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최대주파 10 GHz GaN MESFET의 소자특성

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Device Characteristics of GaN MESFET with the maximum frequency of 10 GHz

Abstract

This paper reports on the fabrication and characteristics of recessed gate GaN MESFETs fabricated using a photoelectrochemical wet etching method. The unique etching process utilizes photo-resistive mask and KOH based etchant. GaN MESFETs with successfully recessed gate structure was characterized in terms of dc and RF performance. The fabricated GaN MESFET exhibits a current saturation at V_{DS} = 4 V and a pinch-off at V_{GS} =-3V. The peak drain current of the device is about 230mA/mm at 300 K and the value is remained almost same for 500K operation. The f_T and f_{max} from the device are 6.35 GHz and 10.25 GHz, respectively. .

Key Words(중요용어) : MESFET, GaN, Recessed gate, Photoelectrochemical Etching, RF 특성, DC 특성

1. INTRODUCTION

Wide bandgap semiconductors based upon the Ⅲ-Nitride system,have many properties which are ideal for electronic and optical devices for high temperature, high frequency, high power,and radiation hard application. A variety of high frequency electronic devices can be fabricated from GaN - based semiconductors and these devices are predicted to offer superior DC and RF performance compared to more conventional Si and GaAs devices. Theoretical calculations for the large-signal performance of GaN MESFET predict output power density near 5 W/mm, power-added efficiency higher than 50 %, and linear power gain about 20dB for an optimized device structure[1].

In addition, GaN can allow for the AlGaN/GaN heterostructures which was demonstrated to produce two - dimensional electron gas(2 DEG) and thus makes possible several novel devices that can operate at frequencies beyond the capability of SiC devices. Also, the 2 DEG permits low resistances and low noise performance not possible with SiC[2].

Despite the excellent electronic properties of GaN, the fabrication of GaN MESFETs with novel designs have been hindered by the chemical inertness of this material. Thus, the most successful etching process so far has been dry etching method including reactive ion etching(RIE)[3], electron cyclotron resonance (ECR) RIE[4], and inductively coupled plasma(ICP)RIE[5]. However,these techniques are known to result in ion-induced damage on the etch surface which is highly undesirable for the high frequency and high power operation of devices. Wet chemical etching is a desirable

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substitute for dry etching method by providing low damage on the surface of active region. There has been a report on the photoelectrochemical wet etching process for GaN films using KOH solution under the illumination of Hg arc lamp[6]. However, the experiment was performed for the Ti metal mask which is not normally used in conventional wet etching process and is not suitable for the fabrication of microelectronic devices. In this paper, we report on the photoelectrochemical etching process for GaN thin films using photoresist mask. For the first time, the etching method is demonstrated to be well applicable to the fabrication of recessed gate GaN MESFET. The I_{DS}, g_m, V_{th}, of the device at different operation temperatures and f_T and f_{max} characteristics are discussed as well.

2.EXPERIMENTS

There is a variety of transistor structures that can be fabricated from wide bandgap semiconductors. However, the photoelectrochemical etching process was motivated, in particular, by the need for designing a recessed gate GaN MESFET. The etching mask used in this experiments is a i-line photoresist(THMR-ip1800, TOK), eliminating the hard baking process which lessens PR adhesion to the surface and hence leads to easy lift-off process. The sample for this experiment consists of 1.3 μm thick undoped ($3\sim4 \times 10^{16}/cm^3$) GaN buffer layer, 500 Å thick Si doped ($2 \times 10^{17}/cm^3$) n-GaN active layer and 300 Å thick Si doped ($2 \times 10^{18}/cm^3$) n^+-GaN cap layer grown on c-plane sapphire substrate by metal-organic chemical vapor deposition (MOCVD) method. GaN epi layer quality was measured by PL, XRD, Hall measurement of 300K. Dry etching for device isolation, MESA etching, was used ECR dry etcher. Etching rate was changed factor of RF bias, microwave power, processing chamber pressure. Prior to the gate recess etching process, the source and the drain ohmic contact with a contact resistance of 4×10^{6} Ωcm^2 was obtained by the deposition of Ti/Al (= 300Å/2000Å) bilayer followed by a rapid thermal annealing (RTA) at 700 ℃ for 10 seconds. The recess wet etching rate was examined as functions of the mole percentage of the KOH solution and the etching time. After an extraction of optimized conditions, the photoelectrochemical etching method was directly employed for the fabrication of a recessed gate GaN MESFET. An n+ cap layer with a thickness of 300 Å was etched out for the recessed gate structure. The schottky contact was formed by a Pt/Au (= 400Å/4000Å) alloy and it showed a good blocking capability. The gate length and the gate width of the device were 0.7 μm and 100 μm, respectively. The spacing between the gate and source or drain was 5 μm. The morphology of the etched surface was characterized by Scanning Electron Micros-copy(SEM) and Atomic Force Microscopy (AFM). The dc performance of the device was characterized at different device operation temperatures. After the s-parameter test, ft and fmax were obtained.

3. RESULTS AND DISCUSSION

Carrier concentration and mobility were changed by the mole fraction of Si. When the Si mole fraction varied in a range of 0.5 ~ 7 nmol/min, the carrier concentration was increased from $2 \times 10^{17}/cm^3$ to $5 \times 10^{18}/cm^3$ and mobility was decreased from 430 $cm^2/V.se$ to 135 $cm^2/V.sec$,respectively. Optimum condition of GaN dry etching is Ar:5, BCl_3:4, Cl_2:3, Pressure:3, RF:450V, Mw:300W, He:3 and the etching rate in this case is about 950Å/min.

Ohmic contact metal used Ti/Al system, contact resistance was $5 \times 10^{6} \Omega cm^2$ at 700°C 10 sec RTP annealing. The etching rate observed in this experiments is comparable with the etching rate achieved in a typical RIE method. Fig. 1 shows the morphology of the etched surface displaying a well defined etched edge. This figure demonstr ates that the photoresist can be used as a suitable pattern mask in this etching process.

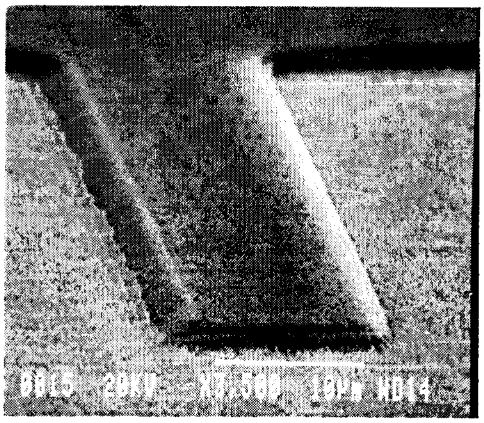

Fig. 1 Morphology of the etched surface displaying a well defined etched edge.

a suitable pattern mask in this etching process.

The surface morphology has been changed by the etching, but the value of etching-induced roughness is low enough to fabricate a MESFET structure with a gate length of 0.7 μm and a channel thickness of 0.05 μm. The optimized etching conditions were directly applied to the fabrication of recessed gate GaN MESFET and Fig. 2 shows the room temperature current - voltage characteristics of the device.

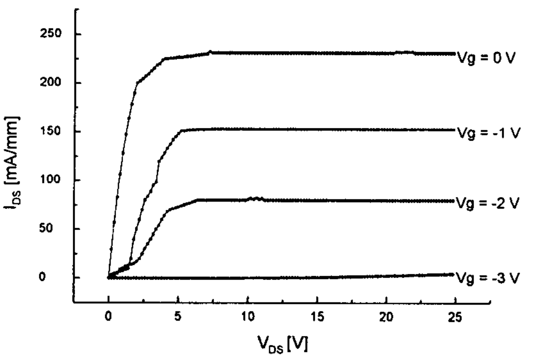

Fig. 2 Room temperature current-voltage characteristics of the GaN MESFET showing a low pinch-off voltage.

The gate voltage step is - 1 V and the saturation of the source-drain current occurs at Vds = 4 V and the pinch-off voltage occurs at Vgs = - 3 V. The maximum drain-source current of the device operating at 300K is about 230mA/mm and any significant change is not made at 500K. The current level is somewhat lower than the value expected from the device design, reasons for which will be discussed later.

The measurement for the RF performance shows Fig. 6. Cut-off frequency, maximum frequency are 6.25 GHz and 10.25 GHz at Vgs = 0 V, Vds = 8 V, respectively.

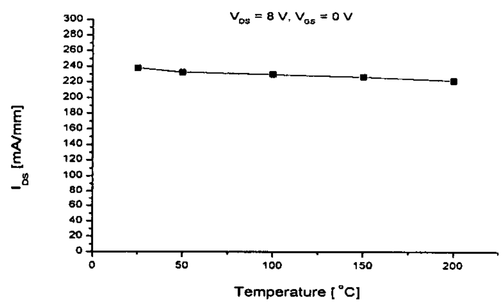

Fig. 3 Temperature dependence of current voltage characteristics of the GaN MESFET.

Theoretically, the current is supposed to be depressed with the device operating temperatures due to the decreased electron velocity and mobility at high temperatures. One explanation for the insensitivity in the drain current level is a high activation energy of dopants for ionization. It has been reported that the activation energy of dopants in thin films with two dimensional defects is known t o be higher than that without the defects[6]. When the activation is high and the dopants are in a "freeze-out region"[7], the number of the effective free carriers increases with temperature.Therefore, it is possible that the insensitivity of the drain current with temperature be attributed to a presumable freeze-out of dopants in the active region of device,otherwise.

the drain current should be decreased due to the decreased mobility and electron velocity at high temperatures. Another explanation for the insensitivity is the trap of carriers at the subgrain boundaries. GaN thin films are known to possess high density of subgrain boundaries that are responsible for the band-bending[8]. The driving force for electrons to overcome to transverse grain boundaries is better provided by the device operation at higher temperatures. Thus,

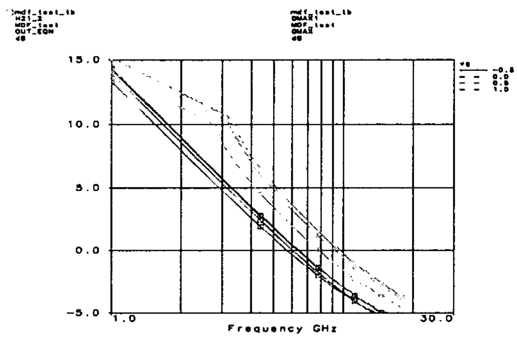

Fig. 4 Frequency(f_t and f_{max})characteristics of a GaN MESFET with f_t and f_{max} of 6.35 and 10 GHz, respectively.

the mobility of electrons at higher temperature could be higher than that at lower temperature as is the observed abnormal behavior in the mobility-doping relationship[9].

4. CONCLUSION

For the first time, the photoelectrochemical etching process using photoresist mask was employed for the fabrication of recessed gate GaN MESFETs. The etching rate with the etchant with 1.0 mol % of KOH for n-GaN is as high as 1600 Å/min. The GaN MESFET thus fabricated exhibits a clear drain current saturation and pinch-off with the maximum drain current of 240 mA/mm at room temperature. Insensitivity of the drain current with temperature was attributed to the defect-related high activation energy of dopants and band-bending. The wet etching process developed is likely to find application in fabrication of devices using GaN or other chemically inert semiconductors in a novel design needed for high breakdown voltages.

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