Contacts to heavily doped n-type GaN

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Keywords: GaN, contacts, solid phase reaction, MAX phase, transmission electron microscopy

GaN is wide bandgap material (3.4 eV) and very promising optoelectronic, microelectronic materials due to its direct bandgap. However, the performance of GaN-based devices is limited by several materials problems. Their contacts are still not well understood or optimized.

In recent years, the ternary compounds $M_{N+1}AX_N$, where N=1 to 3, M is an early transition metal, A is an A-group element (IIIA or IVA), and X is either C and/or N, attract increasing interest owing to their unique properties. MAX phases represent a new class of nitrides and carbides and can be best described as nanolaminates. They combine some of the best properties of metals and ceramics [1].

Au(120 nm) and (40 nm)Ti/Au(120 nm) metal layers have been deposited by thermal evaporation onto Si-doped n-type GaN epitaxial layers ($n\sim2\text{-}4\times10^{18}cm^{-3}$) grown by metal organic chemical vapor deposition (MOCVD) on a c-plane sapphire substrate. The samples have been annealed at 400, 700 or 900 °C for 10 minutes in vacuum. We have investigated the microstructural, nanostructural and electrical properties of the contacts by XTEM, FESEM, XRD and I-V measurements.

The obtained results are the following: transmission electron microscope study of XTEM samples has shown that the metal-semiconductor interface is sharp. The contacts showed a bi-layer structure in the case of as-deposited Ti/Au sample. Annealing induced metal interdiffusion and alloying in the contact layers and Au layers bowled up during high temperature annealing.

In the case of annealed Ti/Au samples the high resolution study of the interface showed the formation of some phases. Figure 1 shows the interface region with a Ti_2GaN (MAX phase) grain on GaN. The HRTEM insert (Fig. 1) shows the characteristic stacking of two Ti−N layers separated by Ga layers. It was found that the distance of Ga layers is about 7 Å and the lattice plane spacing of Ti_2GaN MAX phases is about 1.34 nm. The small nitrogen atoms are not resolved in the micrograph. In these (211) type compounds every third layer is an A-group element, in our case a Ga layer [1]. The “nanolayered” crystal structure of the ternary nitride is clearly revealed, the contrast is changed in every third layer in Fig. 1. The (006) lattice planes of the ternary phase are parallel to the interface. In our series of experiments no such a MAX phase was observed in samples containing only a single Ti layer (annealed at 900 °C). This predicts the conclusion that both Au and Ti plays a role in the formation of the above intermetallic phase and Au grains were also found on GaN after annealing (see Fig. 1) while most of the gold diffused into topmost part of n-GaN.

The Au and Ti/Au contacts are rectifying up to 700 °C. Due to Ti_2GaN (MAX phase), Ti_2N, TiN phases the Ti/Au contacts did not degrade at 900 °C as well as exhibited linear current-voltage characteristics.

W. Grogger, F. Hofer, P. Pölt (Eds.): MC2009, Vol. 3: Materials Science,
DOI: 10.3217/978-3-85125-062-6-387 , © Verlag der TU Graz 2009

XRD studies revealed that obtaining low Schottky barrier requires the penetration of Au through the Ti layer to reach the GaN surface and diffusion into the topmost part of epi GaN layer in addition to N outdiffusing from the GaN surface and into the metal layers.

The FESEM investigations indicated the effect of increasing the surface roughness after annealing. The surfaces of Au and Ti/Au contacts annealed at 900°C have shown fractal-like structures, when the surface patterns of these contacts showed apparent self-similarity. In addition, continuous films of upper Au of contacts tend to break up into discontinuous islands upon high-temperature annealing (see Fig. 2).

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2. This work was supported by Hungarian National Scientific Foundation (OTKA) through Grants Nos. K77331 and K75735.

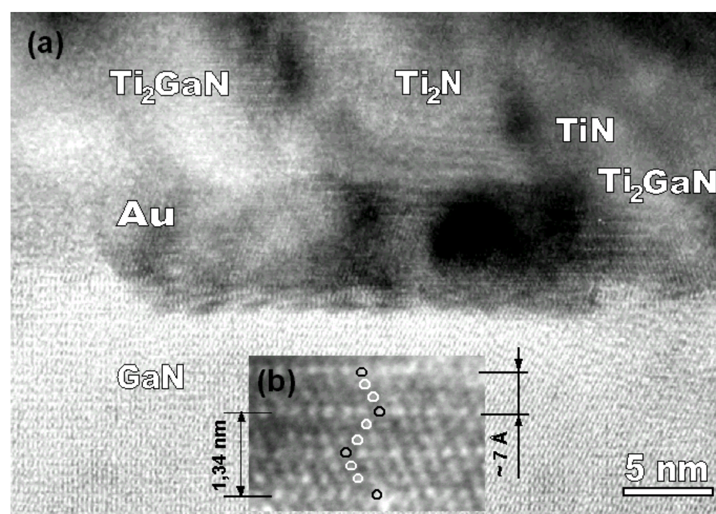

Figure 1. High resolution images of the n-GaN/Ti/Au interface after annealing at 900 °C. (a) HRTEM micrograph with the formed phases. (b) Insert shows the layer sequence in the Ti_2GaN – MAX phase – grain.

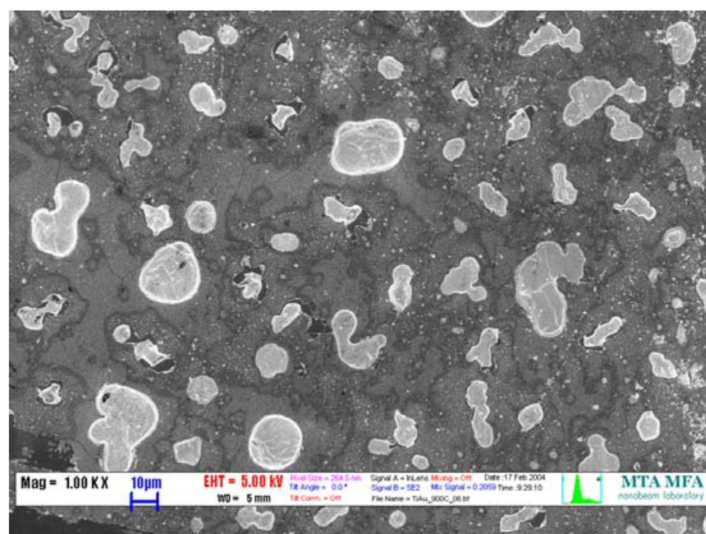

Figure 2. FESEM image of the Au/Ti/n-GaN contact annealed at 900 °C showing the Au crystallite drops on the top of Ti layer.

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