Electrical and DLTS test on GaN PiN diode

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Outline

- GaN PiN on sapphire (fabricated by DLUT)
- Device information
- Electrical properties
- DLTS results

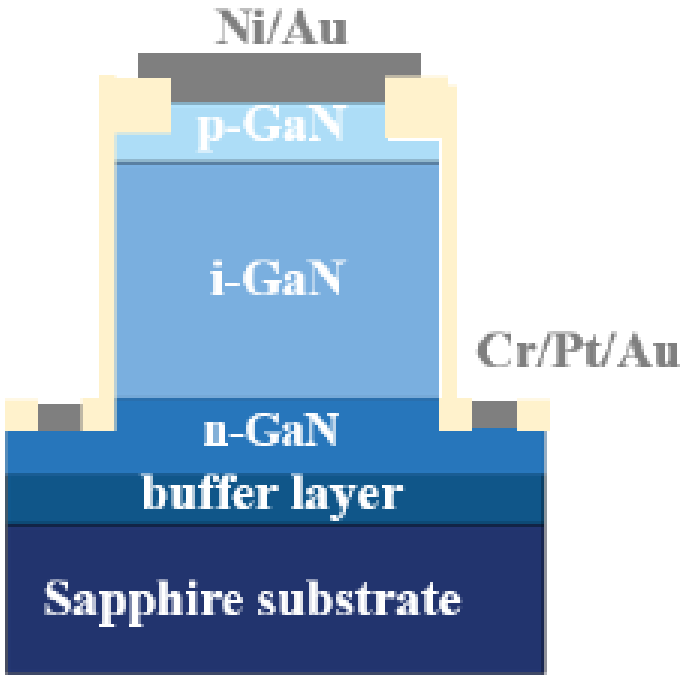
- GaN PiN on Si (fabricated by ShanghaiTech)
- Device information
- Electrical properties
- DLTS results

Part I. GaN p-i-n Diodes on sapphire Substrates fabricated by DLUT

1.器件信息

GaN PiN器件信息（by DLUT）

阳极直径1mm



(i)n-GaN金属电极制备

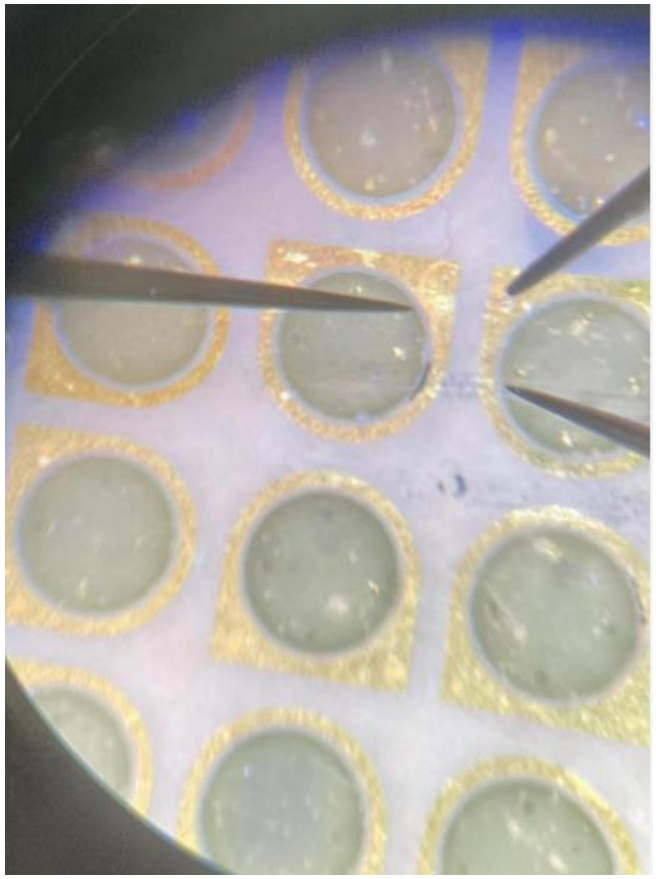
外延层：MOCVD异质外延，
Mg 作为受主杂质，掺杂浓度均在5E19 cm-3，
p-GaN 中的自由空穴浓度约为5E17 cm-3，
Al 的掺杂浓度约为0.214%，
i-GaN 层呈现高阻态，背景载流子浓度4.96E14 cm-3，
n+-GaN 层，掺杂浓度为5E18 cm-3

p-GaN 300 nm
i-GaN 10 μm (undoped/Al-doped) Sample A / Sample B
n^+-GaN 4 μm
Buffer Layer
Sapphire Substrate

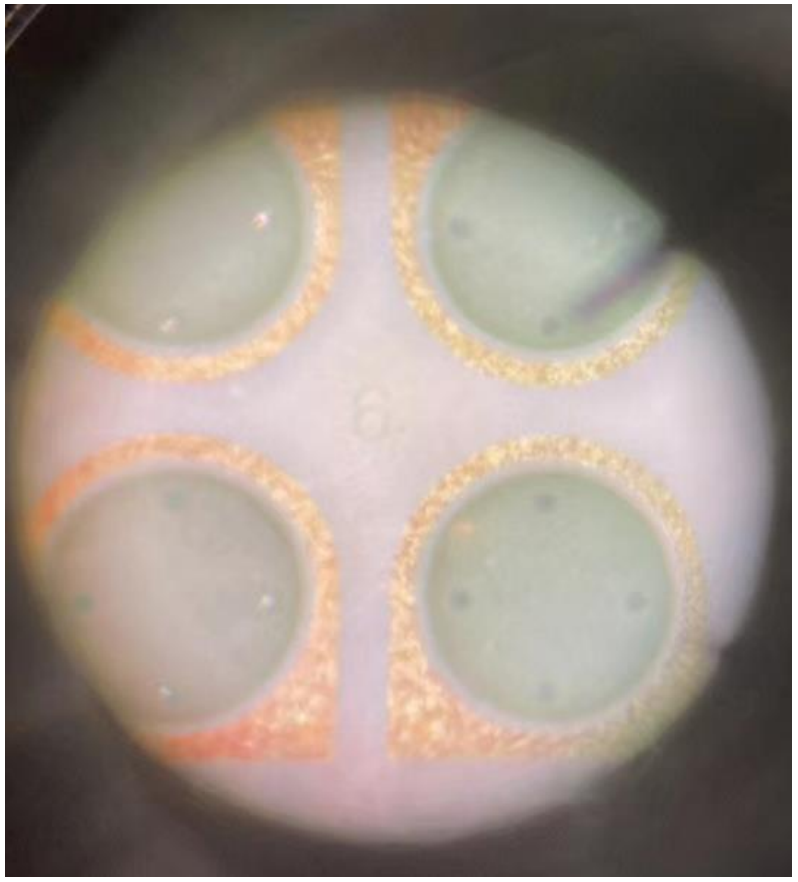
图 3.3 基于蓝宝石衬底 GaN 基 p-i-n 结构外延层示意图

辐照前后的GaN PiN器件

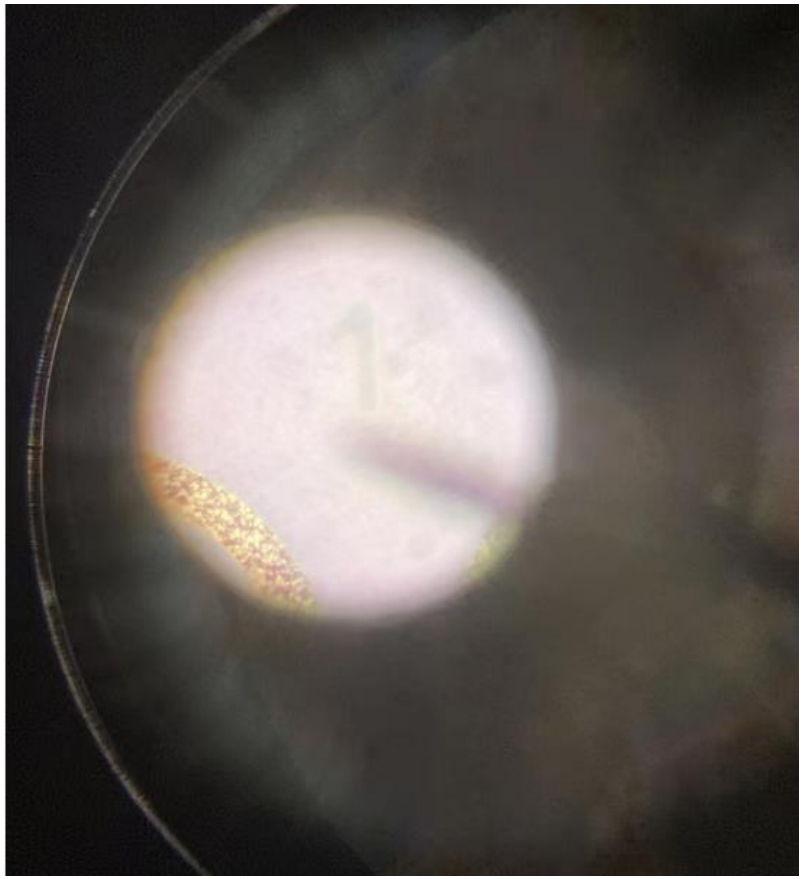
No.1 pristine



No.2 irradiated (1E11)



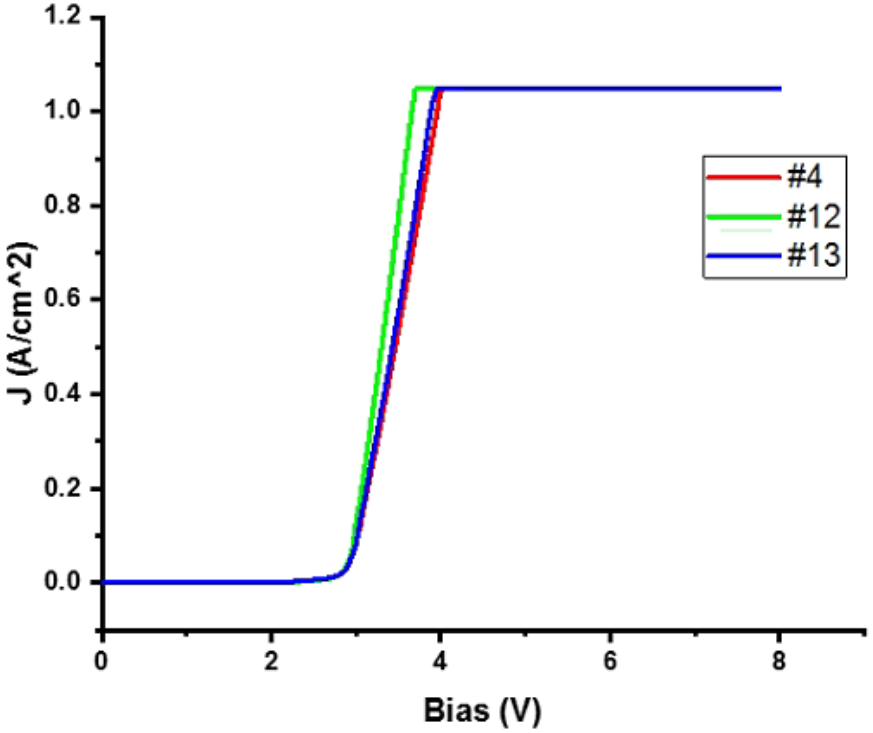
No.3 irradiated (1E14)



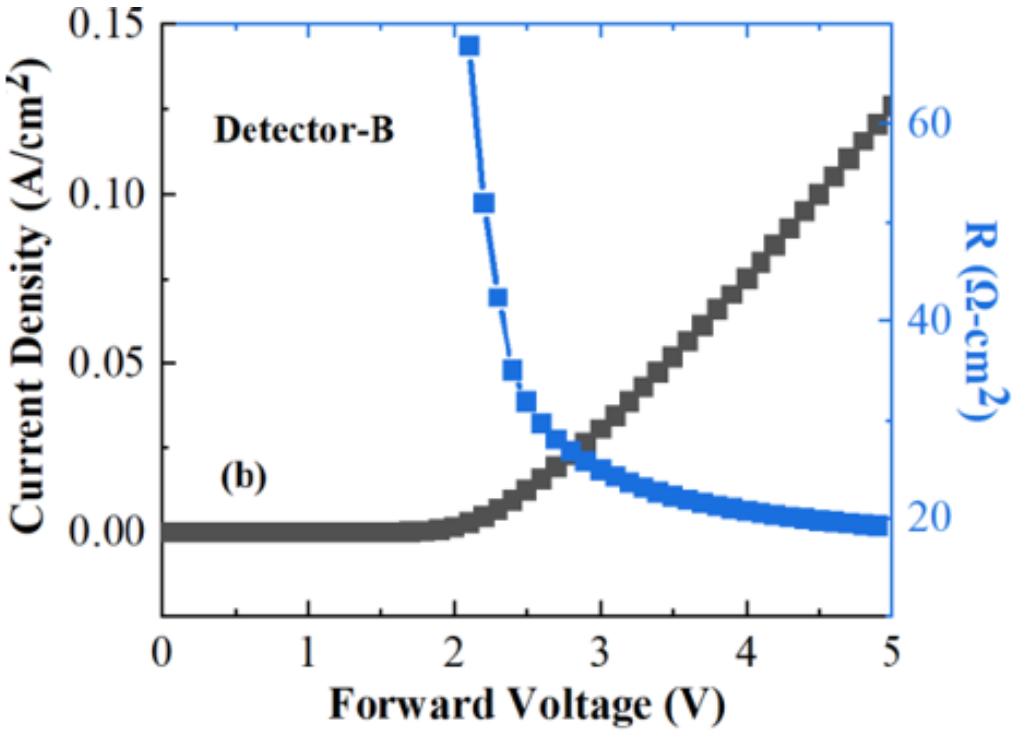
2.GaN PIN 二极管的I-V特性

Pristine正向I-V

实验测得数据



器件数据 by DLUT

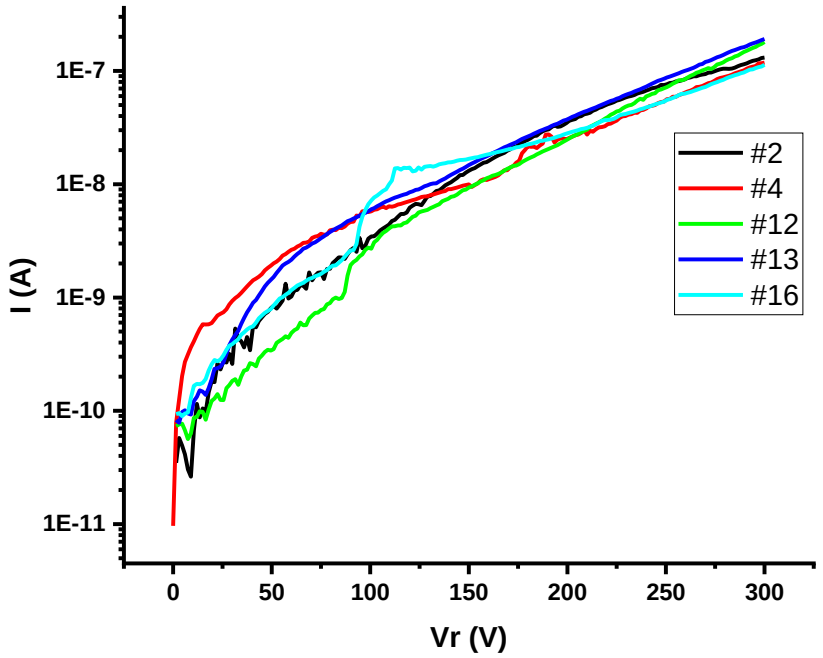


遮光条件下测试IV

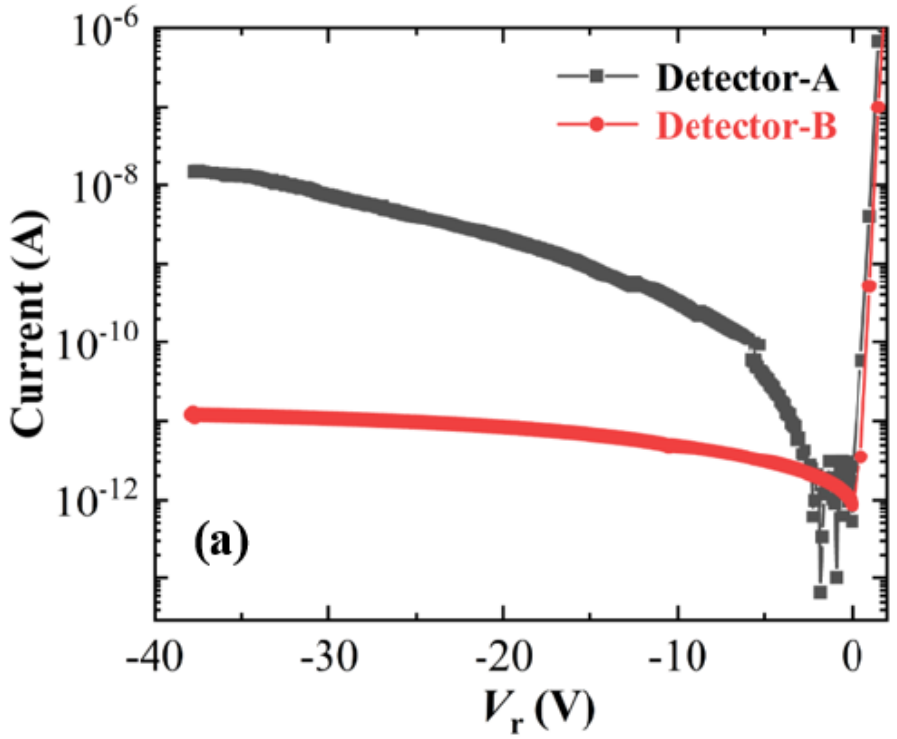
实验测得的数据正向电流密度近似于DLUT的数据

Pristine反向I-V

实验测得数据



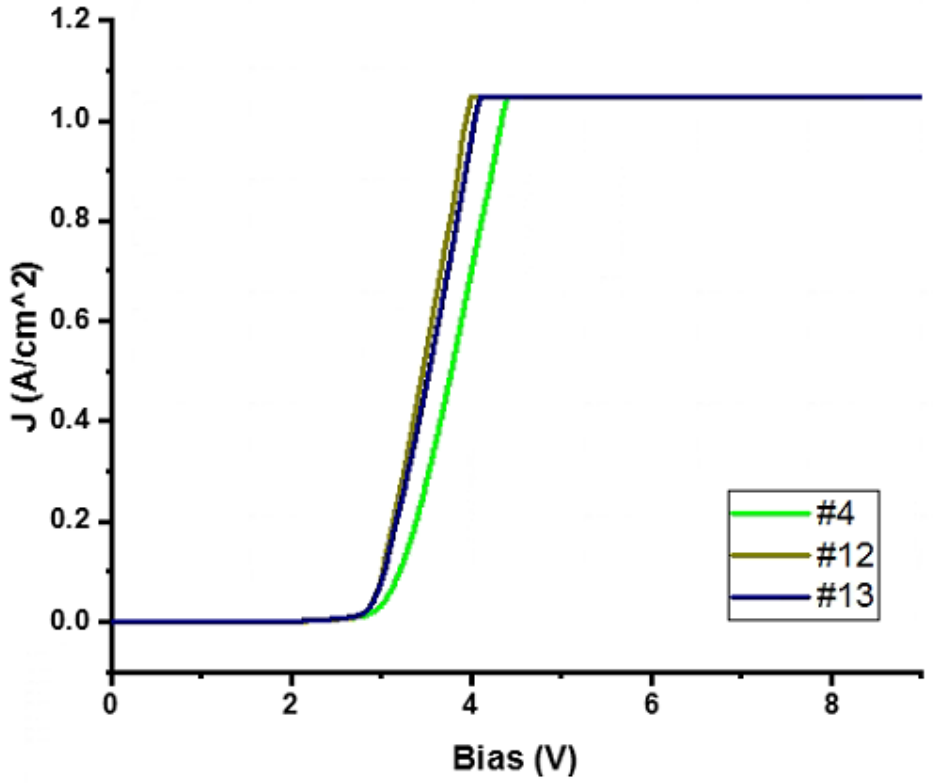
器件数据 by DLUT



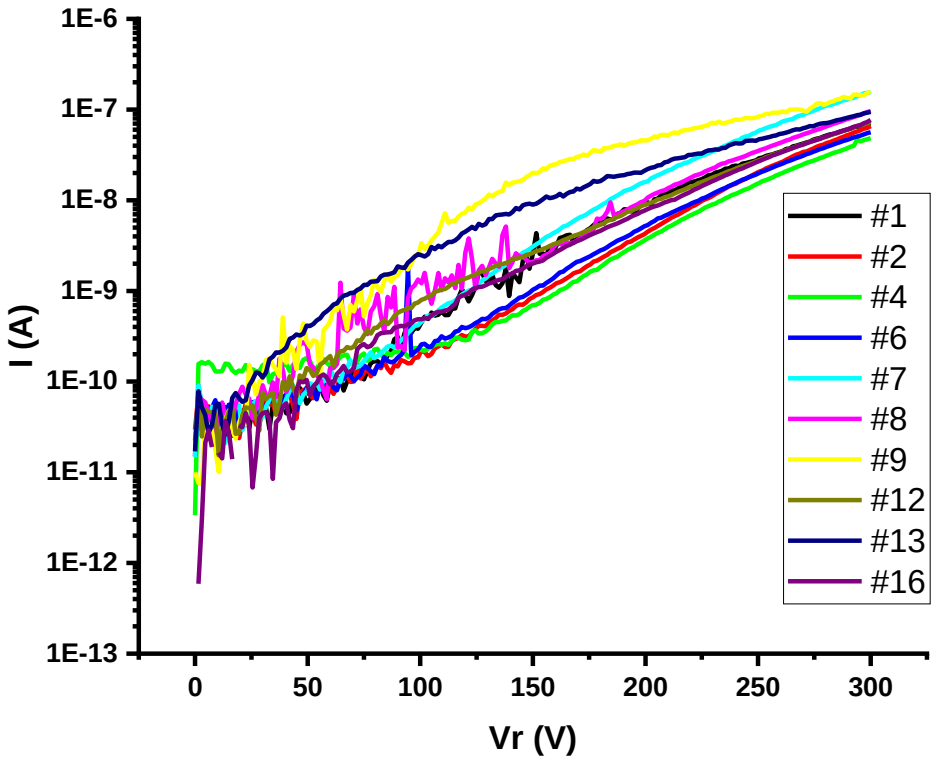
反向电压为-30V时:

实际测量得到的数据，反向漏电在1E-10量级,与博士论文中的反向漏电在1E-11量级近似。

NO.2 辐照剂量1E11 I-V特性

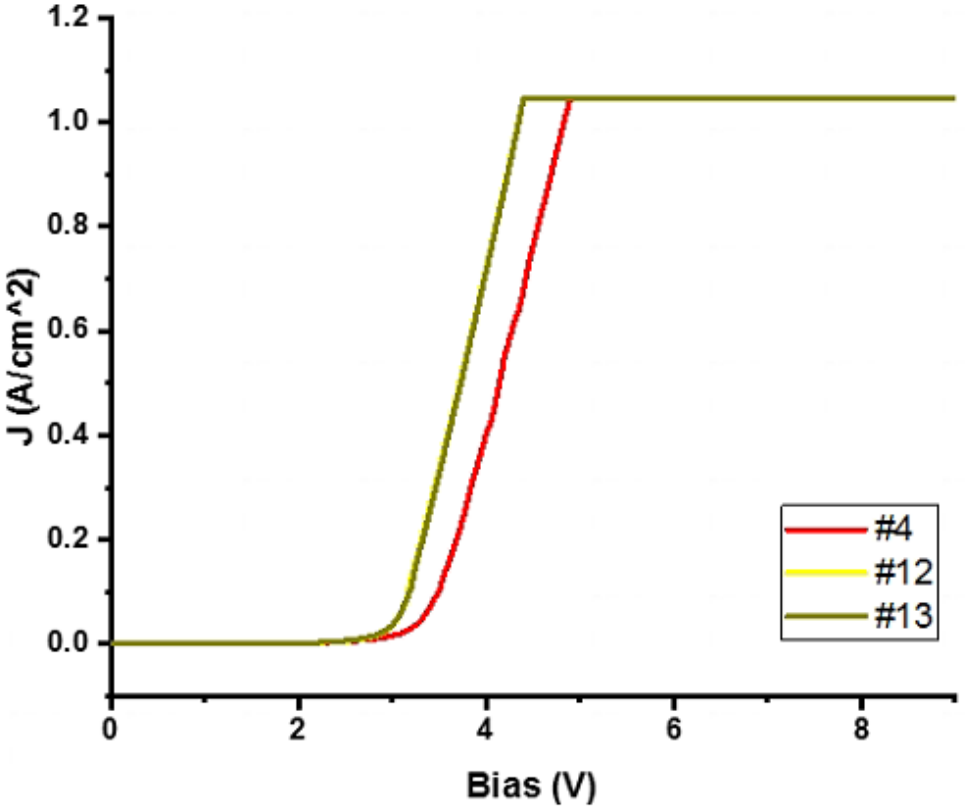


正向IV

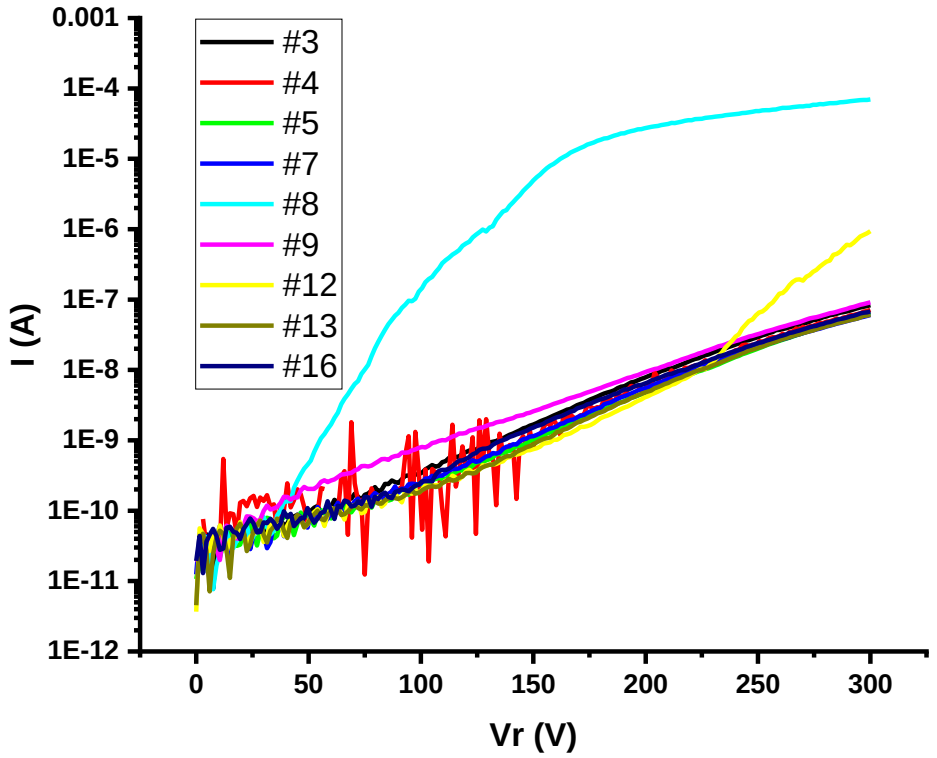


反向IV

No.3 辐照剂量1E14 I-V特性



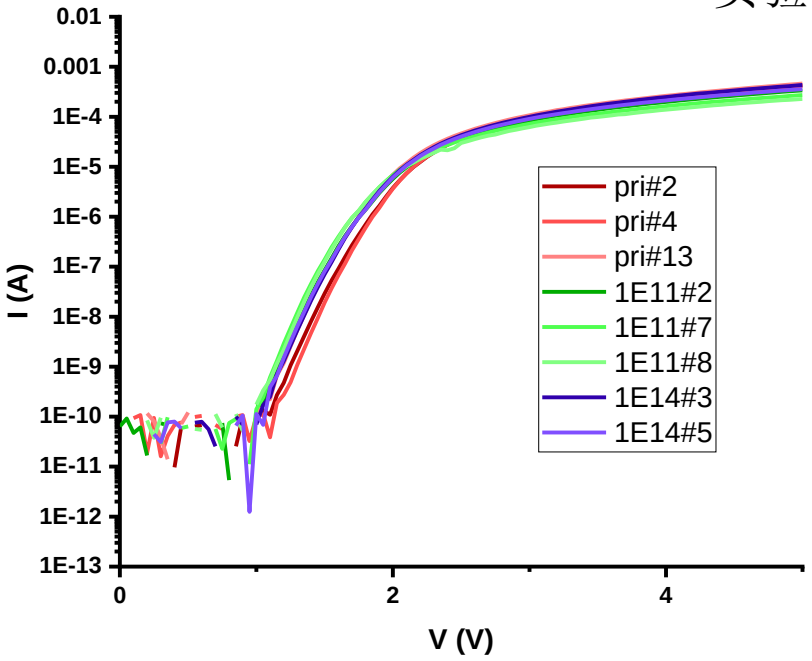
正向IV

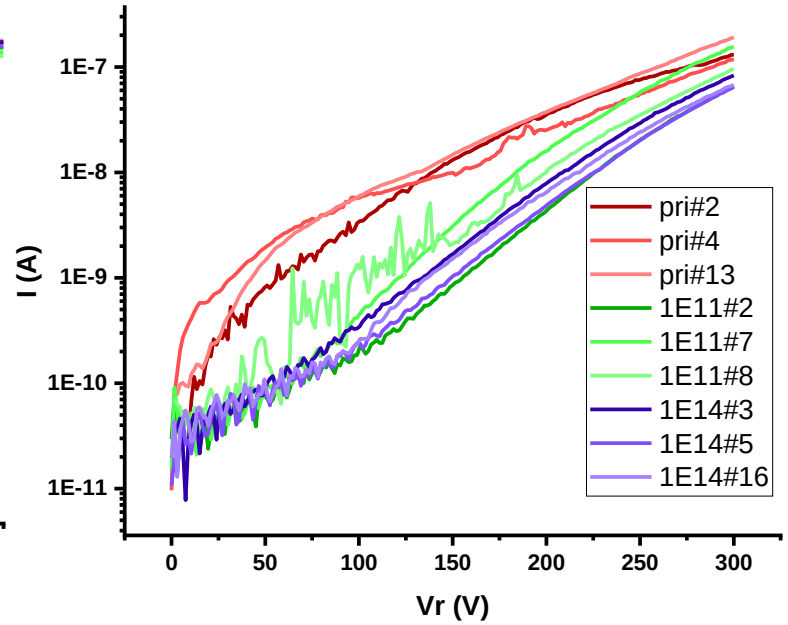


反向IV

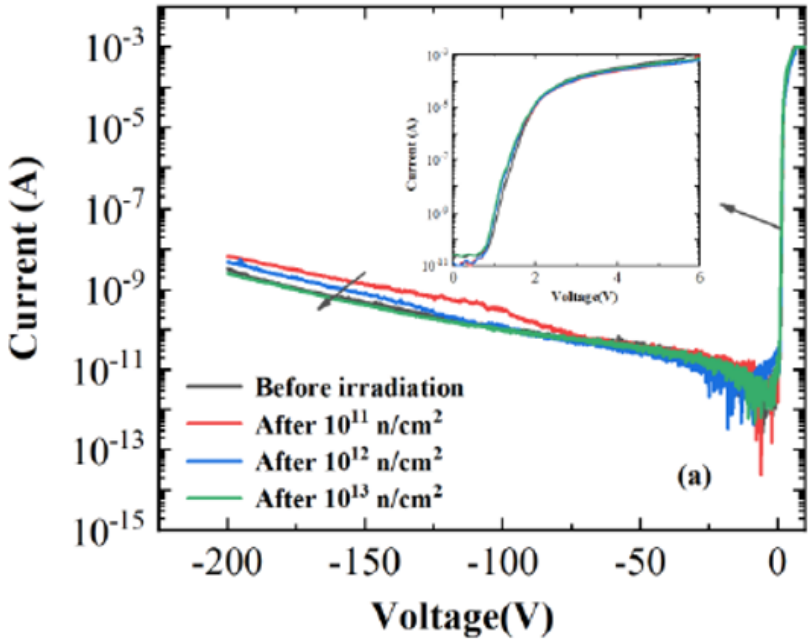
三种器件对比

实验测得数据





器件数据 by DLUT



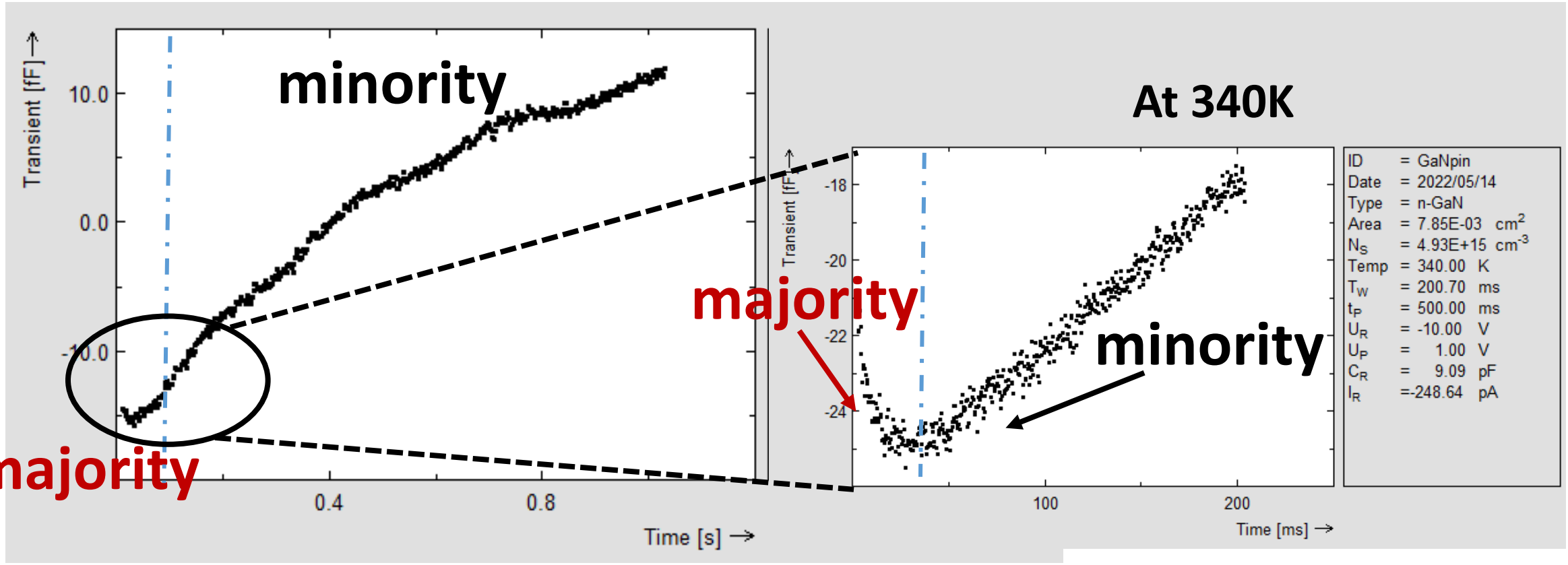
结论：

辐照前后样品正向IV基本一致，辐照后的样品反向漏电略有减小。

3. DLTS for fresh GaN PiN diode

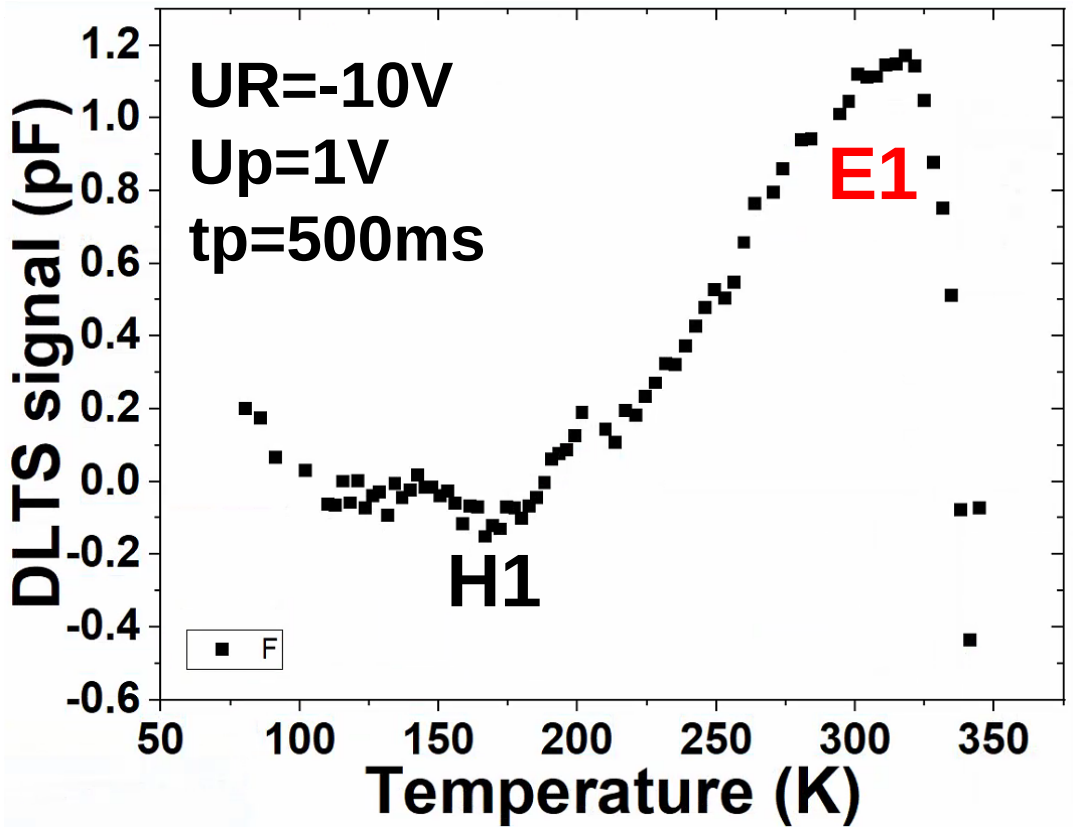
Majority and minority carrier trap

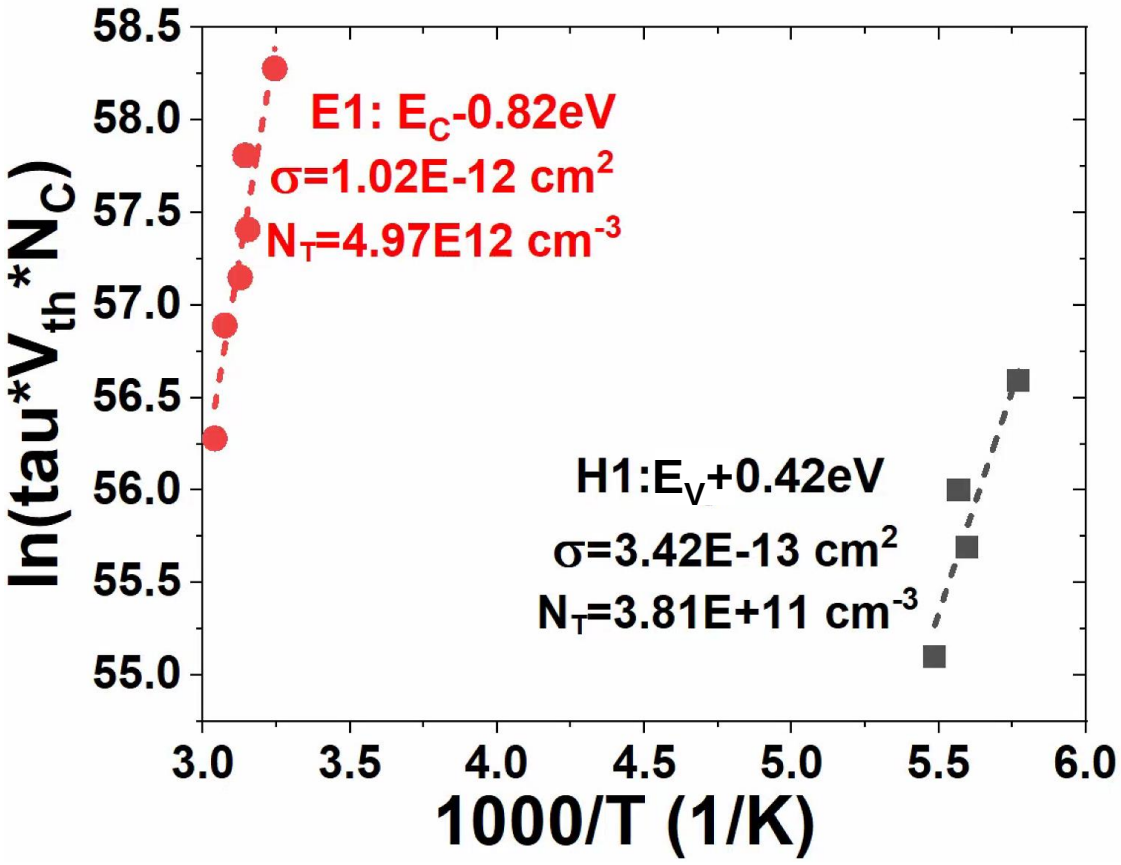
Measured time: 1s **Measured time: 200ms**



We could observed different trends in transient curve indicating majority (electron) and minority (hole) carrier traps could be observed.

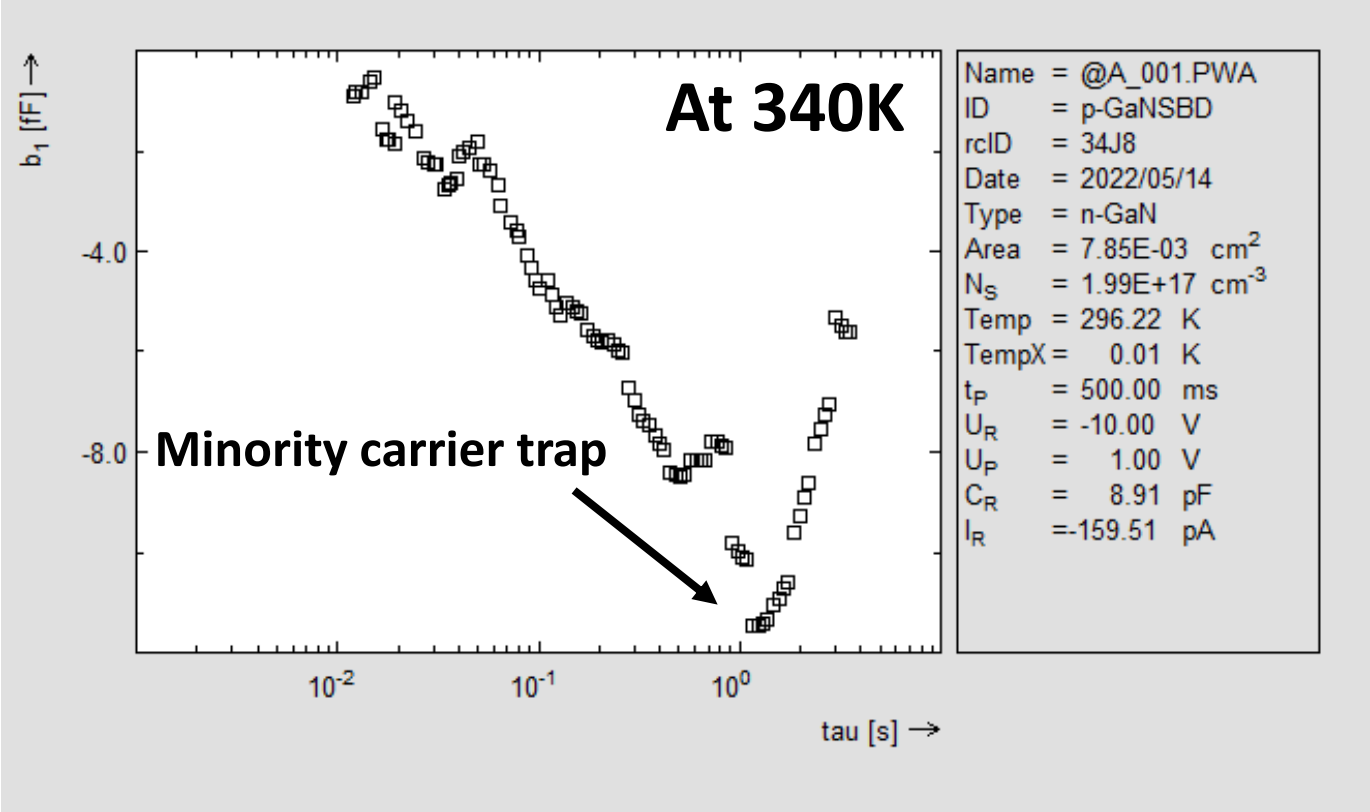
Trap characterization studied by DLTS





- One valley and peak can be observed in the temperature scan from 75K to 350K.
- Trap H1 (0.42eV) is around 175K, and E1 (0.82eV) is around 325K.
- The capture ability of E1 (σ=1.02E-12 cm^2) is larger than H1 (σ=3.42E-13 cm^2) .
- The trap concentration of E1 is higher than H1.

Isothermal DLTS for minority carrier trap (valley)



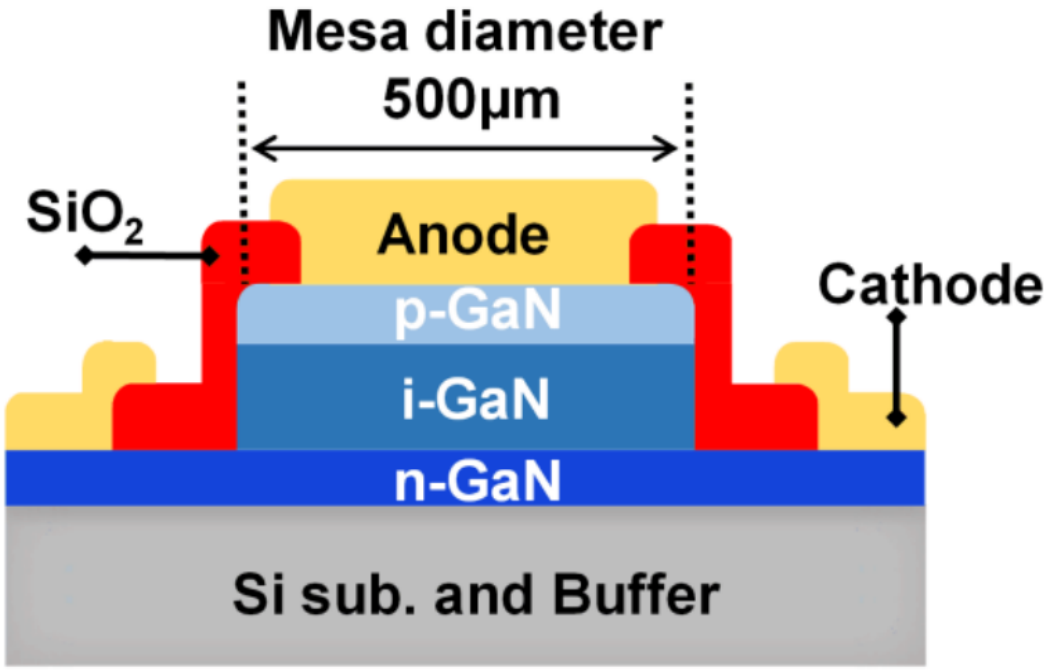
From isothermal DLTS, one valley could also observed, indicating there is a minority carrier (hole) trap.

Conclusion

- Two traps were observed in GaN PiN diode on sapphire by DLTS.
- Hole trap H1 (0.42eV) was found around 175K, and electron trap E1 (0.82eV) was found around 325K.
- The capture ability of E1 is larger than H1.
- The trap concentration of E1 is higher than H1.

Part II. GaN p-i-n Diodes on Si Substrates fabricated by ShanghaiTech

GaN PiN diode by GaNology Lab

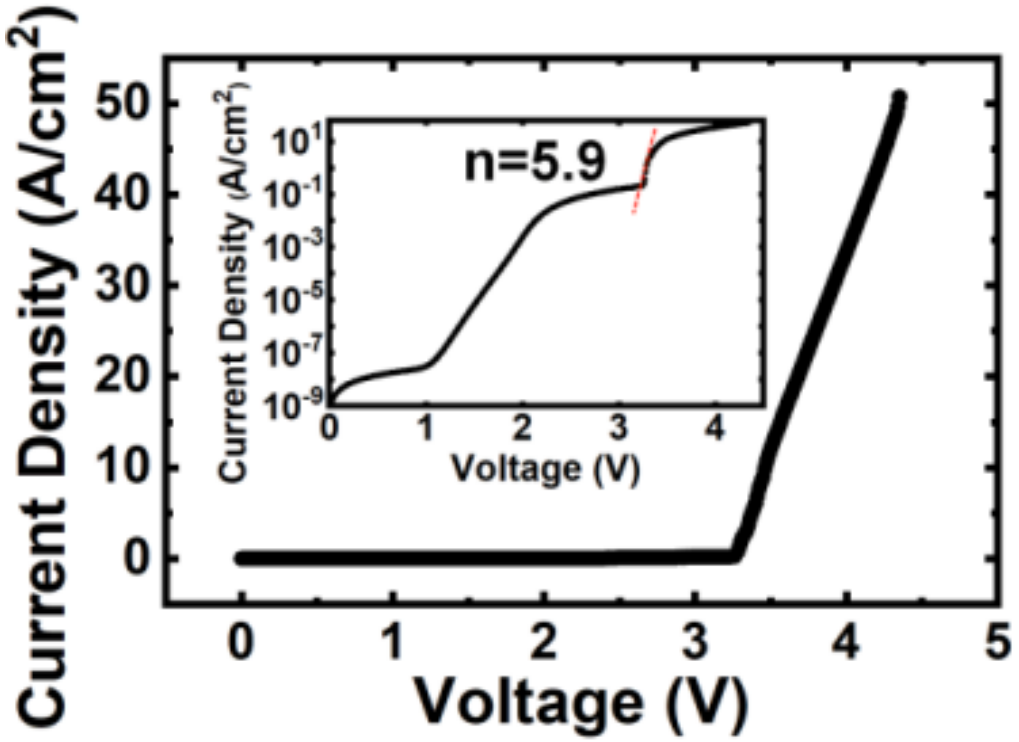


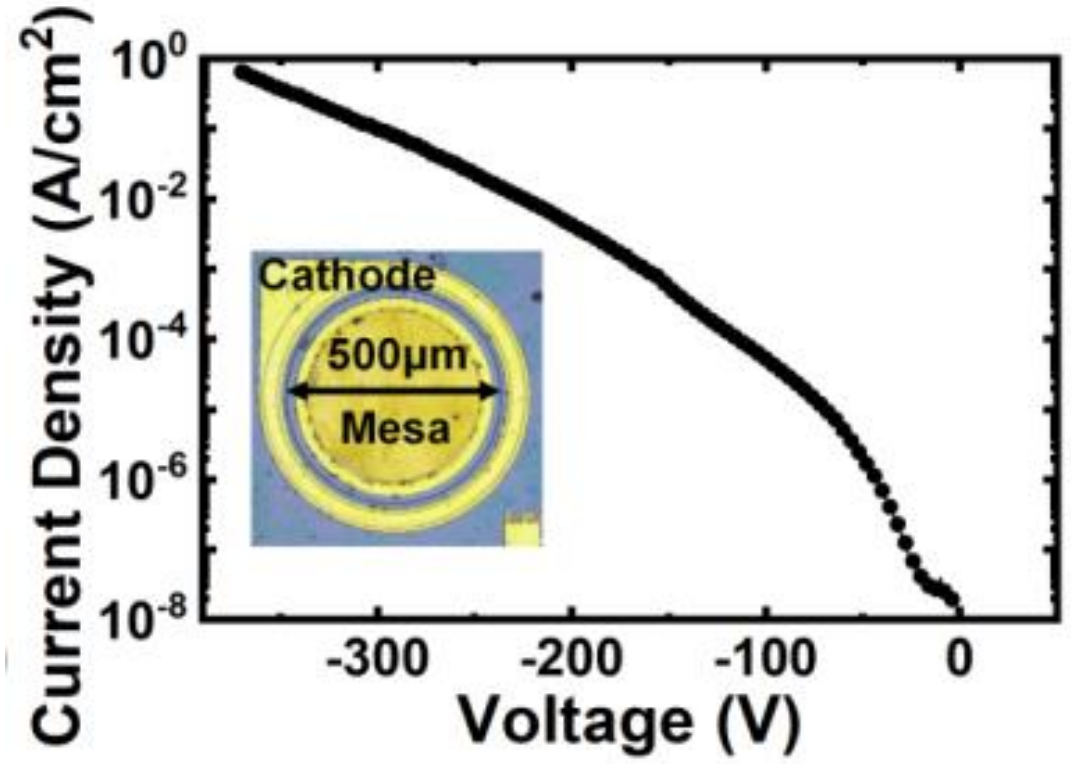
Y. Zhang, X.Zou *et al*., in *IEEE TED*, vol. 67, no. 10, pp. 3992.2020..

- 1.6-μm-thick graded AlGaN and GaN buffer
- a 500-nm-thick Si-doped n-GaN layer (electron concentration n = 1×10^{19} cm^{-3})
- **a 2-μm-thick undoped i-GaN layer** (carrier concentration on the order of 10^{16} cm^{-3})
- a 500-nm-thick Mg-doped p-GaN layer (hole concentration p = 2×10^{17} cm^{-3} at 300 K)

- The sample used in this study was a GaN-based quasi vertical p-i-n diode grown on a Si substrate by metal–organic chemical vapor deposition (MOCVD) phase epitaxy.

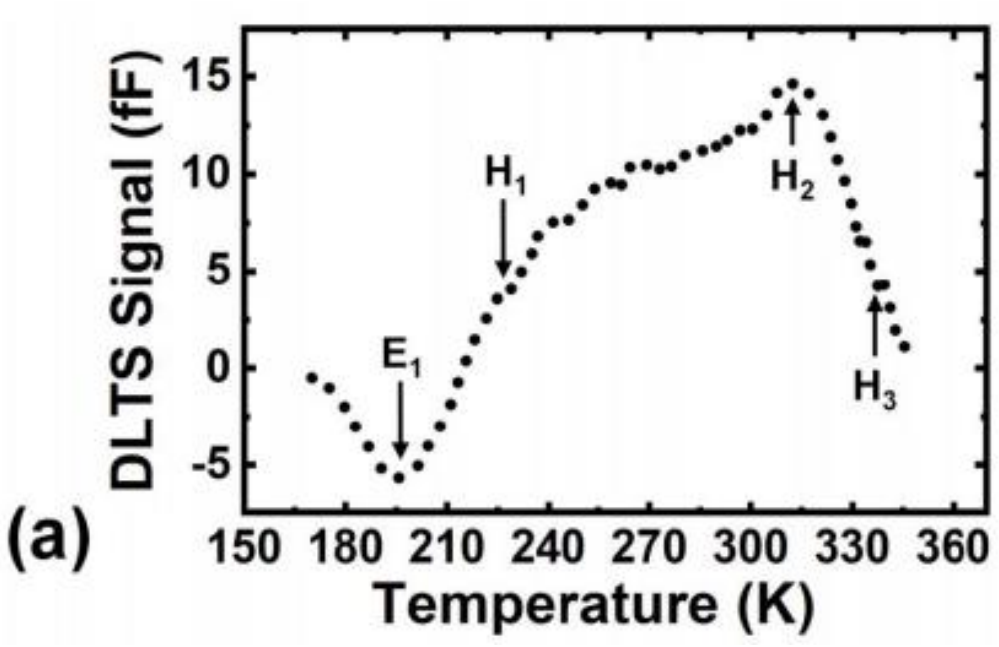
I-V characteristic

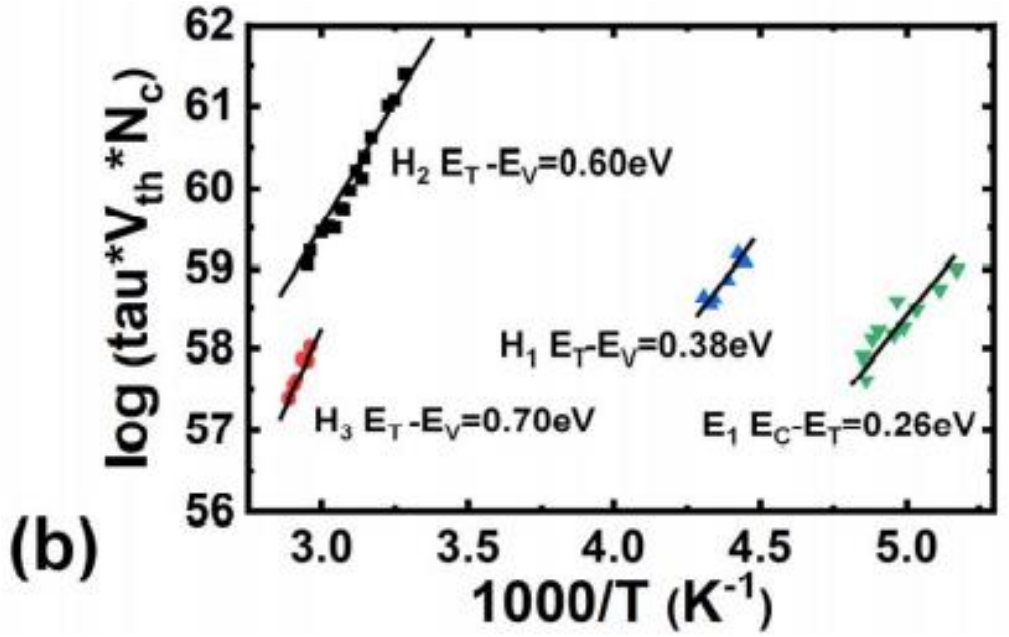




- Beyond the turn-on voltage, the forward current density was increased rapidly due to the carrier injection into the drift layer, where conductivity modulation was observed.
- When reverse biased, the leakage current was only -2×10^{-3} A/cm^2 at −200 V.

Hole and electron traps in GaN PiN diode



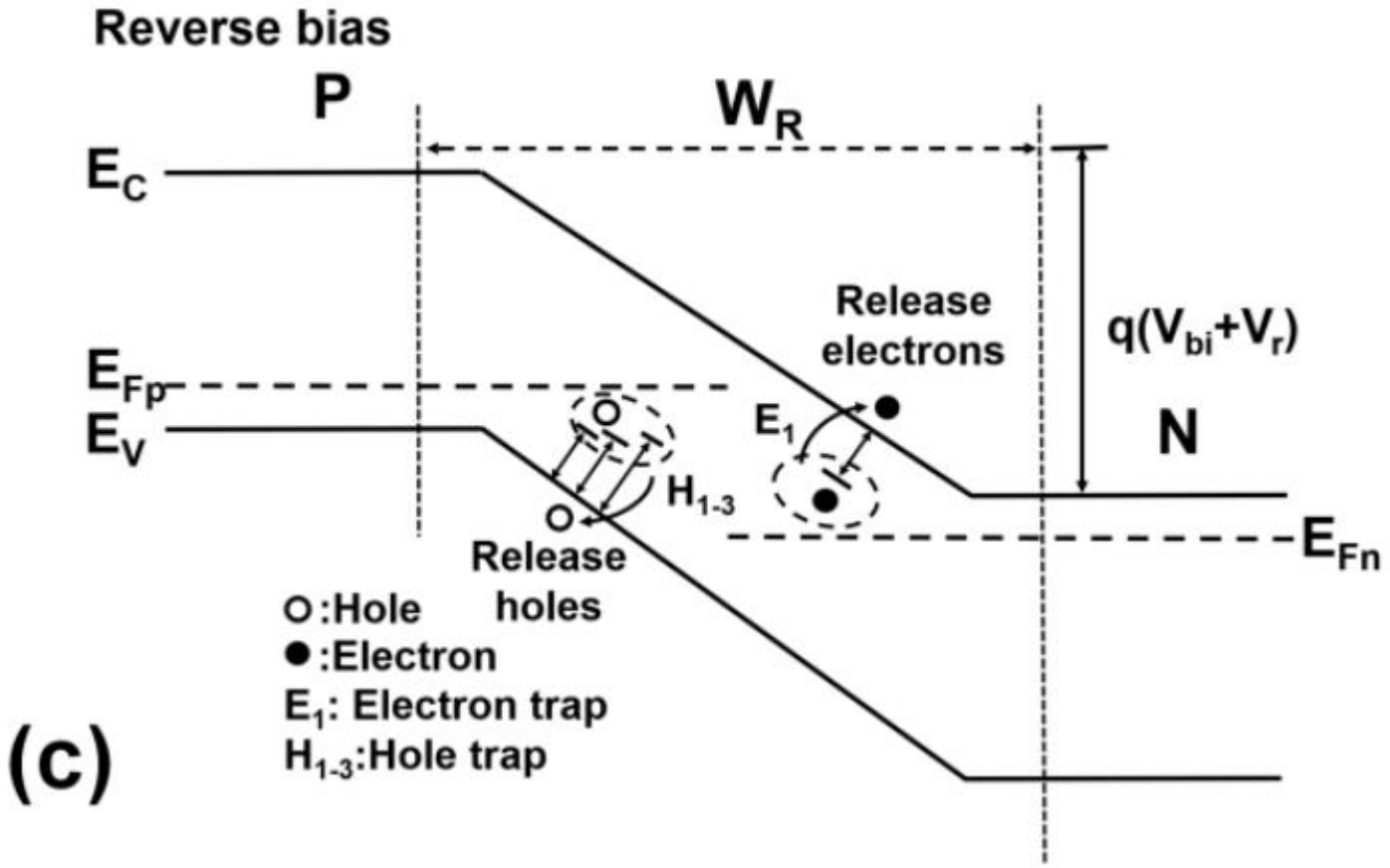


Trap No.	Energy Level (eV)	Capture Cross section (cm^2)	Trap Concentration N_T (cm^{-3})
E_1	E_c-0.26	2.59×10^{-19}	9.37×10^{14}
H_1	E_v+0.38	7.16×10^{-18}	7.68×10^{15}
H_2	E_v+0.60	2.18×10^{-17}	1.94×10^{15}
H_3	E_v+0.70	1.60×10^{-15}	3.72×10^{15}

Y. Zhang, X.Zou *et al*., in *IEEE TED*, vol. 67, no. 10, pp. 3992.2020..

- Three hole traps and one electron trap were observed in DLTS.
- The DLTS signals revealed one majority carrier trap (electron trap) labeled as E1 with an activation energy of 0.26 eV at 200 K.
- And three minority carrier traps (hole traps) labeled as H1, H2, and H3 with an activation energy of 0.38, 0.60, and 0.70 eV at 230, 310, and 340 K, respectively.

Band diagram



- Schematic of the nonequilibrium energy band diagram under reverse bias.

Conclusion

- Three hole traps and one electron trap were found in GaN PiN diode on Si substrate.

- The DLTS signals revealed one majority carrier trap (electron trap) labeled as E1 with an activation energy of 0.26 eV at 200 K.

- And three minority carrier traps (hole traps) labeled as H1, H2, and H3 with an activation energy of 0.38, 0.60, and 0.70 eV at 230, 310, and 340 K, respectively.