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An improved non-alloyed ohmic contact Cr/Ni/Au to n-type GaN with surface treatment

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Received 22 May 2008, in final form 24 June 2008
Published 21 August 2008
Online at stacks.iop.org/JPhysD/41/175107

Abstract

The Cr/Ni/Au non-alloyed ohmic contact resistance on n-type GaN is obtained by chemical surface treatment of n-type GaN films following the laser lift-off of the sapphire substrate. The effects of n-GaN surface treatments on the metal/GaN interface were studied using x-ray photoelectron spectroscopy. Nitrogen vacancies at the n-type GaN surface are therefore produced and act as donors for electrons, improving the non-alloyed ohmic contact resistance induced by the reduction in native oxygen by the surface treatment of chemical solutions. In addition, the n-GaN surface treatment reduces the forward voltage ($V_f$) of the vertical LEDs.

(Some figures in this article are in colour only in the electronic version)

High power light-emitting diodes (LEDs) are in high demand for solid-state lighting applications and are expected to replace conventional lighting applications such as incandescent and fluorescent lamps [1, 2].

These LEDs require high current injection and they generate high temperatures during the operation of the LED. High current injection reduces the internal quantum efficiency of the active layers in the LED by raising the junction temperature, and this causes the brightness and operating voltage of the LED to deteriorate. However, the high current injection can be avoided by fabricating the LED with a vertical structure, where a laser lift-off (LLO) process is used to transfer the GaN film from the sapphire substrate and integrate GaN with thermally and electrically conductive substrate materials such as Si, GaAs and Cu to distribute the paths of current flows and to act as a heat sink [3–5]. Also, surface patterning for producing photonic crystal (PhC) structures and surface texturing have been generated using the dry etching method to improve the extraction efficiency of vertical GaN-based LEDs [6–8].

Unfortunately, these techniques destroy the surface of the GaN film and thus increase the resistivity of the contact region. The surfaces of compound semiconductors have very active chemisorption and production of the native oxide on the surface. A residual native oxide would still exist or regenerate on the surface prior to metal deposition. In order to reduce the surface product and improve the contact resistivity, considerable work has been performed on vertical injection LEDs [9, 10].

Generally, the thermal annealing process of metal activation is used for improving the contact resistivity in conventional lateral GaN-based LEDs, but this inevitably induces thermal damage such as decomposition and a spiky interface within the vertical LED structure because the high temperature process that is used for vertical GaN-based LEDs is incompatible with other substrates (Si or metal substrates). Therefore, the pretreatment of the surface before metal deposition is the key to reducing the contact resistance on GaN.

In our work, we created a non-alloyed ohmic contact with surface treatment using chemical wet-etching on an air-exposed n-GaN surface after LLO and a subsequent undoped GaN etch.

The GaN-based epilayer structure used in this work was grown on a sapphire substrate by metal organic chemical vapour deposition (MOCVD). The LED epilayers consist of an undoped GaN layer ($\sim 2 \mu m$), an Si-doped n-GaN layer ($\sim 3 \mu m$), a five-period InGaN/GaN multi quantum well and a 100 nm thick Mg-doped p-GaN layer. Deposition and annealing of a 280 nm thick transparent indium tin oxide (ITO) film was performed.
to serve as a p-contact to the p-GaN. Subsequently, an Ni(10 Å)/Ag(2000 Å)/Ni(1000 Å)/Cu(70 μm) layer was deposited by an e-beam evaporator on the p-GaN surface. The multi-metal layer acted not only as a reflective mirror layer but also as a conductive seed layer on which a 70 μm thick Cu was electroplated. Using an ArF excimer laser with a wavelength of 193 nm, an LLO process was performed to separate the sapphire substrate from the GaN-based LED structure. The GaN attached with Cu was rinsed in an HCl : DI (1 : 1) solution in order to remove the uppermost low quality Ga nucleation layer. The air-exposed undoped GaN surface was dry etched in Cl2 plasma to remove the Ga oxides that were unintentionally formed under the LLO and subsequent u-GaN etching by ICP. This shows that a large number of Ga oxides can be seen. The peak intensity corresponding to O–Ga and O–C bonds can be seen. The peak intensity corresponding to O ls on n-GaN increased after the LLO and subsequent BOE cleaning. All O ls spectra were deconvoluted into two components. O–Ga and O–C bonds can be seen. The peak intensity corresponding to O ls on n-GaN increased after the LLO and subsequent u-GaN etching by ICP. This shows that a large number of Ga oxides were formed. When the etched sample was treated with BOE, the peak of the Ga oxides was reduced. This suggests that the Ga oxides that were unintentionally formed under the LLO and Cl2 plasma could be removed by the BOE treatment.

Figure 1 shows the change in surface morphology in n-GaN as measured by atomic force microscopy (AFM) of the samples after LLO and LLO/ICP. For the samples that were processed with LLO operation, the rms roughness was increased to 46 Å, while that of as-grown samples was 2 Å. No distinct change in roughness was found after the dry etching of GaN for exposing n-GaN in the LLO/ICP sample (39 Å).

After the surface treatment of n-GaN using BOE, the peak of the Ga–N bond in the Ga 3d core level shifts towards higher binding energies (not shown). The shift of the Ga 3d core level peak is closely associated with the shift of the surface Fermi level, increasing the conductivity of electrons at the n-GaN surface. Figure 3 shows XPS spectra of O ls core levels of the samples after BOE. All O ls spectra were deconvoluted into two components. O–Ga and O–C bonds can be seen. The peak intensity corresponding to O ls on n-GaN increased after the LLO and subsequent u-GaN etching by ICP. This shows that a large number of Ga oxides were formed. When the etched sample was treated with BOE, the peak of the Ga oxides was reduced. This suggests that the Ga oxides that were unintentionally formed under the LLO and Cl2 plasma could be removed by the BOE treatment.

The surface morphology in n-GaN as measured by AFM of the samples after LLO (a) and LLO/ICP (b).
The increase in the Ga/N ratio after LLO, ICP etching and subsequent BOE cleaning is indicative of the formation of a Ga-rich layer near the surface due to the generation of N vacancies.

Figure 4 shows the I–V characteristics of the vertical GaN LED with LLO, u-GaN etching and subsequent surface treatment with BOE, compared with the vertical LED without the surface treatment.

The specific contact resistivity as a function of the BOE cleaning duration.

The Cr/Ni/Au non-alloyed ohmic contact resistance of the n-GaN in the vertical GaN LED was reduced by the BOE surface treatment of n-GaN following LLO and undoped GaN etching. XPS shows the reduction in the native oxide on the n-GaN surface following the BOE treatment. The specific contact resistivity of $1.2 \times 10^{-4} \Omega \text{cm}^2$ was achieved in non-alloyed Cr/Ni/Au contacts on n-GaN of the vertical GaN LED with BOE treatment. This suggests that the Ga oxides that were unintentionally formed under the LLO and Cl\textsubscript{2} plasma could be removed by BOE treatment. Also, the increase in the Ga/N ratio after LLO, ICP etching and subsequent BOE cleaning is indicative of the formation of a Ga-rich layer near the surface due to the generation of N vacancies.

References


