中国原子能科学研究院
中核集团 CNNC CHINA INSTITUTE OF ATOMIC ENERGY

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Experimental study on proton irradiation effect of gallium nitride high electron mobility transistor

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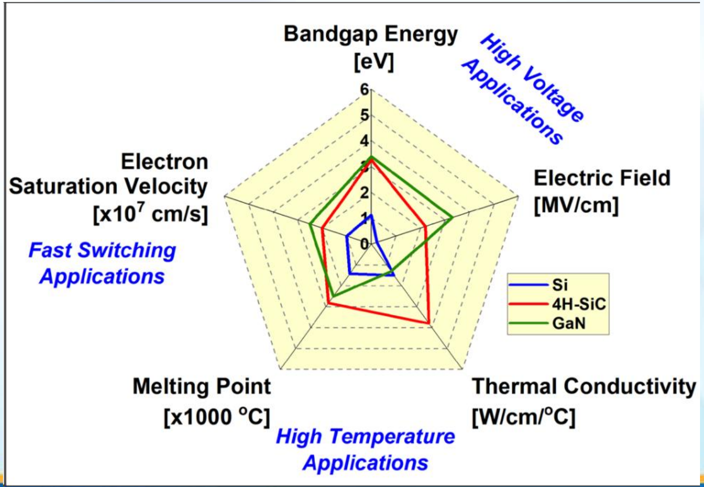
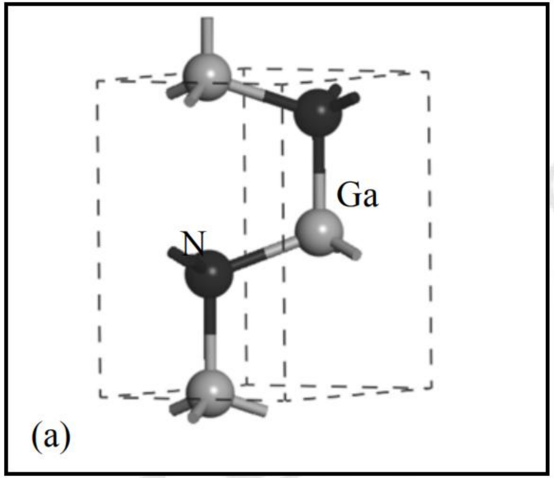
Outline

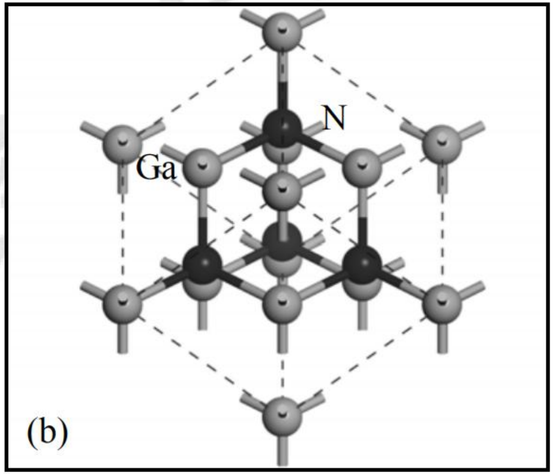
1. Backgroud

Third generation semiconductor materials: Silicon carbide (SiC) and gallium nitride (GaN)

Excellent properties: High breakdown electric field, fast electron saturation speed, high working temperature, and excellent radiation resistance.







1. Backgroud

In 1928, Johason et al. successfully synthesized GaN by hydride gas phase epitaxy (HVPE) technique.

In 1969, Maruska and Tietjen were the first to obtain GaN films on sapphire substrates using HVPE technology.

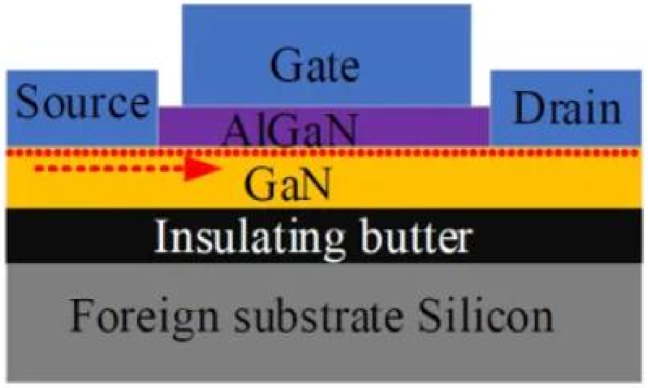
why is the GaN not widely used?

Until the 1990s, GaN has been developed rapidly due to the maturity of MOCVD technology.

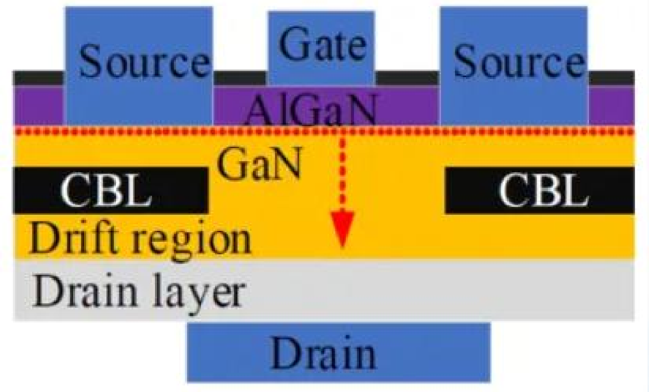
As an important member of GaN-based electronic devices, GaN high electron mobility transistor is widely considered by scientists to be used in the power supply and communication system of spacecraft and satellite.

1. Backgroud

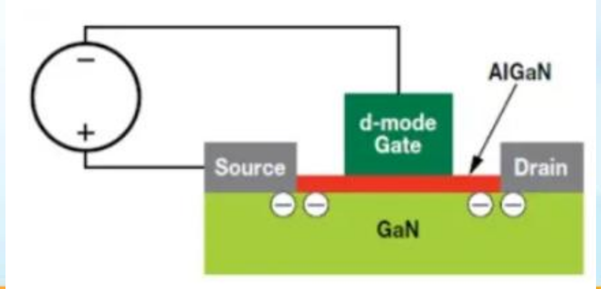
GaN HEMT structures



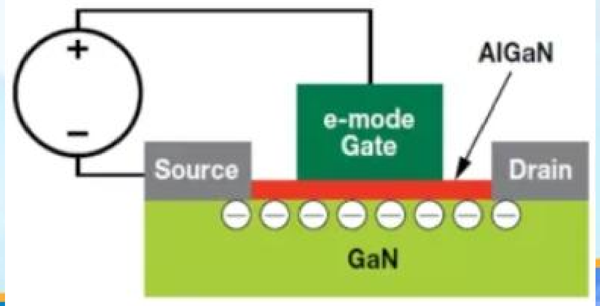
horizontal structure



vertical structure



normally-on



normally-off

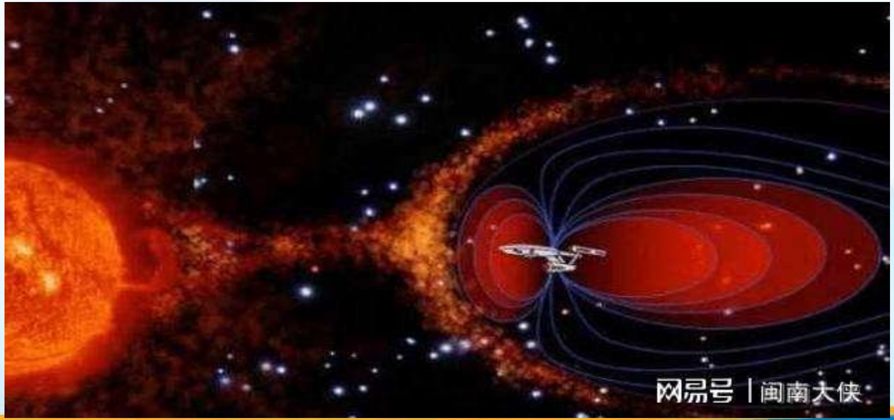
1. Backgroud

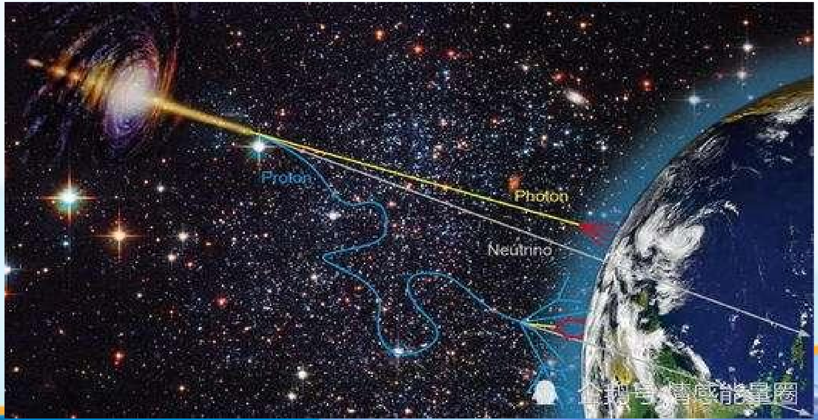
GaN HEMTs will inevitably be affected by the space radiation environment during the space missions.

Solar cosmic rays: **Protons(mainly)**, electrons and heavy ions

Galactic cosmic rays: Protons(85%), alpha ion(14%) and other heavy ions

Van•Allen belts: Protons, electrons and heavy ions





1. Backgroud

The radiation effects of devices can be divided into Single event effects (SEE), Total ionizing dose effect (TID) and Displacement damage (DD).

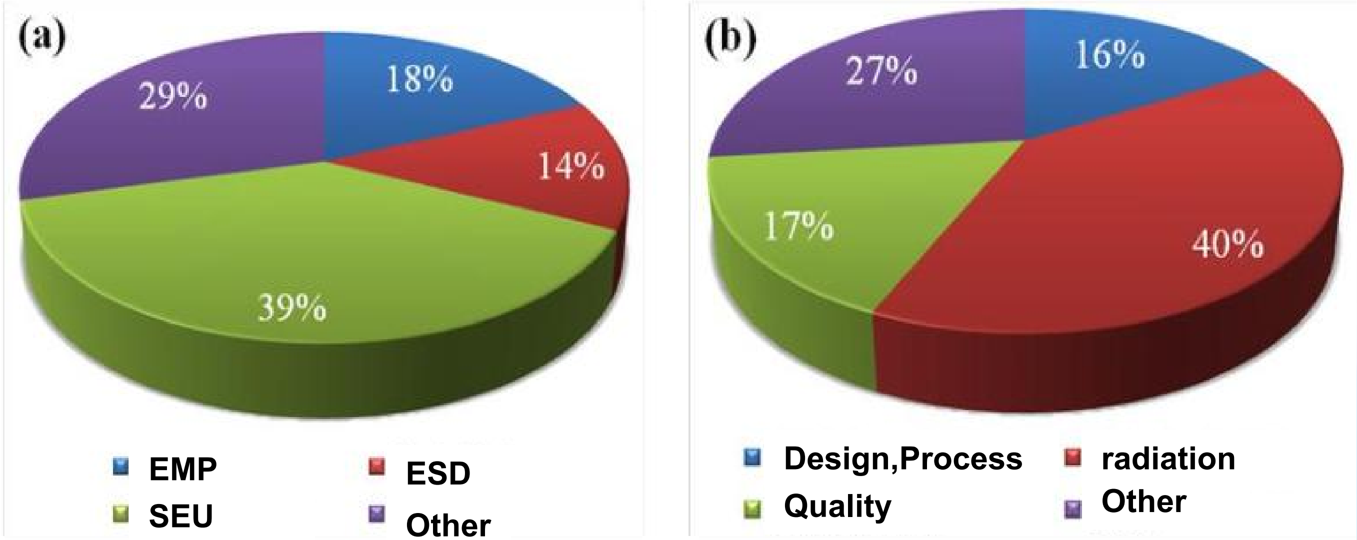
Single event effects: The single energetic particle incident on the sensitive area of the electronic device results in the change of logic state, including SEU, SEB, SEL SEGR and so on.

Total ionizing dose effect: The electrical parameters of electronic devices degrade with the increase of accumulated ionizing dose.

Displacement damage: High-energy particles irradiation causes atoms in semiconductor materials to leave their lattice positions

1. Backgroud

According to statistics, from 1971 to 1986, a total of 1,589 failures occurred in 39 geostationary satellites, in which 1,129 failures were related to space radiation, and 621 of them were caused by the single event effect.



United States **China**

1. Backgroud

Due to the wide band gap of GaN, GaN-based electronic devices should have an excellent radiation resistance in theory.

Unfortunately, the radiation resistance of GaN HEMT is often affected by the preparation process and device structure, so the current radiation resistance of GaN HEMT is still not up to expectations.

The proton irradiation effect is very important for its future application in space

White et al. found that GaN HEMT performance did not change significantly when proton fluence is lower than 10^{14} p/cm^2, the degradation is enhanced with the increase of the proton fluence when the fluence was greater than 10^{15} p/cm^2.

1. Backgroud

Kim et al. found that the performances degradation of GaN HEMT induced by low-energy proton irradiation was more serious than that of high-energy proton irradiation when the proton fluence is 10^{15} p/cm^2.

Greenlee et al. foundthat proton irradiation broadened the heterojunction interface in GaN HEMT, decreased the carrier density and mobility simultaneously.

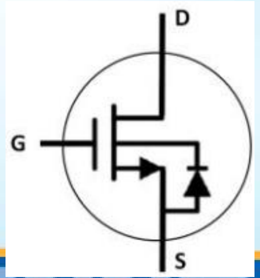
CareyIV et al. found that increasing the content of Al in GaN HEMT could effectively weaken the effect of proton irradiation on its performance parameters.

All the previous researches are based on proton irradiation experiments with energy less than 10 MeV.

2. Experimental details

The structure and electric parameters of the GaN HEMT are shown as below, produced by China Resources Microelectronics Limited (CR MICRO)

XG65T125PS1B

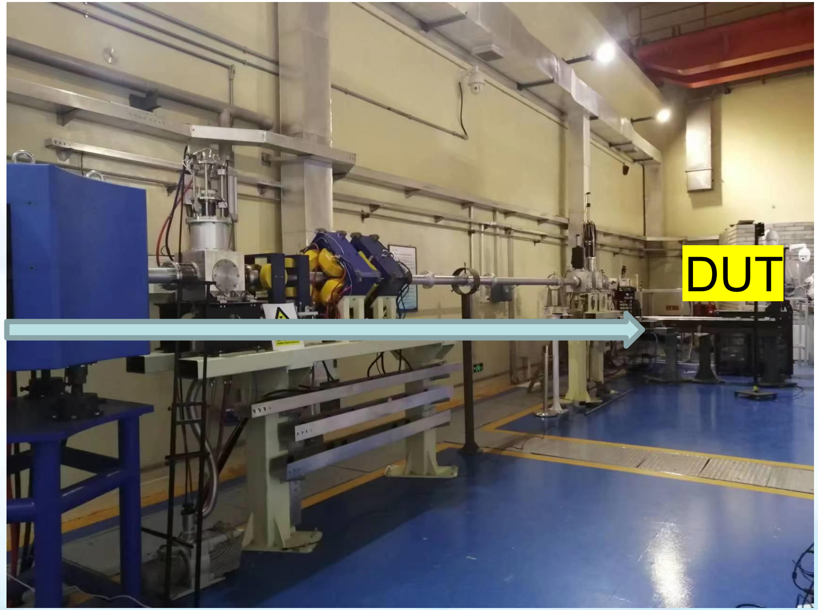


Parameter	Values	Test Condition
Drain source voltage	650V	T_C=25°C
Continuous current	23A	T_J = -55°C to 150°C
Drain-source breakdown voltage	1700V	V_{GS}=0V,I_{DSS}=250μA
Gate threshold voltage	1.82	V_{DS}=V_{GS}, I_D=500μA
Drain-source leakage current	8μA	V_{DS}=700V, V_{GS}=0V, T_J=25°C
Gate-source leakage current	150nA	V_{GS}=20V
Drain-source on-state resistance	125mΩ	V_{GS} = 6 V, I_D = 5 A

2. Experimental details

The proton irradiation experiment of the GaN HEMT is carried out in theof China institute of atomic energy (CIAE).

CYCIAE-100 High current Proton Cyclotron
Current: 200μA



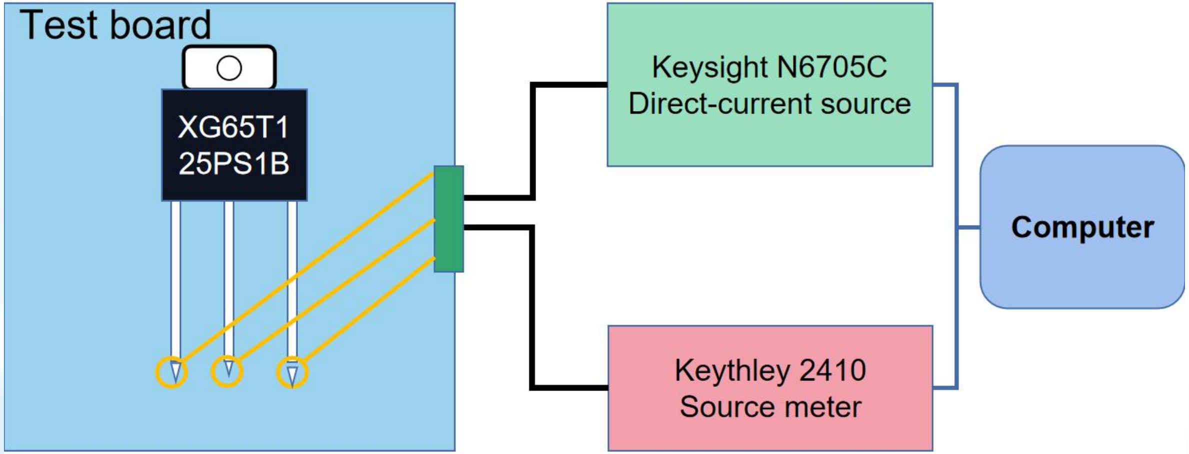
medium-energy proton irradiation platform
Energy range: 30-100MeV
Fluence: 10^2-10^{11} p/cm^2•s

2. Experimental details

Proton irradiation

Parameter	Vaule
Energy	30,40,60,90MeV
fluence rate	10^8 p/cm2•s
total fluence	10^{12} p/cm^2

Test system



The electrical parameters of GaN HEMT were measured at room temperature immediately after proton irradiation using the test system.
After annealing at room temperature for 10 days, the electrical parameters of the GaN HEMT were measured again by this system.

3. Results and Disscusion

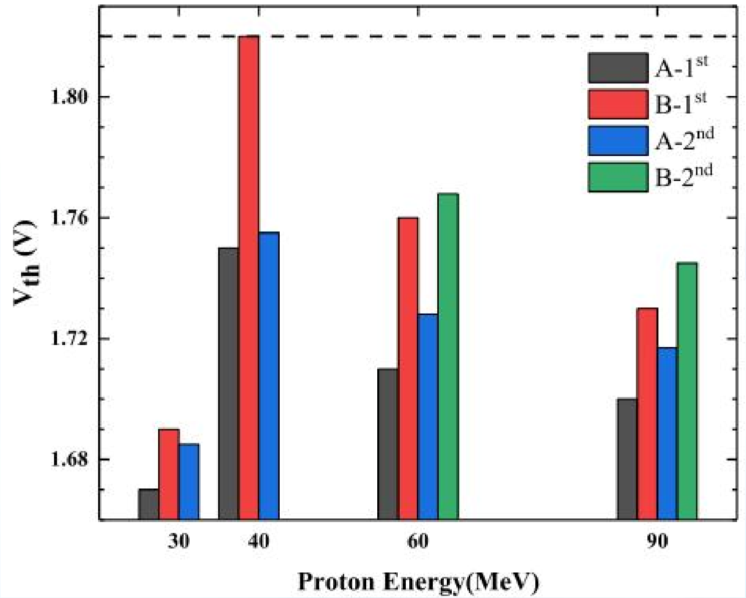


Fig.1 Gate-source threshold voltage of the GaN HEMT after proton irradiation with different energy

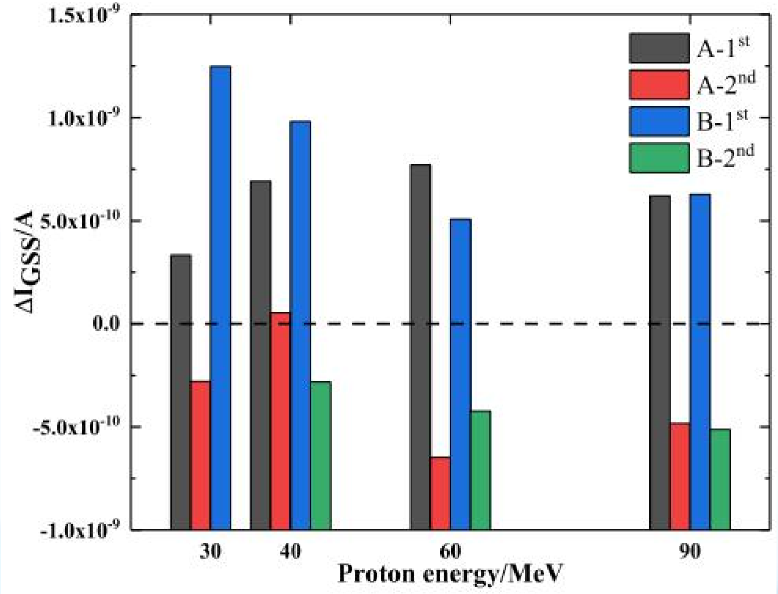


Fig.2 Static forward gate current of the GaN HEMT after proton irradiation with different energy.

3. Results and Disscusion

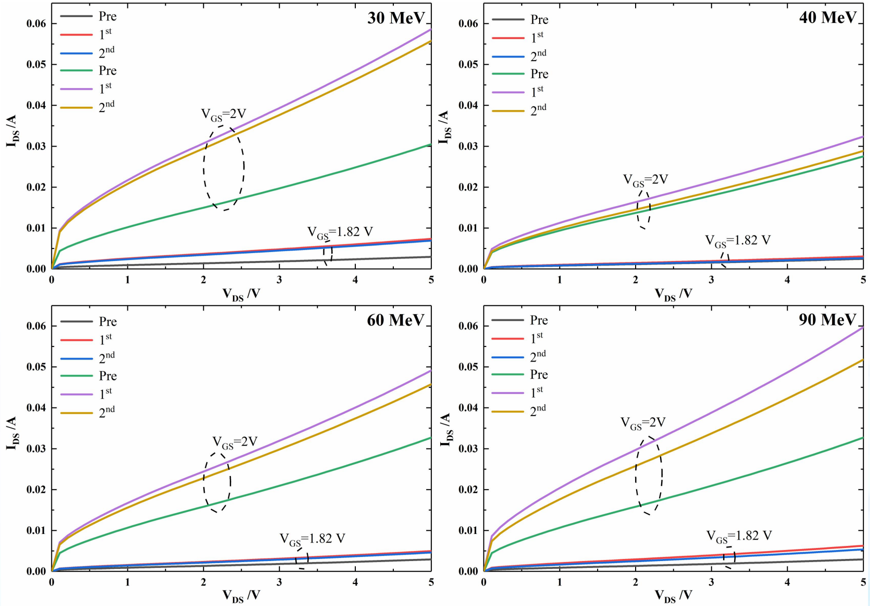


Fig.3 Output characteristic curves of the GaN HEMT in group A before and after proton irradiation with different energy

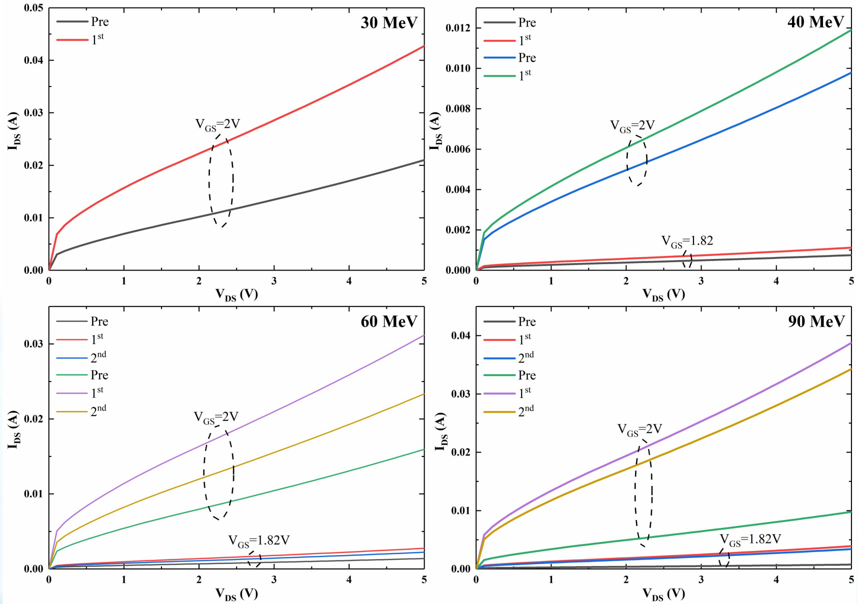


Fig.4 Output characteristic curves of the GaN HEMT in group B before and after proton irradiation with different energy

3. Results and Disscusion

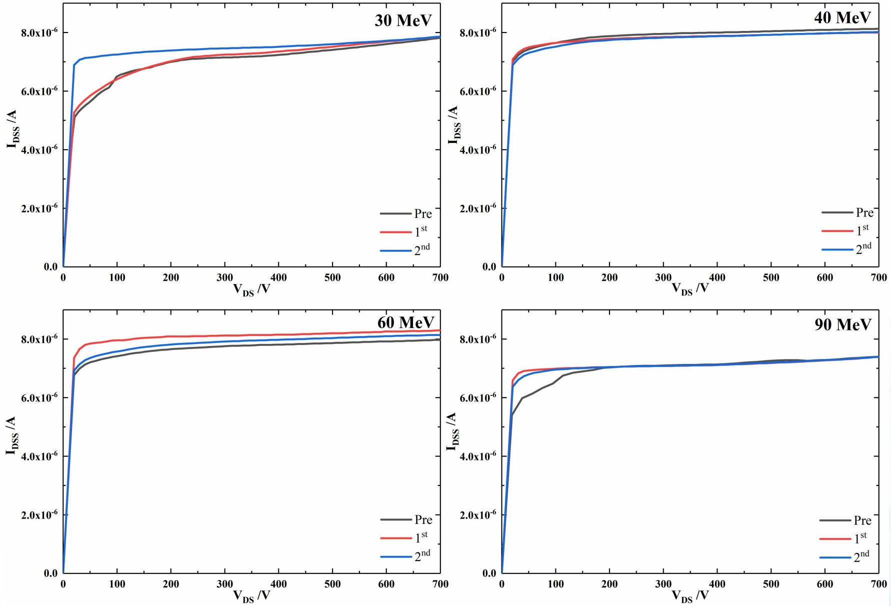


Fig.5 The off state leakage current of the GaN HEMT in group A before and after proton irradiation

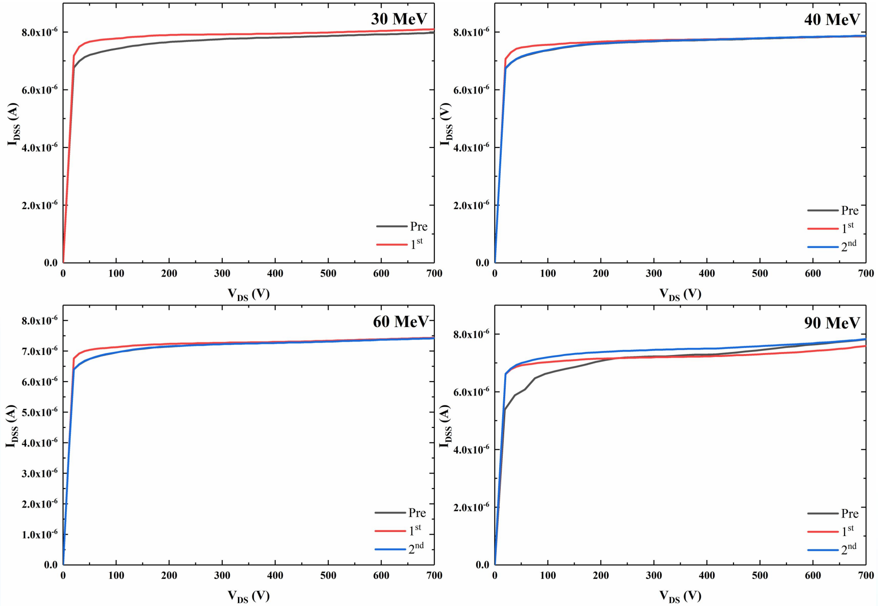


Fig.6 The off state leakage current of the GaN HEMT in group A before and after proton irradiation

3. Results and Disscusion

① The gate-source threshold voltage of the GaN HEMT is decreased by proton irradiation, while the outputcharacteristics, off-state leakage current and static forward gate current are increased by proton irradiation.

② After annealing at room temperature for 10 days, these electrical parameters of the GaN HEMT are restored to the corresponding values before proton irradiation.

③ The electrical properties of the GaN HEMT are improved after proton irradiationn under the experimental conditions in this paper.

Thank you!