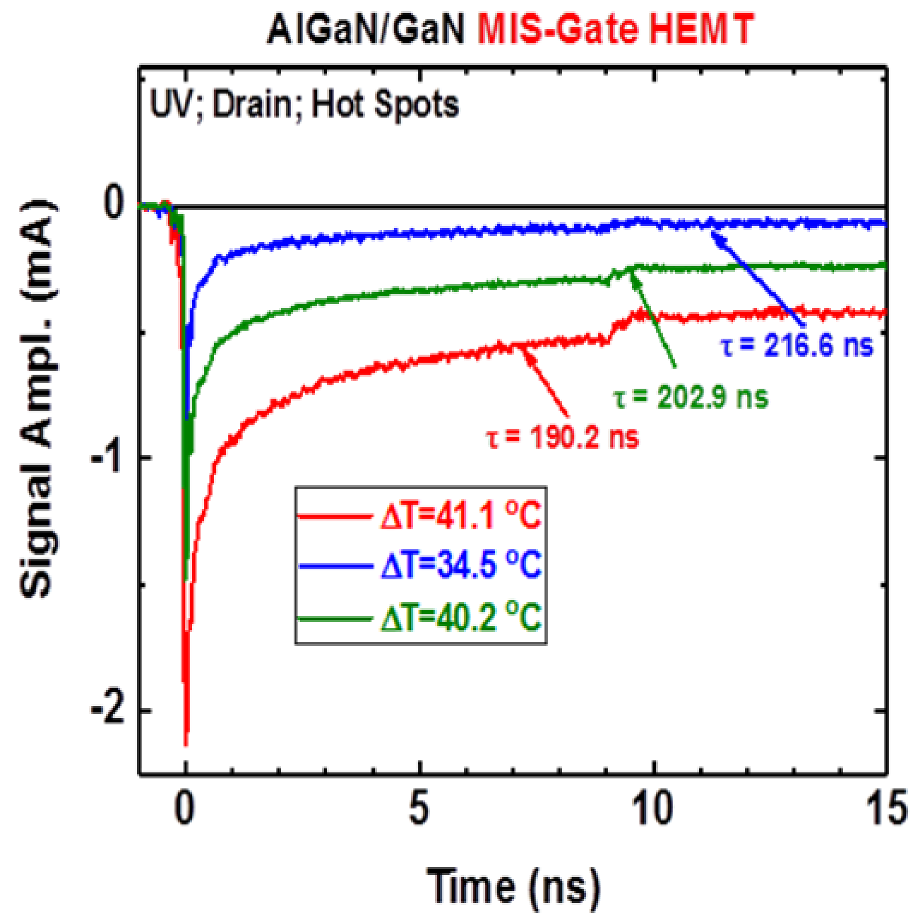
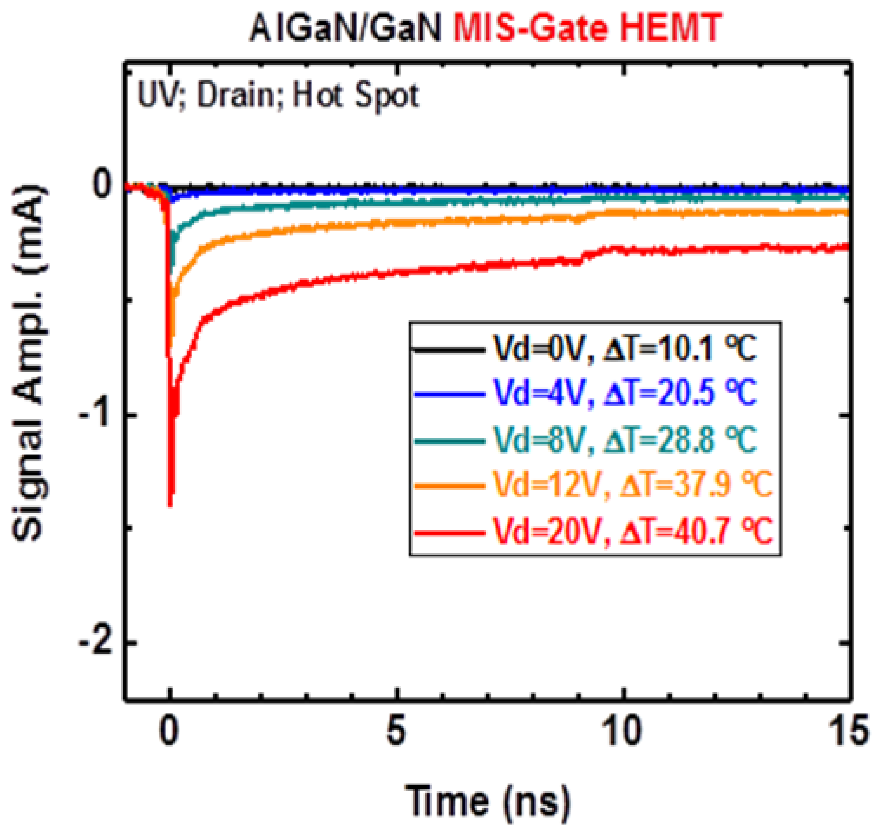




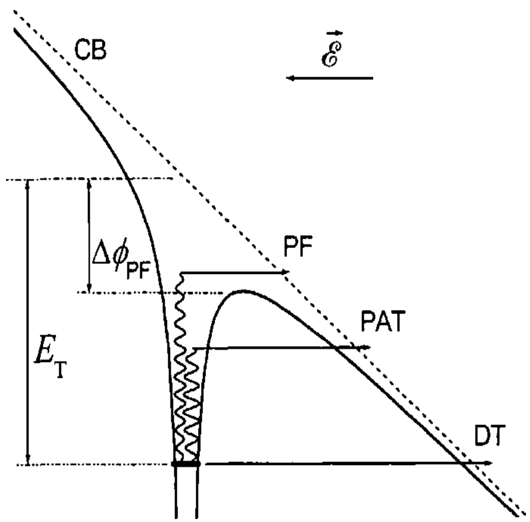
Relationship between TRT and SET

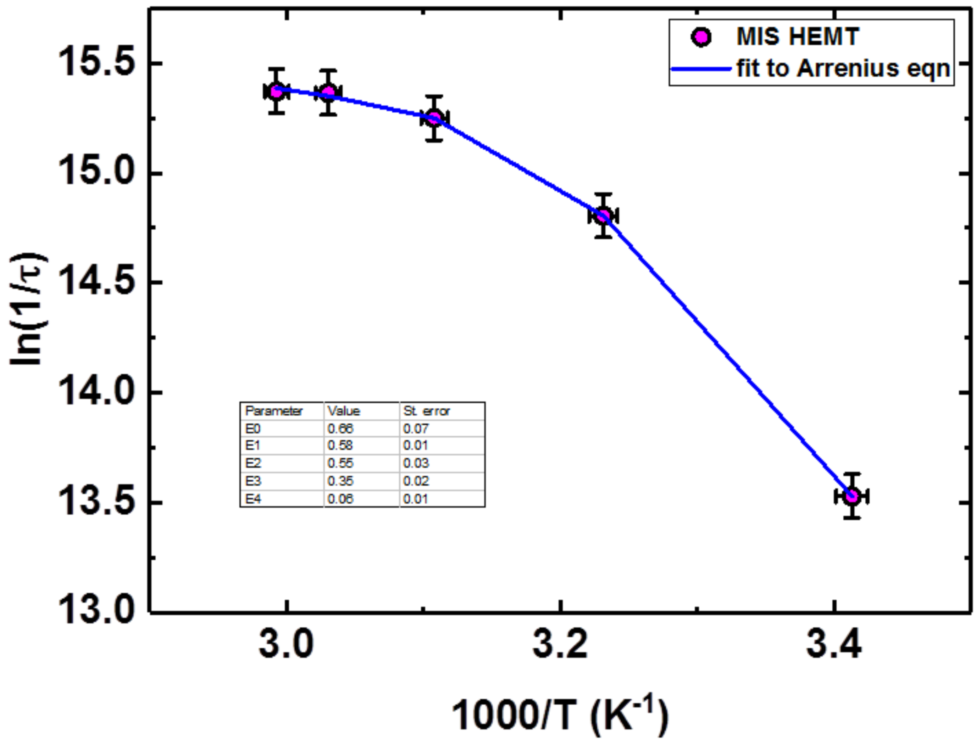
Drain Bias (Volts)	Temp. Change (°C)	Decay Time (ns)
0	0.0	1333
4	20.5	372
8	28.8	238
12	37.9	212
20	40.7	211



Arrhenius and Poole Frenkel

$$\frac{1}{\tau(F,T)} = AT^2\exp[-\frac{E_T-\Delta\varphi_{PF}(F)}{kT}]$$





O. Mitrofanov et al, Jour. Appl. Phys. Vol 95 No. 11 (2004)

Summary

1. Irradiated GaN HEMT with four different sources – SPA, TPA, X-ray and Focused ion beam
2. SETs generated by UV light have long tails due to presence of surface traps.
3. An important factor determining SET shape is the penetration depth relative to the charge collection depth.