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Correlation of electrical and structural properties of Au contacts to KOH treated n-GaN

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Abstract. A correlated current-voltage (I-V), electron beam induced conductivity (EBIC) and X-ray photoelectron spectroscopy (XPS) study of Au contacts to KOH treated n-type GaN is presented. A strong degradation of I-V characteristics occurs following the KOH treatment, mirrored in a reduction in the magnitude of the EBIC current, even though the EBIC images look visibly unaltered. XPS demonstrates a modification in the surfaces states, e.g. resulting in a –0.3eV shift in the binding energy of Ga_{3d} for MBE GaN following KOH processing.

1. Introduction

One of the major limitations to the performance of the GaN based devices arises from the metallic contacts [1]. It has been demonstrated that improvements in contact performance can be achieved by means of careful GaN surface preparation prior to metal deposition. The etching of n-GaN reduces the ohmic contact resistance [2] whilst producing leaky Schottky contacts [3]. This is illustrated by the case of the KOH surface treatment that has been shown to produce a reduction in ohmic contact resistance by up to one order of magnitude [4]. Further investigations are required to investigate the intimate relationship between the structural and chemical modifications to the GaN surface introduced by KOH treatment and the resulting contact performance. The present study uses an electron beam induced current (EBIC) approach to investigate the influence of KOH treatment on the barrier height of Schottky Au contacts, correlated with X-ray photoelectron spectrometry (XPS). Comparison is made between contacts to etched Ga-polar GaN grown by MBE and MOCVD.

2. Experimental

Au/n-GaN Schottky contacts were deposited onto untreated and KOH treated n-GaN samples. The MOCVD GaN/sapphire wafer was 3µm thick with a 0.9µm thick Si-doped capping layer with an estimated n-type carrier concentration of $\sim10^{17}cm^{-3}$. The MBE GaN/sapphire wafer was 2.52µm thick and demonstrated an n-type carrier concentration of $6.38x10^{16}cm^{-3}$ and electron mobility of $212cm^2/Vs$. Cleaved samples were degreased in ultrasonic baths of lotoxane, methanol, acetone, propanol and de-ionised water, each for three minutes. The KOH treatment consisted of dipping in a 6 molar solution of KOH and de-ionised water for 1 minute at 60ºC, followed by a 1 minute dip in de-

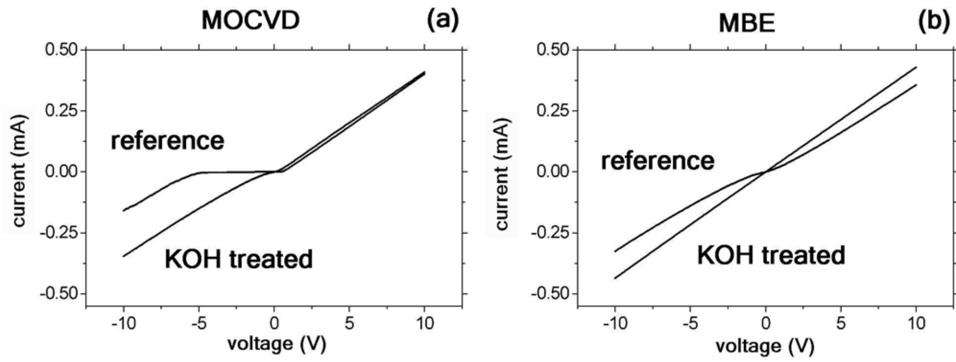

Figure 1. Current-voltage characteristics of reference and KOH treated (a) MOCVD and (b) MBE GaN.

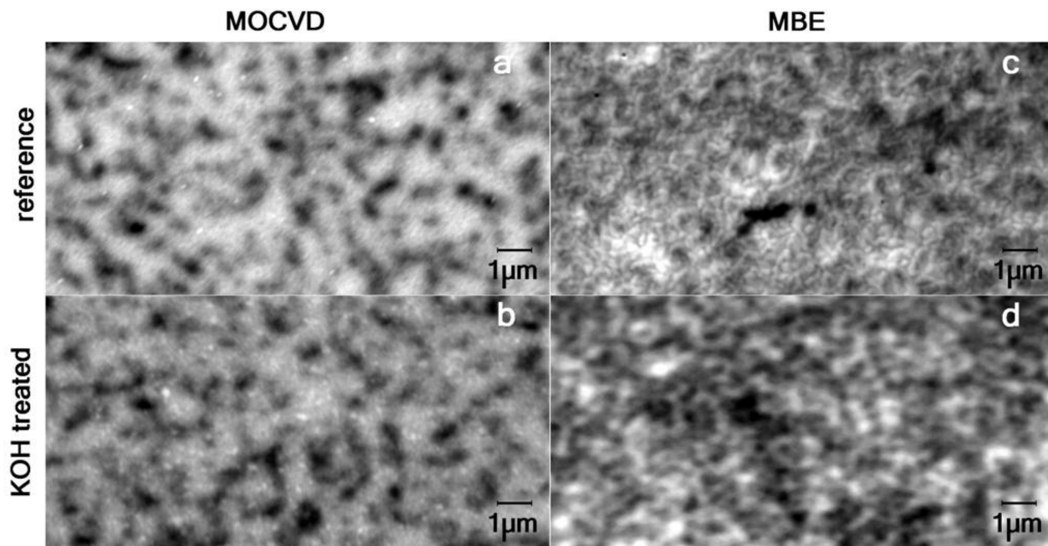

Figure 2. 10kV EBIC images of reference and KOH treated (a, b) MOCVD and (c, d) MBE GaN.

ionised water and finally N_2 blown dry. Prior to each metallisation, the samples were cleaned by dipping into a 37% solution of HCl and de-ionised water for three minutes and again N_2 blown dry. Glass shadow masks were employed for the formation of Au Schottky contacts and ohmic Ti pads for the purpose of ground connection during the EBIC experiments and I-V measurements. Au was deposited simultaneously on all samples at a rate of 3nm/s, to a thickness of 125nm, using a thermal evaporator at a chamber pressure of $4x10^{-6}$ Torr. Ti was deposited at 0.7nm/s, to a thickness of 200nm, using an e-beam evaporator at a chamber pressure of $2.5x10^{-6}$ Torr. EBIC measurements were performed using a JEOL 6400 SEM and a Matelect IV5 amplifier. XPS experiments were performed using a VG scientific ESCALAB with an Al K_α cathode.

3. Results and Discussion

The current-voltage (I-V) behaviour of each sample was recorded at room temperature under light conditions, as presented in Figure 1. The I-V traces demonstrate that the Au contacted MOCVD GaN samples have a stronger Schottky response than the MBE samples, while the reference samples exhibit a stronger Schottky behaviour as compared with the KOH treated samples.

The plan-view EBIC images shown in Figure 2 were intentionally recorded at a low acceleration voltage of 10kV to accentuate the contribution of the GaN surface features.

		Ga (%)	N (%)	O (%)	C (%)	Cl (%)
MOCVD	reference	28.0	64.4	0.7	6.2	0.7
	KOH treated	27.2	68.2	0.3	3.4	1.0
MBE	reference	30.0	64.3	0.9	4.0	0.8
	KOH treated	26.6	68.6	1.0	3.3	0.5

Table 1. GaN surface content quantified from the XPS survey spectra, for the reference and the KOH treated samples.

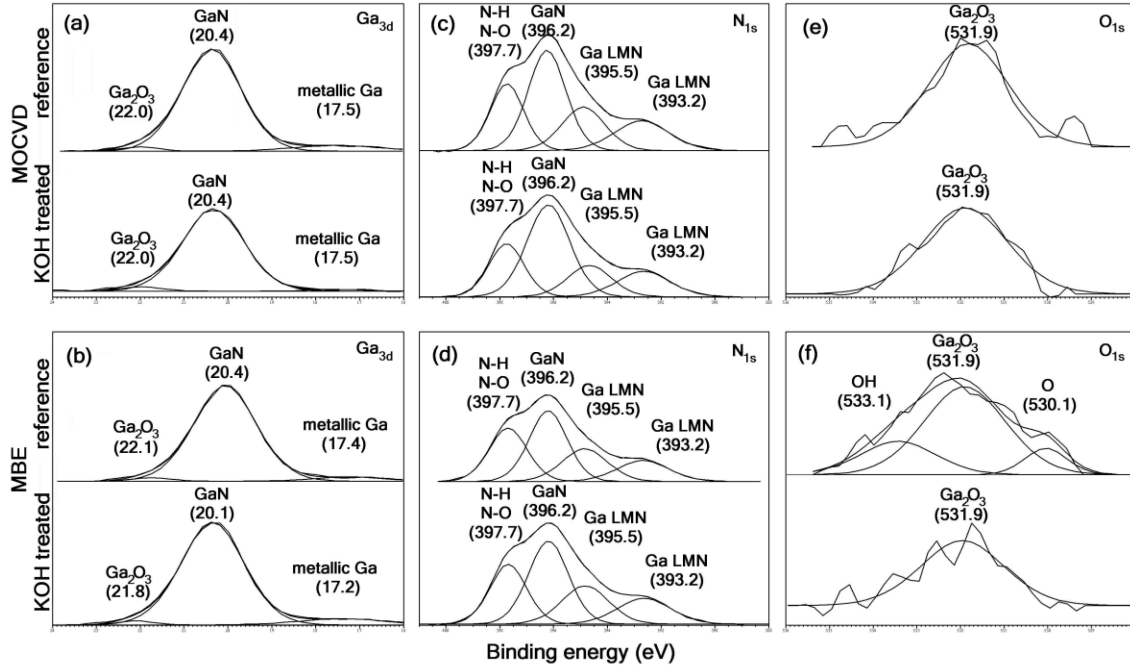

Figure 3. Detailed XPS scans of Ga_{3d}, N_{1s} and O_{1s}, showing the shape and energy (eV) of the de-convoluted peaks.

The MOCVD samples exhibited a smooth surface with large sub-grains of ~1μm in size and a GaN/sapphire threading dislocation density of ~$5x10^6cm^{-2}$ (presuming that each feature within the EBIC image corresponds to an isolated threading dislocation). The MBE sample displayed a rough surface with a high density of small sub-grains of ~350nm in size. The location of low signals within the MBE sample EBIC images appears to correlate with the position of grain boundaries in the secondary electron images [5]. It is noted the MOCVD samples exhibited a larger induced current as compared with the MBE samples, whilst KOH etching was associated with a reduction in both EBIC signal and contrast (Figs. 2c,d). Overall, however, the EBIC images provide no visible change attributable to the effect of KOH treatment (Figs. 2a,b), in contrast to the induced current and I-V measurements. Hence, the suggestion is that the KOH treatment acts to uniformly change the properties of the GaN surface but does not have a localised effect.

In the absence of evidence for any differences in the surface structures with processing, an investigation was made of the changes in surface chemistry induced by the etching procedure to try and explain this difference in contact performance. The sample-set was replicated from the same wafers and processed under identical condition for the purpose of XPS analysis of the GaN surfaces prior to metallisation. The acquired survey spectra were dominated by N and Ga peaks, with only traces of O, C and Cl (attributed to the cleaning treatment in HCl solution). The relative atomic content of Ga, N, O, C and Cl was determined using the Ga_{3d}, N_{1s}, O_{1s}, C_{1s} and Cl_{2p} peaks, as

summarised in Table 1. No K content was identified in the samples even following KOH treatment. The KOH treatment resulted in a small surface Ga content decrease and a small N content increase for both MOCVD and MBE samples. The surface C content significantly decreased following the KOH treatment of the MOCVD sample but only slightly decreased in the case of MBE GaN.

Detailed scans of the Ga, N and O peaks were recorded for more detailed analysis (Fig. 3). The Ga_{3d} peaks were de-convoluted into the contributions of metallic Ga, GaN and Ga_2O_3. The Ga_{3d} binding energies remained unchanged or showed a shift of -0.3eV for the MOCVD and MBE GaN samples, respectively, after KOH treatment, consistent with [6]. A small reduction in the metallic Ga surface content of the MOCVD sample was also recorded due to the KOH treatment. The N_{1s} peaks were de-convoluted into four contributions: a N-O or N-H ionisation peak at 397.7eV, a N-Ga ionisation peak at 396.2eV and two Auger Ga peaks at 395.5eV and 393.2eV, respectively. No changes in the binding energy of these peaks were observed with GaN type or KOH treatment. However, a slight increase of ~ 10% was detected in the N-O or N-H to N-Ga ratio, for both MOCVD and MBE GaN, due to the KOH treatment. The binding energy of the O_{1s} peak similarly remained unchanged with sample type or treatment. However, for the reference MBE sample, the O_{1s} peak could be de-convoluted into three contributions, a chemiabsorbed O peak at 530.1eV, a Ga_2O_3 peak at 531.9eV and an OH peak at 533.1eV, respectively. The KOH treatment was found to eliminate the O and OH peaks, while the overall O content remained constant.

This XPS study indicates that the KOH treatment removes the native C contamination and Ga_2O_3, reducing the surface Ga and resulting in a corresponding increase in surface N. It might be envisaged that atmospheric re-oxidation quickly occurs after the KOH treatment, as the O content remains unchanged, but it is apparent that changes have appeared in the form of the oxygen at the MBE surface. This is again consistent with [6]. These changes in the surface states result in the -0.3eV shift in the binding energy of the Ga_{3d} peak, as demonstrated for the MBE grown GaN, which is believed to be responsible for the degradation of the I-V characteristic of the resulting contact [6]. A corresponding energy shift for KOH etched MOCVD grown GaN was not observed in this work, but shifts of ~ -0.3eV and ~ -0.4eV have been reported for MOCVD GaN following more aggressive treatment in KOH [6, 7]. The implication therefore is that the increased surface roughness associated with the MBE sample assists with the action of the KOH to modify the native surface.

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