Electrical Properties of ICP Plasma-Damaged n-GaN

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Success in the etching of Group-III nitrides has been achieved predominantly by dry plasma etching, although NaOH based photo-enhanced wet etching is beginning to produce appreciable etch rates. Nevertheless the latter technique suffers a major drawback of not being commercially viable currently, since most of the experiments were performed in small-scale electrochemical cells. GaN in particular is highly chemically inert and a plausible solution is provided by Inductively Coupled Plasma (ICP) etching, a high-density plasma etching technique, which could yield etch rates of beyond 200nm/min and a fine surface morphology. Despite such favourable characteristics, there are bound to be near-surface changes which would affect the electrical and optical properties. Plasma damage to the material will hinder the fabrication of GaN based devices. For example the fabrication of an GaN/InGaN/AlGaN laser diode typically involves etching which terminates on an n -GaN layer, on which an ohmic contact is t o be deposited. Knowledge of electrical properties of plasma damaged n-GaN would be valuable

A Si-doped epitaxial layer (n ~ $5x10^{17}$) of 1.3μm thickness was grown in an EMCORE MOCVD reactor on a sapphire substrate, with an undoped GaN 25nm buffer layer sandwiched in between. Planar resistors in the form of Hallbars were patterned by photolithography and etched in a Plasma-Therm 770 reactor set to 300W of RIE power and 400W of ICP power. The Hallbars were subsequently exposed to the ICP plasma for 30s. The plasma chemistry consisted of 8 sccm of Cl_2 and 20 sccm of BCl_3. The samples were subjected to RTA treatment in an N_2 ambient at 900°C for 3min. Ti (35nm)/Al(115nm) contacts were deposited by e-beam evaporation and defined by a conventional lift-off technique. Formation of ohmic contacts X-ray photoelectron spectroscopy (XPS) was performed on a VG ESSCALAB 220I-XL, and the current/voltage characteristics was measured using an HP parameter analyzer.

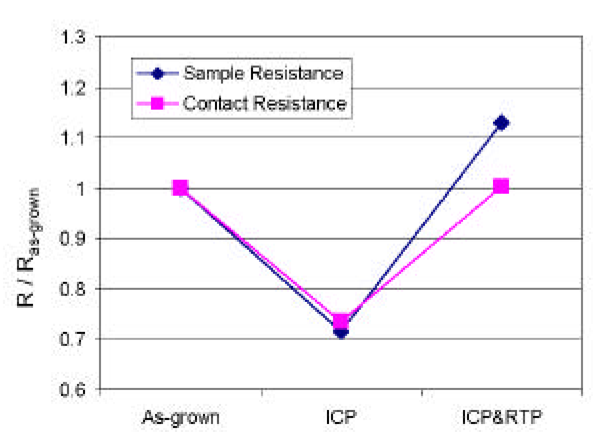

Figure 1. Effect of ICP plasma exposure and subsequent RTA treatment on the sample and contact resistance.

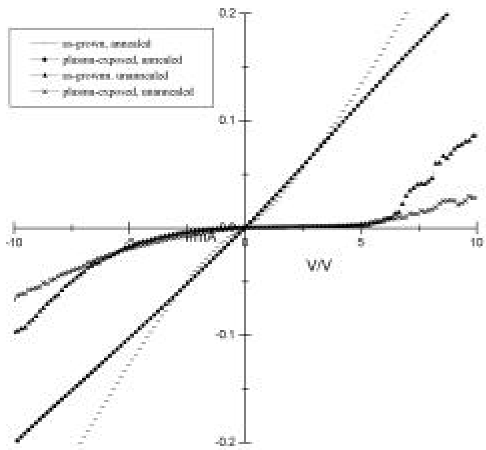

Figure 2. Current/voltage plot illustrating the ohmic characteristics of contacts deposited on as-grown and plasma-exposed GaN surface.

Figure 1 shows the changes to the sample and contact resistance of the hallbars consequent to ICP exposure and RTA treatments. When the samples have been exposed to the ICP plasma a drop in both the sample and contact resistance was measured. RTA treatments restores the resistances to the initial levels. Since the as-deposited contacts were non-ohmic, it is difficult to draw any inference from the variations in the contact resistance. Instead the current/voltage characteristics was determined to gain further insight into the nature of the contacts. The I-V plots are shown in Figure 2. The unannealed contacts were non-ohmic regardless of whether they were deposited on an as-grown or plasma-exposed sample. This is partly due to the low level of doping in the epi-layer. Annealing of the contacts results in the as-grown sample approaching ohmic behaviour, while the plasma-exposed sample exhibits a perfectly linear I-V relationship. Hence, the exposure of GaN surfaces to an ICP plasma resulted in a reduction in resistance and it has also facilitated the formation of ohmic contacts.

In order to elucidate the observations, the near surface stoichiometry changes due to plasma exposure has been studied by XPS. Wide XPS scan for the (a)as grown (b)plasma exposed and (c)plasma exposed & annealed samples has been performed. Comparing the Ga3d:N1s ratio between the as-grown sample (Ga/N ratio = 2.65:1) and the plasma exposed sample (Ga/N ratio = 5.76:1), we do notice that there is a loss of N atoms during the ICP process. This can be understood by considering the mechanism of ICP etching, which involves a physical sputtering step, followed by chemical reactions that take place on the sputtered surface. During the latter stage GaN dissociates to reacts with Cl_2 and BCl_3 to form chlorides and bromides and nitrogen. Since nitrogen is the most volatile of the products it is preferentially removed, leaving a N_2 depleted surface. Such N_2 loss occurs in the very near-surface region.

Nitrogen loss and the formation of N vacancies is the key mechanism that gives rise to changes in resistance and ohmic contact formation. N vacancies at the surface would result in an n^+ region at the surface, since it is believed that N vacancies contribute to the background conductivity in GaN. The excess of electrons brings about an increase in conductivity, hence the resistance drop. Contact formation on an n^+ surface also improves its ohmic behaviour. Based on the N vacancies theory, the return of the resistance to the initial level upon annealing could be explained by the restoration of a stoichiometric surface (Ga/N = 1.45:1).