

ShanghaiTech GaNology Lab
氮化镓电子器件实验室

Electrical Characteristics of Neutron-irradiated GaN Schottky Barrier Diodes

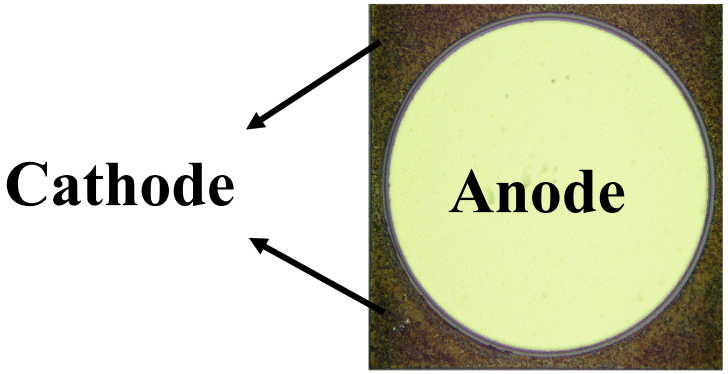
Seminar report

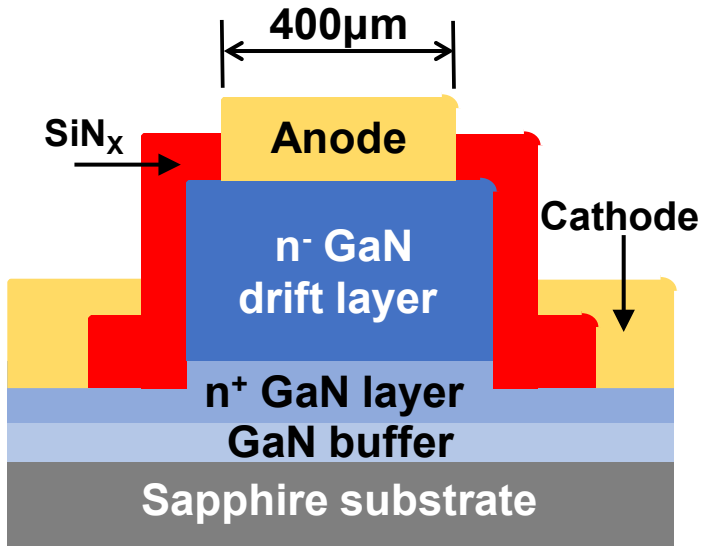
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Part 1: Electrical characteristics

GaN SBD-Device Under Test



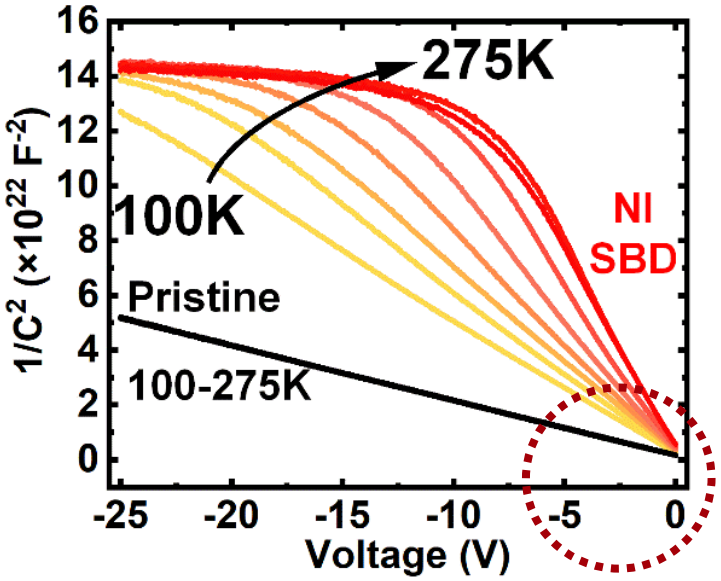


- Metal-organic Chemical Vapor Deposition (MOCVD)
- 2-inch Sapphire substrate
- 1-μm-thick **GaN buffer**
- 1.8-μm-thick n+ **GaN layer**
  (electron concentration 5×10^{18} cm^{-3} at 300 K)
- 5.8-μm-thick undoped **GaN layer**
- Device diameter **400 μm**

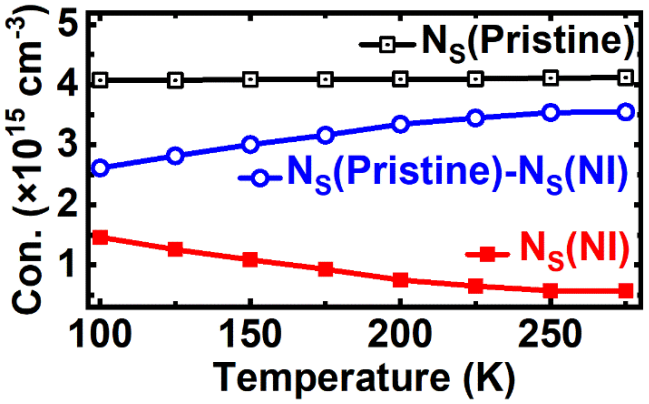
- Neutron irradiation with a 14.9 MeV
- fast neutron beam dose (8×10^{14} n cm^{-2})
- deuterium-tritium fusion at the K600 Neutron Generator in China Institute of Atomic Energy (**CIAE**)



GaN SBD-Carrier remove effect

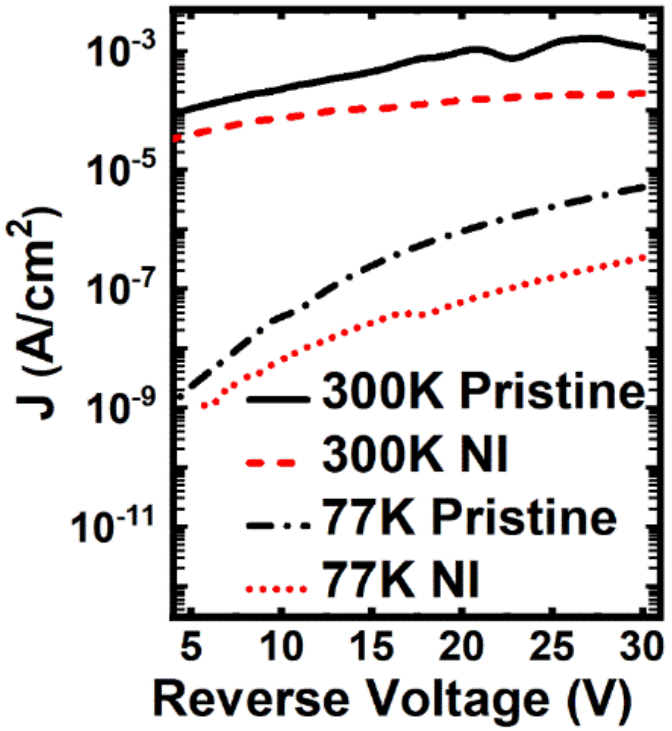


$$\frac{1}{C^2} = \frac{2}{\varepsilon_0 \varepsilon_s q F^2 N_S}\left(V_{bi} - \frac{k_B T}{q} - V\right)$$



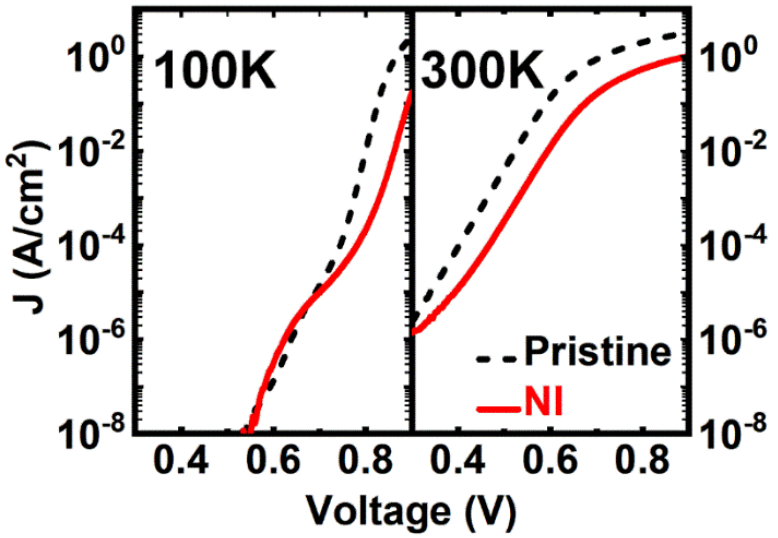
Effective carrier concentration (Ns)

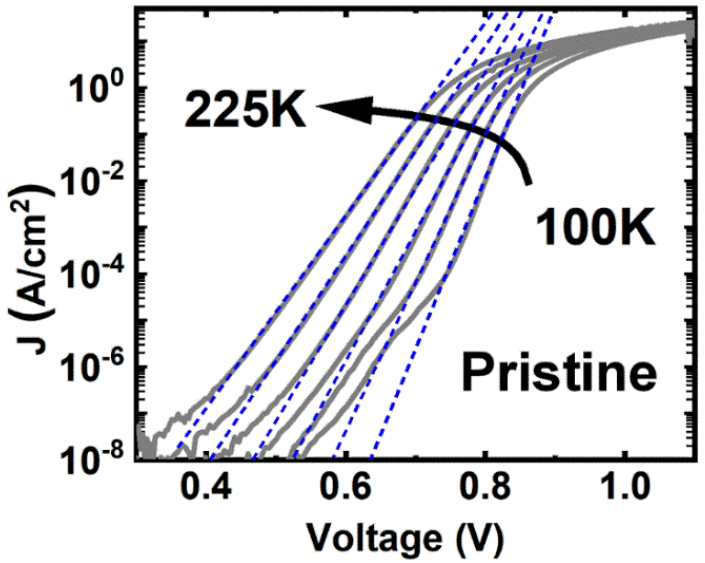
- Leakage current decreased upon neutron irradiation both in HT/LT

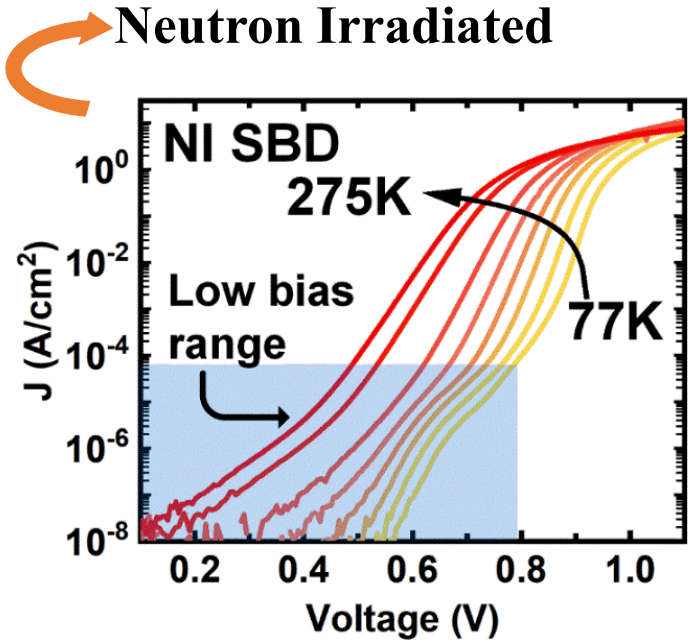


- Effective carrier concentration decreased upon neutron irradiation

GaN SBD-Forward I-V-T







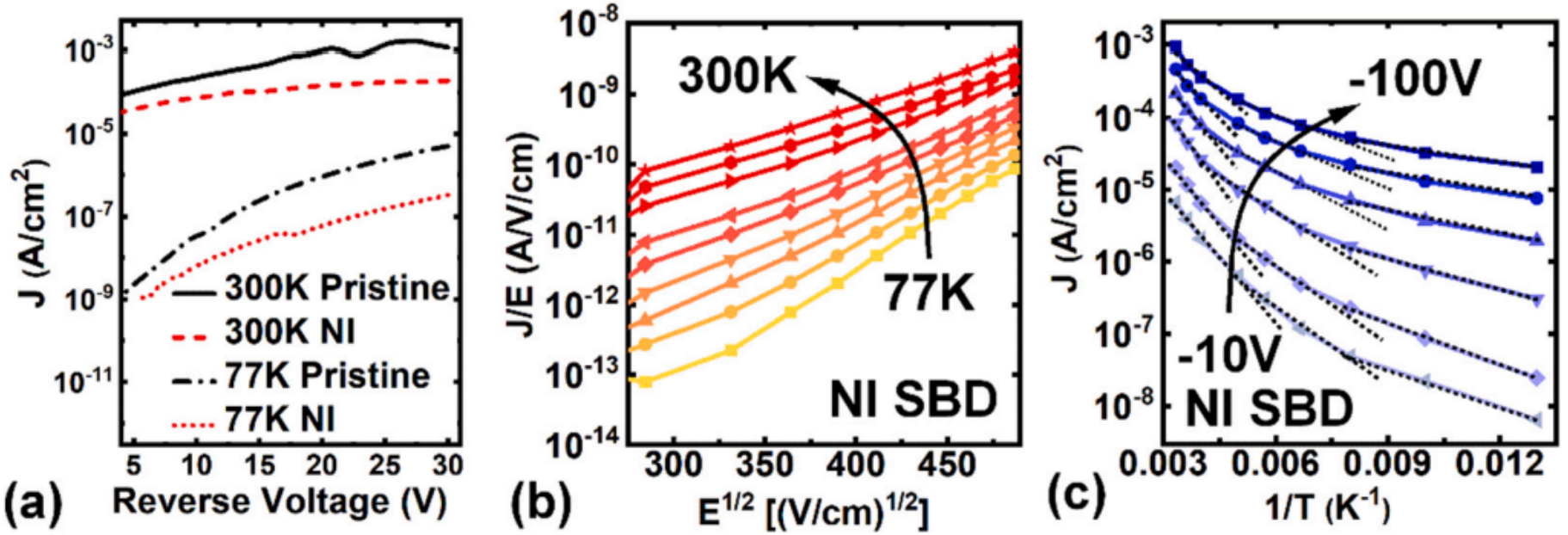
Thermionic emission (TE) model:

$$J_{TE} = A^{*}T^{2}exp\left(\frac{-q\phi_{B-IV}}{k_{B}T}\right)\left[exp\left(\frac{qV}{nk_{B}T}\right)-1\right]$$

- Neutron irradiation decrease forward current density
- Barrier height inhomogeneity enhanced
- Two-barrier model enhanced in each temperature

Pristine SBD			NI SBD		
T(K)	Low SBH (eV)	High SBH (eV)	T(K)	Low SBH (eV)	High SBH (eV)
			77	0.37	0.58
100	0.45	0.70	100	0.49	0.68
125	0.50	0.74	125	0.58	0.76
150	0.58	0.83	150	0.62	0.84
175	0.84		175	0.63	0.88
200	0.86		200	0.65	0.91
225	0.89		250	0.73	0.96
			275	0.78	0.98

Leakage current analysis



The average reverse current of the NI SBDs were slightly lower than that of the pristine samples.

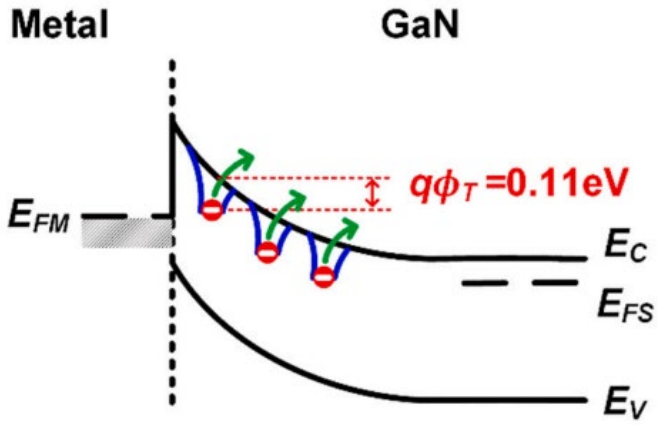
From 77-300K, electrical field and temperature dependent leakage current could be explained by **Poole-Frenkel emission (PFE).**

$$J_{PF} = C' E \exp\left[-\frac{q}{k_B T}\left(\phi_T - \sqrt{\frac{qE}{\pi \varepsilon_0 \varepsilon_s}} \right) \right]$$

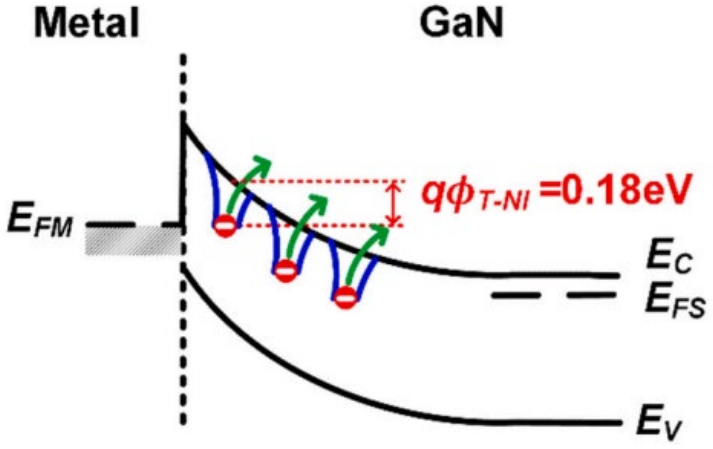
$q\phi_T$

Effective barrier height from PFE

Pristine SBD



NI SBD



The **effective barrier height or activation energy qϕT:**
for NI SBD (0.18 eV)
for pristine SBD (0.11 eV)

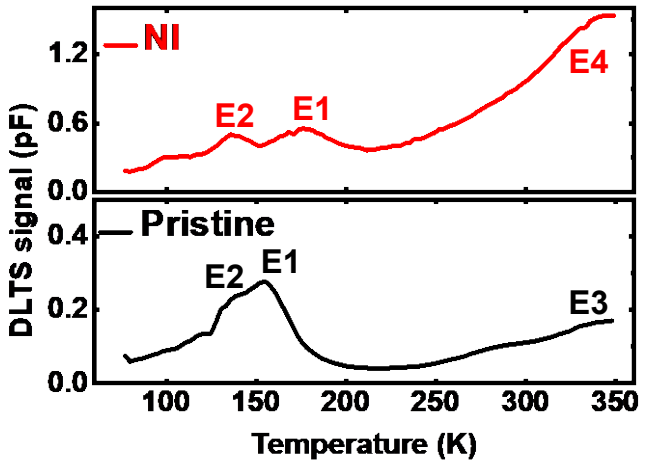
Upon neutron irradiation, a larger activation energy was obtained for NI-SBD



a larger barrier height to overcome for electron emission, in a good agreement with the reduced leakage current measured.

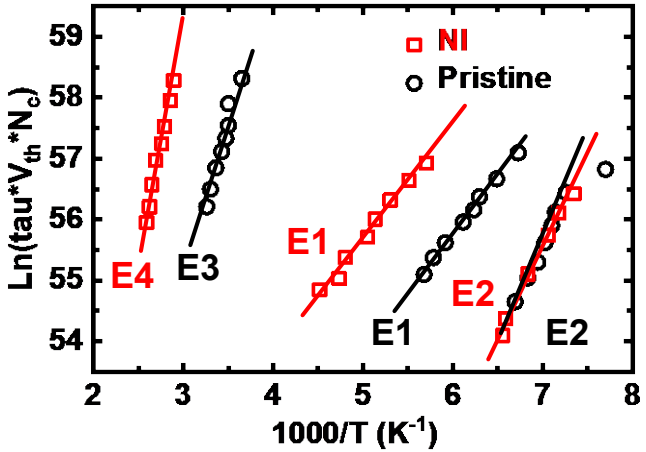
Part 2: Defect analysis

GaN SBD-DLTS Measurement



DLTS signal

		E_C-E_T (eV)	σ (cm^2)	N_T ($\times 10^{14}$ cm^{-3})
Pristine	E1	0.144	1.06×10^{-21}	1.16
	E2	0.266	2.87×10^{-15}	0.61
	E3	0.468	1.78×10^{-17}	0.58
NI	E1	0.149	3.50×10^{-21}	1.60
	E2	0.254	6.44×10^{-16}	1.40
	E4	0.640	9.77×10^{-17}	5.06



Arrhenius plot

- A new deep-level trap in irradiated SBD
- E4 has the highest trap concentration
- Trap concentration of E1 and E2 increased

Part 3: Conclusions

GaN SBD-Summary

- Neutron irradiation degraded GaN SBD forward current density and enhanced two barrier model
- The average reverse current of the NI SBDs were slightly lower than that of the pristine samples.
- Carrier removal effect induced by neutron irradiation.
- A new deep-level trap found in neutron irradiated GaN SBD