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Low Gate Leakage Current InAlAs/InGaAs Metamorphic HEMTs Using HBr + UV Illumination Gate Treatment Technology

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1. Introduction

Recently, many investigations of inversion-mode InGaAs MOSFETs and AlGaAs/ InGaAs heterostructure FETs have reported excellent devices performance due to its surface chemical treatment [1-3]. The HBr chemical treatment of InGaAs surface has obtained considerable attention because of its simplicity and suitability for commercial exploitation. Thus, reported article indicated that HBr treated InGaAs surface is hydrophilic and is believed to be helpful to passivate InGaAs surface from surface recombination velocity measurement [4]. In this work, we have systematically studied for HBr treatment and HBr + ultraviolet (UV) treatment on InAlAs/ InGaAs metamorphic HEMTs (mHEMTs). These experimental results indicated that the novel HBr + UV treatment InGaAs provided a thin native oxide interfacial layer with good surface morphology on InGaAs is formed which is beneficial for improving device performance and the surface traps can be suppressed substantially. Furthermore, HBr + UV treatment exhibit a lower surface leakage current is also beneficial for improving the power of MOSFETs.

2. Device Structures and Fabrication

To further investigate the HBr + UV treatment of the interfacial chemical bonding characteristics between metal and InGaAs, InGaAs samples with and without HBr + UV treatment were prepared for the X-ray photoelectron spectroscopy (XPS). The XPS was conducted to measure the binding energy of interfacial layer. Fig.1 shows the XPS spectra of core level states of (a) Ga 2p, (b) As 3d and (c) In 3d of the InGaAs layer. Fig.1 (a) shows Ga 2p core level spectra, no treatment of Ga peak at 1116.8 eV and Ga–O bond at 1117.2 eV is present in HBr + UV treatment and Fig.1 (b) shows As 3d core level spectra, no treatment of As peak at 41.2 eV and As–O bond at 44.8 eV is present in HBr + UV treatment. In addition, HBr + UV treatment also leads to enhancement of In–O bond, as illustrated by In 3d core level spectra in Fig.1 (c) which was recorded in handbook of x-ray photoelectron spectroscopy.

Fig.2 shows the brief epitaxy structure which were grown by molecular beam epitaxy (MBE) on semi-insulating GaAs substrates. For devices fabrication, ohmic contacts of Au/Ge/Ni alloy metals were deposited by electron-beam evaporation and patterned by a conventional lift-off process. Then, following by rapid thermal alloying of evaporated at 350 ℃ for 2 min in an N_2-rich chamber. An $H_3PO_4/H_2O_2/H_2O$ solution was used for mesa etching. As to the critical gate-recessed process, a high selective succinic acid solution was applied for high uniformity consideration. Before Ti/Au metal gate was deposited for gate electrode, for standard treatment, the device was only cleaned by NH_4OH/H_2O for 30 sec. In this study, the 2nm InGaAs with HBr treatment and HBr + UV treatment for 10sec to from a thin oxide film as an insulator can effective reduce gate leakage current. Finally, the interconnection was used by 1 μm long Ti/Au metal layer and 200nm SiO_2 was deposited for passivation layer.

3. Results and Discussions

The Schottky gate forward and reverse current–voltage (I_g–V_g) curves of 1 μm × 50 μm for HBr + UV treatment mHEMT, HBr treatment mHEMT and standard mHEMT were shown in Fig.3. The breakdown voltage (gate reversed current =1mA/mm) of HBr + UV treatment mHEMT was -13.4 V, HBr treatment mHEMT was -11.6 V and standard mHEMT was -11.2 V. The gate leakage current for the HBr + UV treatment mHEMT was lower especially at large negative gate voltage, because of the elimination of tunneling current from the gate to the channel at high electric field. The lower gate leakage current not only improves the device breakdown voltage but is also beneficial to the improvement of the PAE at a high input power swing. The turn on voltage also defined by a 1mA/mm of gate current, HBr + UV treatment mHEMT was 1.5 V which was only 0.7 V for HBr treatment mHEMT and standard mHEMT. In addition, the ideality factor of Schottky diode of HBr + UV treatment mHEMT was 1.94, HBr treatment mHEMT was 1.77 and the value was 1.76 for standard mHEMT. Therefore, HBr + UV treatment mHEMT achieved a MOS like interface instead of traditional metal-semiconductor interface owing to the increase of ideality factor. Fig.4 shows the V_{gs} dependence of transconductance (gm) and I_{ds} curves at a fixed V_{ds} =2 V for HBr + UV treatment mHEMT, HBr treatment mHEMT and standard mHEMT. The maximum I_{ds} and gm were 470 mA/mm and 386 mS/mm for HBr + UV treatment mHEMT, 493 mA/mm and 370 mS/mm for HBr treatment mHEMT, and 477 mA/mm, 372 mS/mm for standard mHEMT. Based on the performance evaluations, the HBr + UV treatment mHEMT obtained a higher peak gm due to its surface chemical treatment was beneficial for improving gate-to-channel modulation ability. The S-parameter matrix for the two-port network is probably the most commonly used and serves as the basic building block for generating the higher order matrices for transistor intrinsic and extrinsic elements of small-signal networks. The relationship between the reflected and incident power waves measured by S parameters can be used to extract the transistor gain and bandwidth at microwave frequencies. From the measured S parameters, the current gain cut-off frequency (f_T) were 20, 17.6 and 16.2 GHz, and the maximum oscillation frequency (f_{Max}) were 64, 58 and 57 GHz for HBr + UV treatment mHEMT, HBr treatment mHEMT and standard mHEMT, respectively. The flicker noise measurement, which was sensitive to the semiconductor interface, was made to elucidate further the relationship between the flicker noise and the interface property of the metal-semiconductor contact. The bias was of V_{ds} = 2 V associated with an I_{ds} of 100 mA/mm for devices. As presented in Fig.5, the HBr + UV treatment mHEMT exhibited a lower noise spectra compared to HBr treatment mHEMT and standard mHEMT because a thin native oxide layer with good surface morphology on InGaAs is formed and the number of interface states was simultaneously reduced. The microwave power characteristics were evaluated by a load-pull system with automatic tuners, which provides conjugate matched input and load impedances simultaneously for the maximum output power. Microwave load-pull power performance was measured at 3.5 GHz with a drain bias of 2 V. The devices were operated at class AB. Fig.6 shows the output power (P_{out}), power gain (G_p) and power added efficiency (PAE) as a function of the input power (P_{in}) for 1.0 μm ×50 μm^2 gate-dimension devices. From these power performance results, the maximum output power density were 11.1, 12.1 and 12 dBm, the power-added efficiency were 46.6 %, 52.6 % and 55.6 % and the linear power gain of 16.7, 17.1 and 17.3dB for HBr + UV treatment mHEMT, HBr treatment mHEMT and standard mHEMT, respectively As a result, the microwave power performance is improved by the MOSHEMTs structure and exhibits excellent channel modulation ability and low gate leakage current.

4. Conclusions

In summary, low gate leakage current and higher power performance metamorphic HEMTs using HBr + UV illumination treatment after gate recess process have been developed and discussed. HBr + UV treatment technology provides a simple manufacturing process, the higher breakdown voltage, and the low surface states together with comparable device performance to the traditional NH_4OH treated devices. This novel HBr + UV treatment technology achieved a better surface roughness and a lower flicker noise. Based on measurement results, a lower interface traps can be obtained due to a thin native oxide on InGaAs is formed and the number of interface states was simultaneously reduced. Therefore, HBr + UV treatment provides a highly potential for novel GaAs MOS-HEMTs process for power amplifier applications.

References

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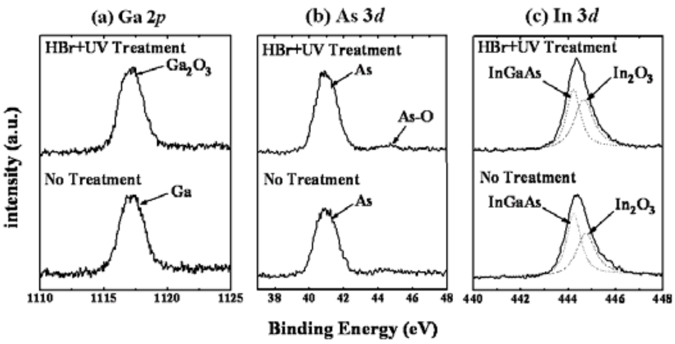

Fig.1. The core levels XPS spectra of InGaAs layer (a) Ga 2p, (b) As 3d, (c). In 3d.

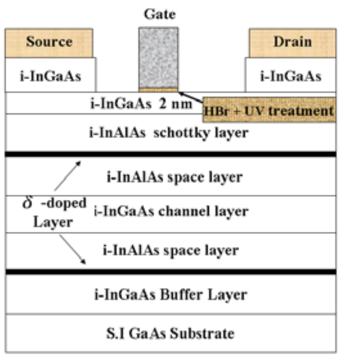

Fig.2. The cross-sectional structure of mHEMTs.

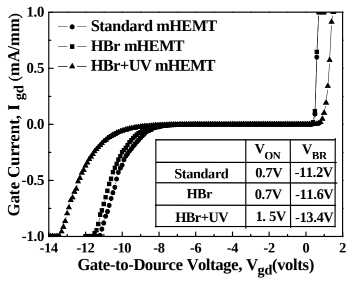

Fig.3. The Schottky characteristics for various devices.

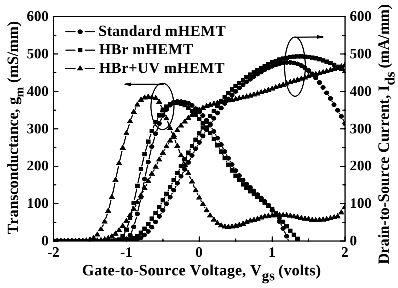

Fig.4. The I_{ds}-V_{gs} characteristics for various devices.

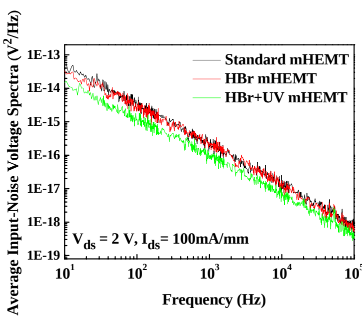

Fig.5. The flicker noise spectra for various devices.

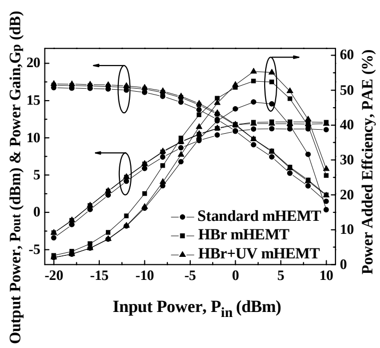

Fig.6. Microwave power performance for various devices.