GaN on SOI substrate: strain and defects

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1. INTRODUCTION

GaN is a widely used material in optoelectronic devices like LEDs which are epitaxially grown mostly onto sapphire substrates. For cost reasons, silicon is studied as a possible contender, because of bigger dimension and easier optical integration than sapphire. However, the significant lattice and thermal expansion coefficient mismatches between silicon and nitrides lead to cracks and dislocations.

In order to cope with these issues, strain engineering during growth is necessary. This is usually carried out through the insertion of strain compensating layers before the growth of the active regions, which tend to be somewhat time consuming and thus expensive. A possible alternative consists in using compliant substrates such as Silicon-on-Insulator substrates (SOI) for strain accommodation during growth and/or upon cooling down.

2. RESULTS

2.1 Experiment conditions

GaN epilayers were grown by molecular beam epitaxy (MBE) on SOI substrates (top silicon is 16 nm thick and oxide is 150 nm). Reference samples were grown onto bulk silicon. To investigate the influence of the misfit on the compliance effect, the nitride layers were grown onto <110> oriented silicon: for this particular c-GaN / {110}-Si interface, the misfit is high in one direction (18% when <10-10>-GaN // <001>-Si) and low in the perpendicular direction (below 1% when <11-20>-GaN // <-110>-Si).

2.2 Growth study

A first evaluation of misfit stress relaxation can be undertaken by counting misfit dislocations (MD) at the hetero- interface. Here the number of MD at the AlN/Si interface was compared for the two perpendicular directions. More specifically this study was done for two samples: GaN/AlN/Si <110> and GaN/AlN/SOI whose top silicon is <110>-oriented and only 16 nm thick.

For both samples, in the high misfit <10-10> interface direction, we found a MD every 5 AlN planes (fig. 1). On the perpendicular interface direction we found 1 MD every 125 AlN planes on Si bulk substrate, while only 1 every 258 AlN planes on the SOI substrate. This corresponds to a slightly tensile stress in case of AlN on SOI substrate.

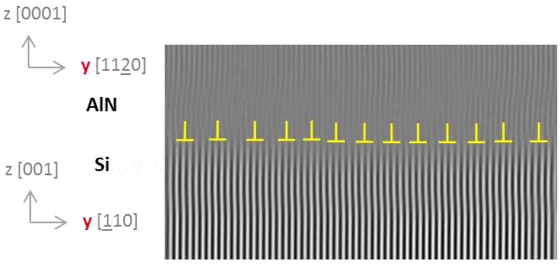

Figure 1. Filtered HRTEM image showing misfit dislocations at the AlN/SOI interface, among the high misfit direction (y).

2.3 Compliance investigations

In order to assess a possible elastic compliant effect, the distribution of strain was measured in the nitride layers and the top silicon layer of the SOI. TEM measurements were carried out to determine the strain information accurately and for a given AlN/Si interface direction. This was achieved by using nanobeam electron diffraction

(NBED) in precession mode. This technique permits to obtain 2 nm spatial resolution combined with 2.10^{-4} strain precision. It consists in acquiring diffraction patterns in precession mode on a selected area and in comparing them to a reference region, which, in our case, cannot be on the same sample, for example the substrate, because it has a different crystallographic orientation.

These measurements show clearly some compressive strain in the top silicon layer of the SOI (fig. 2), which is not the case when dealing with the AlN bulk silicon interface, for which no strain was measured in the silicon. One possible explanation is that some stress has been transferred from the AlN layer to the SOI.

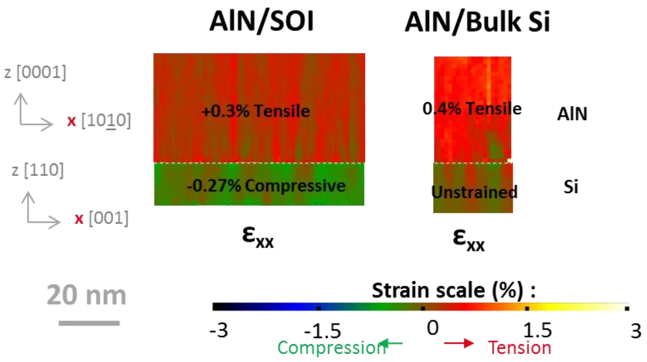

Figure 2. Strain mapping in the AlN/Si and AlN/SOI interface, among the low misfit direction, by NBED with precession.

Moreover, strain profiles in GaN and AlN were obtained by NBED with precession too, as shown in fig. 3. These profiles are plotted from the AlN to the top of the sample. Here the measured lateral strain in nitrides for each direction of AlN/Si misfit is presented. We could notice the inversion of strain in the GaN layer: from compressive strain next to the AlN interface to tension further up in the layer. While compression in GaN could be attributed to the lattice misfit between GaN and AlN, the main explanation for tension is due to thermal expansion during growth.

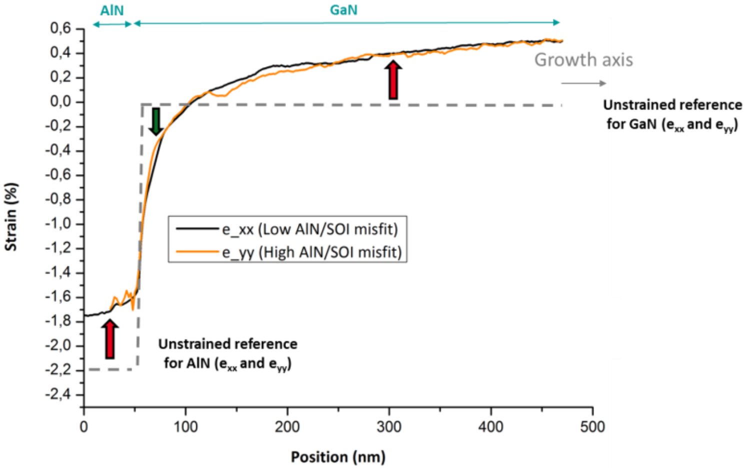

Figure 3. Strain profile in GaN/AlN layers for each direction of AlN/Si misfit, showing the tensile and compressive parts in the nitrides.

3. CONCLUSION

In order to assess a possible elastic compliant effect, the distribution of strain was measured in the nitride layers and the top silicon layer of the SOI. This was carried out by using complementary TEM techniques performed on a FEI Titan3 Microscope: diffraction contrast, HR(S)TEM, and nanobeam electron diffraction in precession mode.

We could demonstrate the presence of strain in the top silicon layer, attributable to stress transfer from the layer to the substrate, meaningful in case of thin silicon and for the low misfit interface. Also, strain maps and profiles gave us information about the evolution of stress into the nitride layers during and after growth, either on SOI and bulk silicon substrate.