STUDY OF STRESS IN GaN-BASED TRANSISTOR HETEROSTRUCTURES

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1. Introduction

GaN-based heterostructures are used for broad spectrum of devices such as blue-lasers, light emitting diodes, detectors and high electron mobility transistors (HEMTs) [1]. GaN layers were successfully grown on Si substrate with AlN buffer layer [2] . The large difference in the thermal expansion coefficient and lattice mismatch between GaN and Si generates residual tensile stress in GaN and many cracks in the grown layers [2]. Therefore, the residual tensile stress is the most serious problem for the growth of GaN on Si.

In this work, we present evaluation of residual stress in the $In_xAl_{1-x}N$/GaN HEMT heterostructures grown on Si substrate by means of micro-Raman spectroscopy.

2. Experimental details

Studied structures were prepared on Si (111) substrate by MOCVD technique and consist of an AlN buffer layer - ≈100 nm thick, a GaN layer - 2.8 μm thick, and $In_xAl_{1-x}N$ cap layer - 10 nm thick. Composition of the cap layer changes from $x_{In} = 0.13$ to 0.23. Micro-Raman spectra were recorded at room temperature utilizing Horiba-Jobin Yvon-Dilor system equipped by He-Ne laser (633 nm line). The laser beam was focused on the sample surface to a spot of 1 μm in diameter. Backscattering geometry Raman spectroscopy was used for experiments. A field emission gun SEM (LEO 1550) operating at 15kV acceleration voltage was used to take the secondary electron images of the sample cross-sections.

3. Results and discussion

The typical Raman spectrum taken from studied structure with the $In_{0.18}Al_{0.82}N$ top layer is shown in Fig.1. The peak at frequency position 520 cm^{-1} corresponds to Si-substrate. The peaks indicated as E_2^H and A1 (LO) correspond to GaN layer in the structure. The low intensity peak at position ~ 650 cm^{-1} can be assigned to AlN buffer layer. Its magnification is shown in the inset of Fig.1.

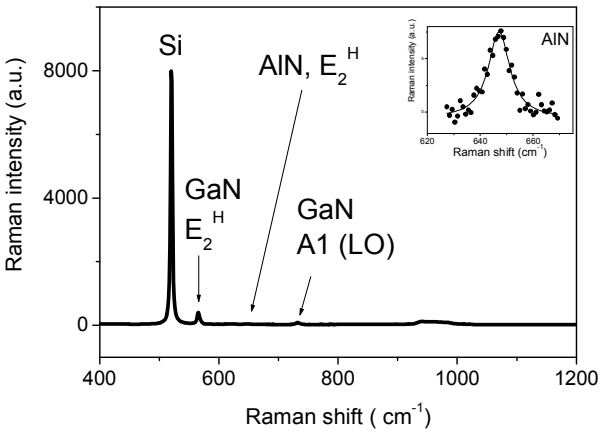

Fig. 1: *Micro-Raman spectra taken from the studied structure (*$In_{0.18}Al_{0.82}N$/GaN*). Detail of Raman spectrum at* E_2^H *peak of AlN compound is in the inset.*

The frequency position of Raman peak E_2^H of bulk unstrained GaN was estimated at 567.6 cm^{-1} [3]. This peak shows the highest intensity of all active GaN Raman peaks and it is known that this peak is shifted by stress only [4]. Due to the biaxial stress in the structure, the position of this Raman peak is linearly shifted by 3.6 cm^{-1} per GPa [3]. By using this constant we have calculated the stress in all measured samples. The results are depicted in Fig.2. We are able to divide all structures in 3 groups: with In mole fraction in the $In_xAl_{1-x}N$ around 15 %, 18 % and 21 %. The highest tensile stress was found in the samples with In mole fraction around 18 %. It is surprising result, because for this value $In_xAl_{1-x}N$ should be nearly lattice matched [5] to GaN and one would expect the smallest residual stress for this composition of the cap layer. To better understand this unexpected result, we have investigated the surface and cross-section of the structures by optical microscopy and scanning electron microscopy (SEM). The cross-sectional SEM diagnostic of the structures (Fig. 3c, 3d) shows that the buffer layer consists not only of an 100 nm thick AlN layer, but also of four additional layers (total thickness ~ 200nm), probably $Al_{1-x}Ga_xN$ graded layers with increasing fraction of Ga. These layers have a function to lattice-match GaN to Si more exactly than by using of pure AlN layer. This technique is already known from the preparation of advanced heterostructures [6]. The structural quality of the preparation of buffer layers of AlN and not known accumulated layers stuck influences mainly the residual stress in the GaN layer.

In the Fig. 3 we compare the optical microsopy images from the structures (13% and 18 % In) in which we have found the highest difference in estimated residual strain in GaN, 500 and 250 MPa, respectively. From the comparison of the cross-sections in Fig. 3c and 3d we see that buffer layers in sample with 18 % In is worse (rough, not smooth interfaces) than in sample with 13 % In. The reason for this difference we could found in different technological conditions for preparation of buffer layers. We believe that it is reason for higher residual stress in 18% In sample than in 13% In sample. Due to the residual stress in

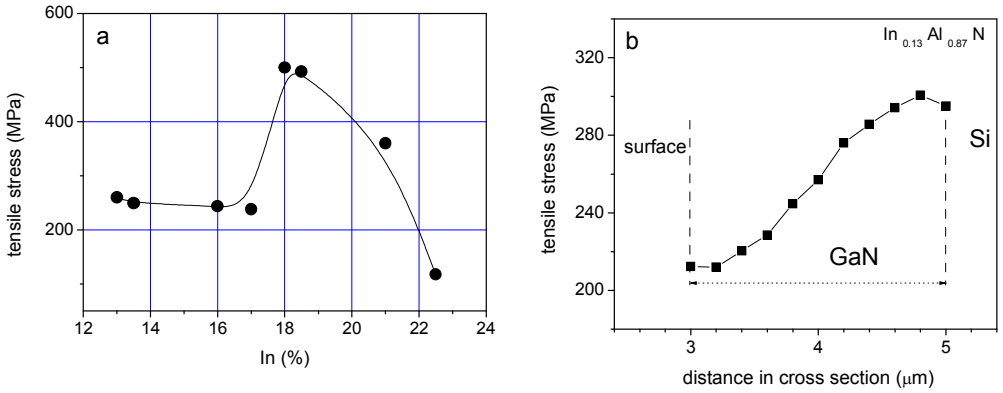

Fig. 2: *The dependence of the average tensile stress on the value of In fraction in $In_x Al_{1-x}N/GaN$ structure as measured from the surface (left). (b) Tensile stress in cross-section of the structure (right).*

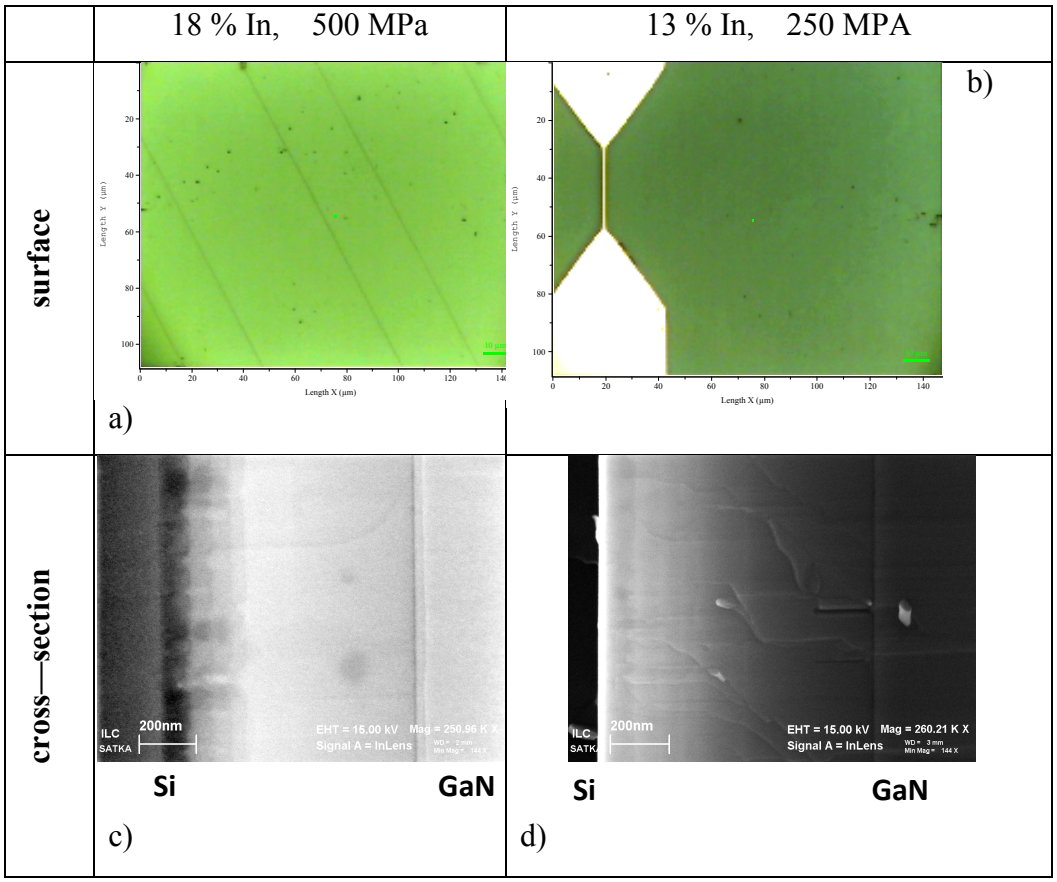

Fig.3: *Optical microscopy of the structure surface (a, b) and SEM images (c,d) of the cross-sections taken from two structures(13 % and 18 % of In). On the left sides of figures c, d one can see the Si substrate (dark black colored).*

` GaN layer the $In_x Al_{1-x}N$ cap layer will be not matched at In fraction of 17-18 % (theoretical match) and therefore crystallographic defects are created at the GaN/$In_{0.18}Al_{0.82}N$ interface : the presence of misfit dislocations (MDs) is clearly visible in Fig. 3a. On the other hand in 13% In sample the presence of MDs is very rare (in Fig. 3b MDs were not detected at the surface). From this discussion it is clear, that buffer layers mainly influence residual stress in GaN layer and, as a consequence the residual stress in GaN influences the stress in cap layer of $In_{1-x}Al_xN$. Therefore theoretical matched composition ~ $In_{0.18}Al_{0.83}N$ is suitable only when GaN is not stressed. In our case the most suitable for the stressed GaN layer it is composition 13-15 % of In fraction, i.e. by using of $In_{0.13}Al_{0.87}N$ cap layer low density of MDs was observed on the surface (Fig. 3b) and stress in GaN layer was the half value of the stress evaluated in the structure, when it was used $In_{0.18}Al_{0.83}N$ as cap layer.

4. Conclusion

By the using of micro-Raman spectroscopy we have evaluated average residual tensile stress in the set of $In_xAl_{1-x}N$/GaN epitaxial structures. The value of this stress was in the range of 100–500 MPa. The stress in GaN layer is decreased in direction from the buffer layer to the surface. It is influenced more by the crystallographic quality of the buffer layers, than by the influence of of $In_xAl_{1-x}N$ cap layer.

Acknowledgement

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