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EBIC study of Au / n-type GaN Schottky contacts

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ABSTRACT: The performance of Au / n-type GaN Schottky contacts is strongly dependent on the GaN surface processing prior to contacting. Current-voltage and EBIC line scans demonstrate that KOH treatment acts to degrade the Schottky contacts. EBIC imaging reveals the differing sub-grain boundary structures of MBE and MOCVD grown GaN / sapphire. The KOH treatment acts to uniformly change the properties of the GaN surface, rather than having a localised effect.

1. INTRODUCTION

Metal contacts to GaN still represent one of the strongest limitations to the performance of GaN based devices (Pearton *et al* 2000). Many studies present in the literature report a wide variety of Schottky and ohmic behaviours and these cannot be simply explained with reference just to the metal free energy (Liu *et al* 1998). It is clear that the quality and the surface processing of the GaN also have a dominant effect on the resultant contact properties. Previous studies (Cao *et al* 1999, Ping *et al* 1997) have demonstrated that the etching of n-type GaN is detrimental to the formation of Schottky contacts, whilst such processes improve the performance of ohmic contacts. Consequently, the intimate relationship between the surface processing treatment and the resultant contact electrical properties requires further investigation. The present study compares the electron beam induced current (EBIC) at the Schottky barrier of Au / n-type GaN contacts and profiles the changes in the local electrical activity of MBE and MOCVD grown material as a consequence of KOH surface treatment.

2. EXPERIMENT

Four Au / GaN Schottky contacts, having different bulk properties, were prepared, allowing the comparison of MBE and CVD GaN in the untreated and KOH treated condition. The source MBE GaN / sapphire sample was 2.52 μm thick and demonstrated an n-type carrier concentration of 6.38 x 10^{16} cm^{-3} and electron mobility of 212 cm^2/Vs. The MOCVD GaN / sapphire sample was 3 μm thick with a 0.9 μm thick Si-doped capping layer, with an estimated n-type carrier concentration of ~$10^{17}cm^{-3}$. Both wafers exhibited a Ga surface polarity. Cleaved samples were degreased in an ultrasonic bath using a sequence of lotoxane, methanol, acetone, iso-propanol and de-ionised water, each for a duration of three minutes. Both MBE and MOCVD samples were treated in a 6 molar solution of KOH and de-ionised water at 60º C for 1 minute, followed by a 1 minute dip in de-ionised water and then nitrogen blown dry. All the samples were then further cleaned by dipping into a 37% solution of HCl and de-ionised water for three minutes and again blown dry using nitrogen. Shadow masks were applied to both etched and unetched MBE and MOCVD samples and Au was deposited at a rate of 3 nm/s to a thickness of 125 nm using a thermal evaporator, at 4 x 10^{-6} Torr chamber pressure. The shadow masks were then removed and the samples were again cleaned with HCl. Shadow mask were again applied and ohmic Ti pads were deposited at 0.7 nm/s to a thickness of

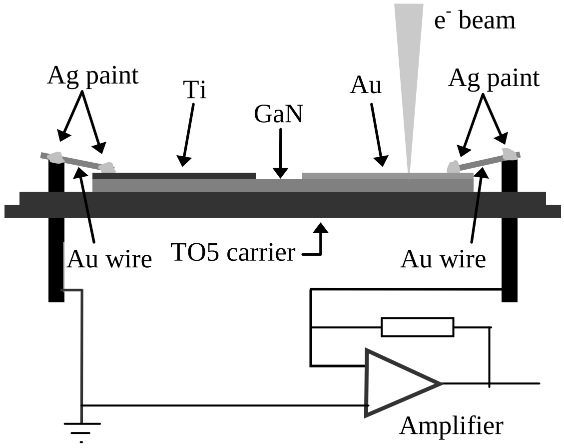
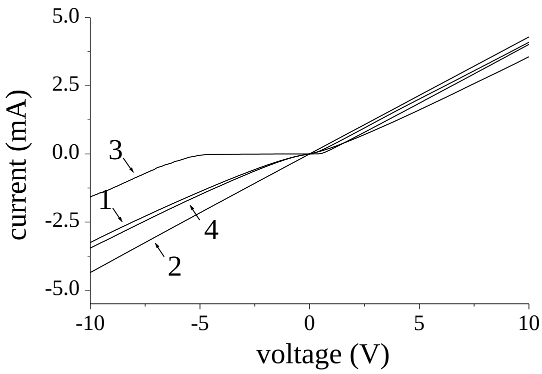
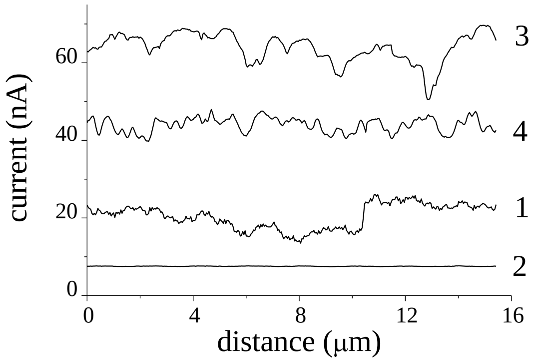


Figure 1: Schematic of Schottky device structure used for EBIC investigation.

Sample	Magnitude of induced current (signal)	Standard deviation of induced current (contrast)
MBE unetched	43.89 nA	1.86 nA
MBE etched	7.55 nA	0.04 nA
MOCVD unetched	64.04 nA	3.79 nA
MOCVD etched	20.44 nA	3.20 nA

Table 1: Comparison of EBIC signal and contrast.





(1) untreated MBE, (2) KOH treated MBE, (3) untreated MOCVD and (4) KOH treated MOCVD

Figure 2: Current-voltage behaviour of the four Schottky contacts.

Figure 3: EBIC line scan profiles.

200 nm using an e-beam evaporator, at a 2.5 x 10^{-6} Torr chamber pressure. Each sample was then mounted on a TO5 carrier and connections were made to the Au and Ti pads using Au wire and Ag paint (Fig. 1).

The samples were loaded into a Jeol 6400 WinSEM and connected to a Matelect IV5 amplifier using the Au pads as the collection junction. For a given sample and acquisition set-up, best EBIC signal-to-noise ratio and resolution were achieved using a microscope acceleration voltage of 30 kV, ~90 nm probe size and a slow scan of 320 seconds. The EBIC amplifier was set on the 200 nA range. Secondary electron (SE) images were also acquired at 10 kV and probe size of ~220 nm.

3. RESULTS & DISCUSSION

The current-voltage behaviour of each sample, as recorded at room temperature under light conditions, is presented in Fig. 2. Overall, the Au contacted MOCVD GaN samples exhibited stronger Schottky behaviour, as compared with the MBE samples. Also, both MBE and MOCVD untreated samples show a stronger Schottky behaviour as compared with the KOH treated samples. Thus, the KOH treatment acts to degrade the Schottky barrier, which is consistent with literature (Ping *et al* 1997). EBIC line scan profiles were recorded (Fig. 3) and the magnitude of the mean induced currents (signal) and standard deviations (contrast) are compared in Table 1. The MOCVD samples exhibited a larger induced current as compared with the MBE samples, whilst KOH etching

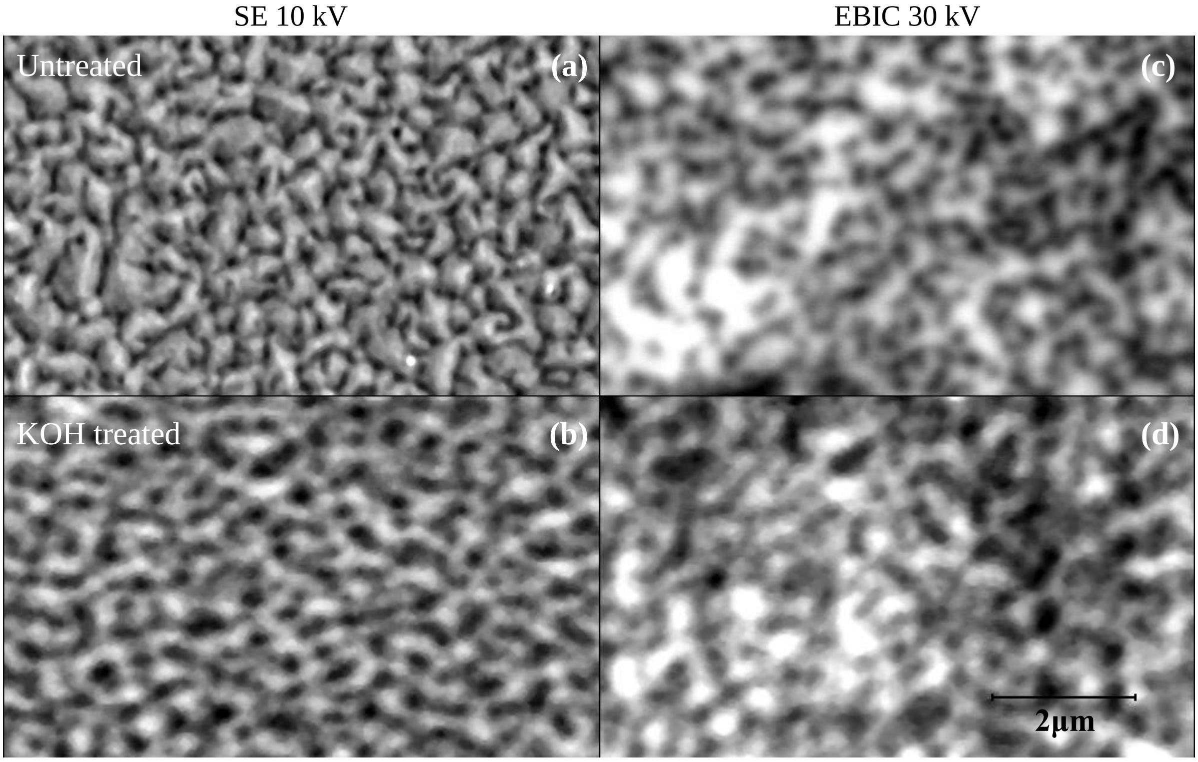


Figure 4: (a,b) SE and (c,d) EBIC images of Au / GaN_{MBE} Schottky contacts for (a,c) untreated and (b,d) KOH treated conditions.

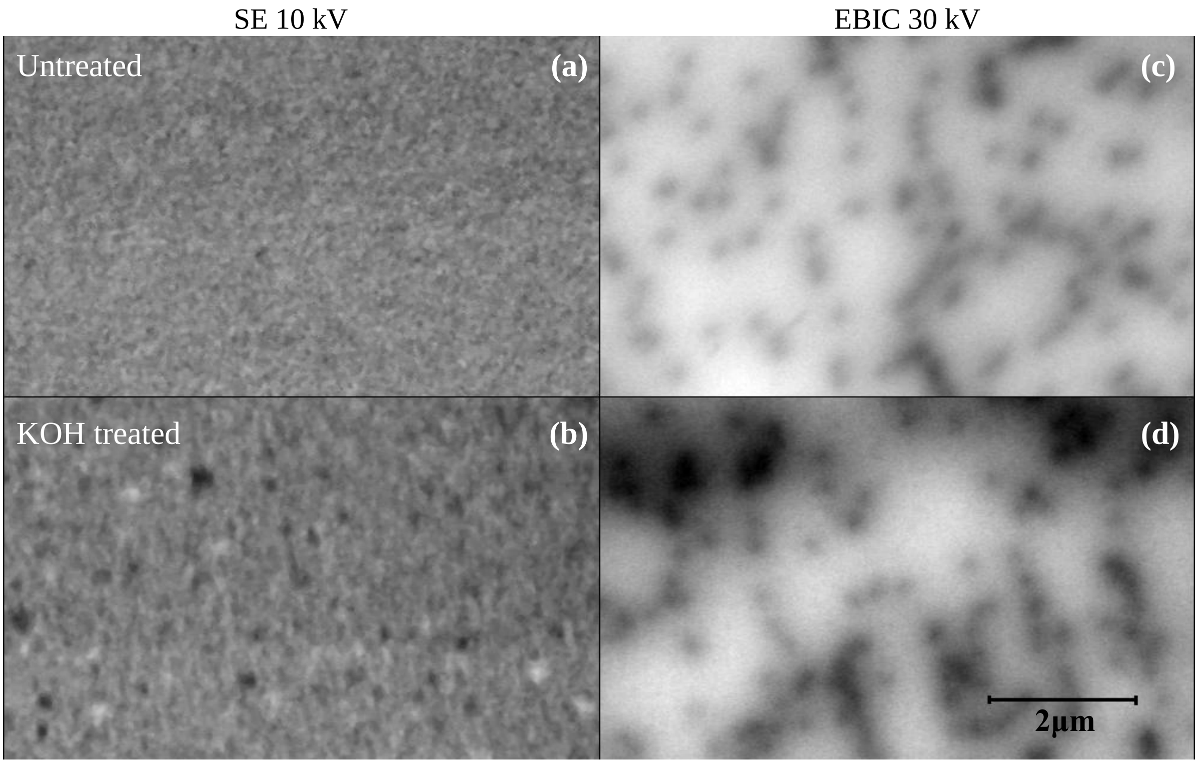


Figure 5: (a,b) SE and (c,d) EBIC images of Au / GaN_{MOCVD} Schottky contacts for (a,c) untreated and (b,d) KOH treated conditions.

was associated with a reduction in both EBIC signal and contrast, in accordance with the current-voltage response for these contacts. Correlated SE and EBIC images acquired from these Schottky contacted MBE and MOCVD GaN samples are presented in Figures 4 and 5, respectively.

The EBIC images reveal differences in the grain structures and the distribution of threading dislocations within these MBE and MOCVD samples, but provide no visible change due to the effect of KOH treatment. The suggestion therefore is that the KOH treatment employed acts to uniformly change the properties of the GaN surface, rather than having a localised effect. The SE image of Fig. 4a indicates a rough MBE GaN surface with a high density of small sub-grains of ~350 nm in size. The location of low signal within the EBIC images (Figs. 4c,d) appears to correlate with the position of the grain boundaries in the SE image, as expected. Conversely, the MOCVD sample exhibited a smooth surface, whilst the EBIC images (Figs 5c,d) suggest larger sub-grains of ~1μm in size, with a GaN / sapphire threading dislocation density of ~$5x10^6$ cm^{-2} (presuming each feature within the EBIC image corresponds to an isolated threading dislocation).

Both the current-voltage data and the differences in the collection efficiency of the EBIC induced signals demonstrate that the KOH treatment of the GaN surface prior to metal deposition significantly degrades the Schottky contact. KOH is used to discriminate between the opposite polar faces of GaN, acting to etch N-polar GaN surfaces but not Ga-polar surfaces (Li *et al* 2001). It is considered that this difference in behaviour is related the bonding configuration of nitrogen and possibly the Ga_2O_3 surface termination of the Ga-polar surface which makes it difficult to etch. Nevertheless, some surface modification of these KOH treated Ga-polar GaN surfaces prior to Au contacting must have occurred, as compared with the untreated samples, even though no visible changes were apparent within the EBIC images. Whilst the fundamental reason for this difference remains unclear, one can speculate that the extent of remnant oxide coverage, hydrocarbon contamination and associated pinned surface states of the as-cleaned GaN samples as compared with the KOH treated samples is related to this change in Schottky contact behaviour. In this context, one notes that XPS studies indicate band bending at the surfaces of KOH treated Ga-polar GaN samples (Li *et al* 2001) and this will indeed lead to a change in the Schottky contact behaviour.

5. SUMMARY

Current-voltage data and EBIC measurements of Au contacted MBE and MOCVD grown n-type GaN samples have enabled the effects of KOH surface treatments to be appraised. Schottky performance if strongly dependent on the GaN surface processing prior to contacting, with KOH treatment leading to a degradation of the contacts. EBIC imaging also revealed the differences in the grain boundary distributions of MBE and MOCVD GaN / sapphire samples, as expected. The KOH treatment employed acts to uniformly change the properties of the GaN surface, rather than having a localised effect.

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