Combined analysis of the interplay between composition, strain, and luminescence at the nanoscale in quasi-bulk InGaN structures

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1. INTRODUCTION

The wide gap tunability and high absorption coefficient of InGaN alloys make ~~these alloys~~them very attractive for photovoltaic applications. Several key material issues need, however, to be addressed before the full potential of InGaN for photovoltaics can be brought out. These include severe roughening, indium segregation, and strain relaxation. A breakthrough in the field was recently achieved with the introduction of quasi-bulk InGaN/GaN structures [1]. In these structures, the distribution of indium in the grown epilayer is controlled at the nanometer scale, leading to a significant improvement in the material quality over InGaN epilayers grown without this technique. In the present contribution, three advanced analytic microscopy techniques (quantified HAADF, holodark, STEM-CL) are combined for the first time to investigate the interplay between composition, strain, and luminescence in such InGaN quasi-bulk structures, in an effort to better understand the properties of such structures at the nanometric scale.

2. RESULTS

2.1 Experimental details

For the purpose of this study, a 135nm thick quasi-bulk InGaN sample containing a nominal 16% indium was grown using MOCVD. After coating the sample with a carbon/silicon nitride bi-layer that preserves its surface, a lamella for the transmission electron microscopy experiments was prepared ~~from the sample~~ using focused ion beam etching. Then, a region of the sample was chosen to measure the indium composition, strain, and luminescence using quantified HAADF, holodark, and STEM-CL. Details on each techniques and the conditions for the experiments can be found in References [2-4].

2.2 Nanometrically-resolved chemical mappings

A HAADF-STEM image of the quasi-bulk InGaN sample and the corresponding chemical mapping is shown in Figure 1. The mappings reveal that the epilayer has a laterally homogeneous distribution of indium. A slight vertical gradient in the indium composition of the individual InGaN wells, from 13% for the first well, to 16% for the last, is, however, observed. The mapping also reveals that the GaN barrier contain between 5% and 10% indium, serving their intended mission of resorbing the excess indium that accumulates during InGaN growth and preventing the layer from transitioning into the three-dimensional growth mode responsible for the severe degradation of the material.

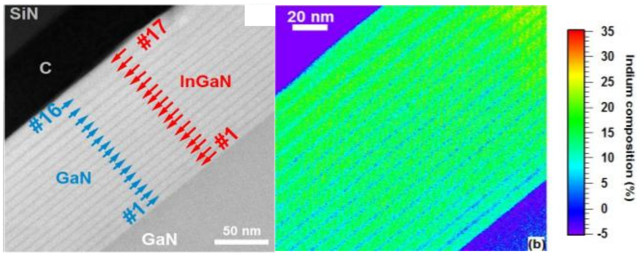

Figure 1. (a) HAADF-STEM image of the quasi-bulk InGaN sample and (b) corresponding chemical mapping.

2.3 Mappings of in- and out-of-plane strain

Mappings of the strain along the growth (b) and in-plane direction (c) are shown in Figure 2. An HAADF-STEM image of the region where Holodark experiments were performed is also shown (a). This region encompasses the one where the chemical mappings discussed in Section 2.2 were acquired. The mappings reveal that there is no in-plane strain, while average out-of-plane strain of 2% is measured in the InGaN wells. These values are in good agreement with what an InGaN epilayer containing 16% indium and that is pseudomorphically accommodated on GaN.

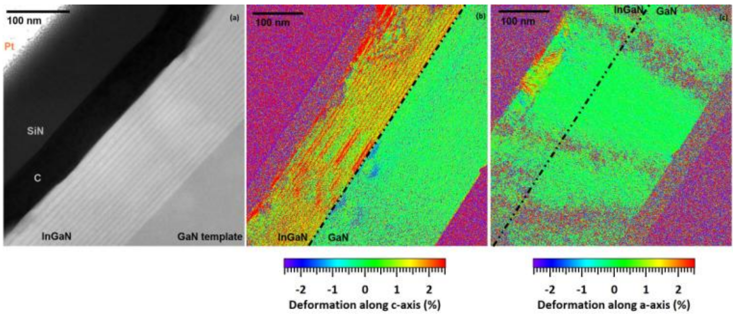

Figure 2. (a) HAADF-STEM image of the region were the holodark measurements were performed; (b) mapping of the out-of-plane strain; (c) mapping of the in-plane strain.

2.4 Cathodoluminescence in quasi-bulk InGaN

Results from the STEM-CL measurements performed on the quasi-bulk InGaN sample are summarized Figure 3. Four main emissions were identified in the spectral image. Comparing the chemical mapping to energy-filtered slices associated to the peak of each of those emissions allows one to identify two types of emission: a homogeneous emission, present in the layer as a whole (see Figure 3 c) and emissions from indium-rich clusters present near the surface of the sample. The emission energies associated with those peaks are in good agreement with the data from the composition and strain mappings presented above.

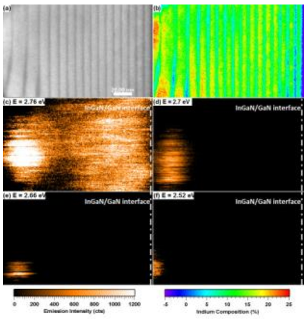

Figure 3. (a) HAADF-STEM image of the region were the spectral image was acquired; (b) corresponding composition mapping; (c-f) energy-filtered slices of the spectral image corresponding to four emissions identified in it.

3. CONCLUSION

Quantified HAADF, Holodark, and STEM-CL have been combined for the first time and helped provide an in-depth analysis if complex epitaxial InGaN/GaN structures. A wealth of information on the material has been gained from this combination, providing unprecedented insights as to its properties. This combination of information on chemistry, strain, and luminescence sets the standard for the future of materials science studies using transmission electron microscopy.

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