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Leakage current and sub-bandgap photo-response of oxygen-plasma treated GaN Schottky barrier diodes

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ABSTRACT

The effect of oxygen plasma treatment on the performance of GaN Schottky barrier diodes is studied. The GaN surface is intentionally exposed to oxygen plasma generated in an inductively coupled plasma etching system before Schottky metal deposition. The reverse leakage current of the treated diodes is suppressed in low bias range with enhanced diode ideality factor and series resistance. However, in high bias range the treated diodes exhibit higher reverse leakage current and corresponding lower breakdown voltage. The X-ray photoelectron spectroscopy analysis reveals the growth of a thin GaO_x layer on GaN surface during oxygen plasma treatment. Under sub-bandgap light illumination, the plasma-treated diodes show larger photovoltaic response compared with that of untreated diodes, suggesting that additional defect states at GaN surface are induced by the oxygen plasma treatment.

1. Introduction

GaN and its related alloys have superior material characteristics such as large bandgap, high breakdown electrical field, and high electron saturation velocity, which are well suited for power device [1], microwave device [2] and optoelectronic device applications [3]. Although important progress in GaN technology has been made in recent years, there are still several major technical problems to be solved, which greatly impede further improvement of device performance. One of them is the commonly-observed excess reverse leakage current of GaN-based Schottky junctions, which are fundamental building blocks of many III-nitride-based high-power and high-frequency devices.

Besides improving GaN crystalline quality, it is evident that surface treatment could play a role in reducing the high leakage current of GaN Schottky barrier diodes (SBDs). Several surface treatment methods have been reported with more or less success, such as $(NH_4)_2S_x$ solution treatment [4], electrochemical surface treatment [5], and CF_4 plasma treatment [6]. Surface oxidation of GaN is also proposed as a feasible way to reduce the leakage current of GaN Schottky junctions. Since GaN is quite stable in low-temperature range and starts to decompose at high temperatures (>850 °C) leading to degraded surface morphology [7,8], thermal oxidation of GaN in oxygen atmosphere is less used. Alternatively, oxygen plasma treatment of GaN and AlGaN/GaN hetero-structure surface has been studied by a few groups [9,10]. O_2 plasma treatment could induce the growth of a thin GaO_x layer on GaN surface, which is reported to effectively reduce both leakage current and interface state density of the GaN Schottky junctions.

In this work, we studied the effect of oxygen plasma treatment on GaN surface by using an inductively coupled plasma (ICP) etching system prior to Schottky metal deposition. It is found that although the oxygen plasma treatment could reduce leakage current of the diodes in low reverse bias range, the treated diodes show stronger sub-bandgap photovoltaic response, suggesting increased interface state density. In addition, the treated diodes also exhibit reduced breakdown voltage.

2. Experimental procedures

The GaN samples used in this work were grown by metal organic chemical vapor deposition on *c*-plane sapphire substrate. The epi-structure consists of a 1.0 μm n^+ GaN layer ($\sim 5 \times 10^{18}\,cm^{-3}$) followed by a 4 μm n^- GaN layer ($\sim 2 \times 10^{16}\,cm^{-3}$). The full width at half maximum of the GaN (0002) peak in X-ray diffraction rocking curve is 291.6 arcsec. Planar SBDs were fabricated to study the electrical and optical properties, which consist of 200 μm circular Schottky dots separated radially by 30 μm from ohmic contacts. Ohmic contacts were firstly formed by deposit-

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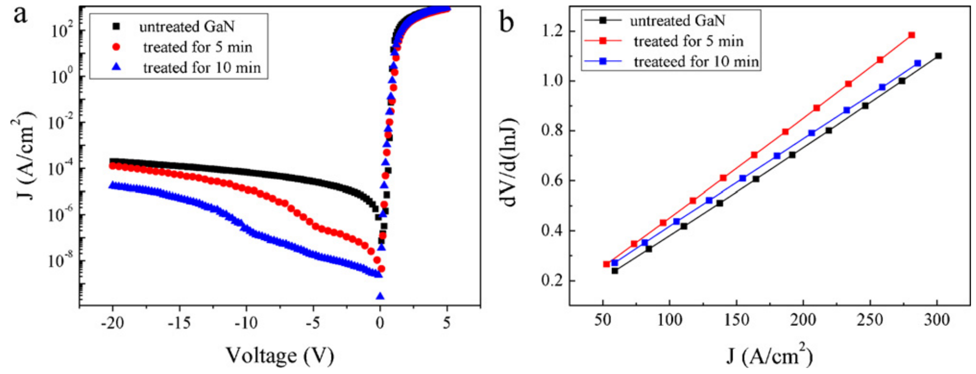

Fig. 1. (a) *I*–*V* characteristics of the GaN SBDs with and without oxygen plasma treatment and (b) the corresponding *dV*/*d*(ln*J*) vs *J* plots in forward bias range.

ing Ti/Al/Ti/Au (20 nm/80 nm/30 nm/80 nm) metal stack by e-beam evaporation followed by annealing at 850 °C for 30 s in nitrogen ambient. A 200 nm SiO_2 field oxide layer was then deposited by plasma-enhanced chemical vapor deposition. After opening circular windows in the oxide layer and evaporating a 200 nm Ni contact metal, Schottky dots with 5 μm overlap on the field oxide layer were defined by photolithography and formed by wet chemical etching.

Oxygen plasma treatment to the exposed GaN surface was performed just before the Schottky metal deposition by using a standard load-lock ICP etching system (Oxford Plasmalab 100 ICP). Since theoretically during ICP etching process ICP power mainly works to generate reactive ions and RF power works to enhance physical bombardment, to minimize plasma-induced surface damage a RF power as low as possible was used in our treatment process, which is just enough to strike the oxygen plasma. The major process parameters include RF power of 10 W, ICP power of 800 W, chamber pressure of 15 mTorr, and O_2 flow rate of 100 sccm. The plasma treatment times are 5 and 10 min respectively at room temperature.

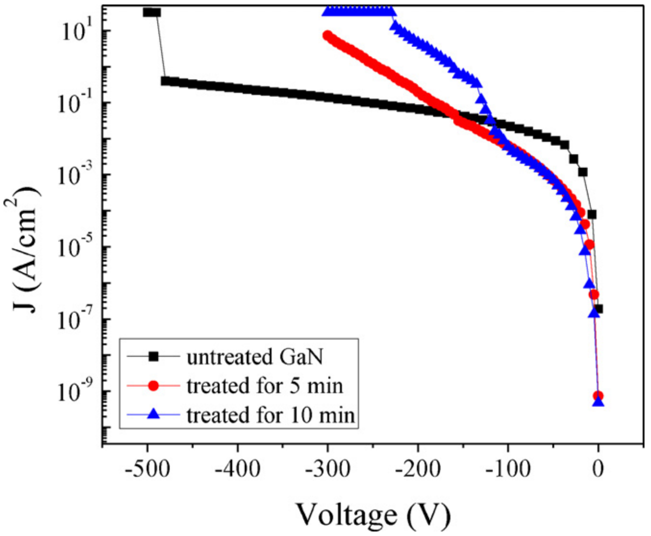

Fig. 3. Breakdown characteristics of the GaN SBDs with and without oxygen plasma treatment.

3. Results and discussion

Fig. 1(a) shows current–voltage (*I*–*V*) characteristics of the GaN SBDs with and without oxygen plasma treatment. It is clear that with increasing treatment time, the leakage current of the diodes is considerably reduced in low reverse bias range, while there is no apparent change in diode forward characteristics. The ideality factor and the series resistance of the SBDs are calculated using the method developed by Cheung and Cheung [11]. Cheung's function in terms of current density *J* can be expressed as:

$$\frac{dV}{d(\ln J)} = ARsJ + \frac{nkT}{q} \tag{1}$$

where *A* is the effective Schottky contact area, *Rs* is the series resistance, and *n* is the ideality factor. Fig. 1(b) shows the *dV*/*d*(ln*J*) vs *J* plots of the untreated and treated GaN SBDs, which give *ARs* as the slope and *nkT*/*q* as the *y*-axis intercept. The derived ideality factors (*n*) for untreated, 5 min, and 10 min's treated SBDs are 1.28, 2.06 and

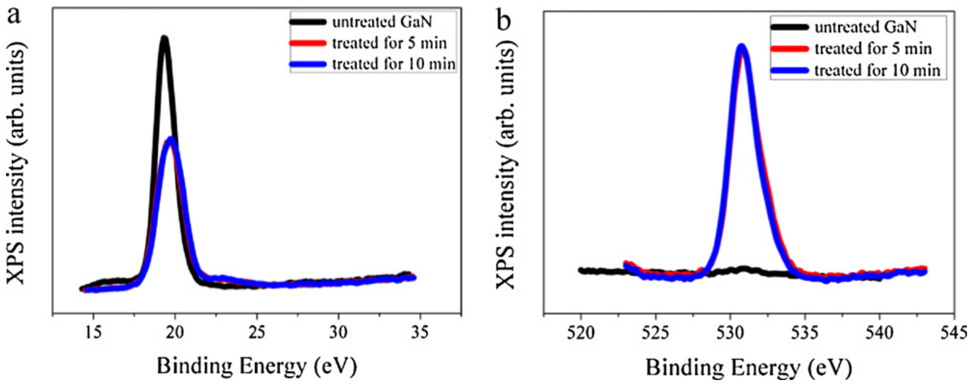

Fig. 2. XPS spectra of (a) Ga 3d and (b) O 1s for untreated and oxygen-plasma-treated GaN surface.