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Report:

InGaN is a key material for blue-green light emitting devices. However, due to a miscibility gap its composition is hard to control at higher indium contents. At higher concentration it tends to bimodal and spinodal decomposition in quantum wells forming locally In-rich and In-poor regions. A better understanding of the growth of InGaN quantum dots is a crucial issue for future applications of such InGaN dots and their stacks in laser diodes. Therefore, the influence of the In concentration on layer homogeneity and the GaN capping on the quantum dot structure needs to be investigated. For this purpose the Extended X-ray Absorption Fine Structure (EXAFS) is a perfect tool. From the EXAFS analysis the local structure around a indium atoms can be derived, i.e. the distance between the absorbing atom and its surrounding, the number of atoms in coordination shell and mean-square deviation from ideal atomic positions due to thermal vibrations structural disorder as well as chemical compositions.

InGaN stabilizes in wurtzite structure. Two kinds of In-N bonds can be distinguished: a longer single bond along the *c*-axis (*b*) and three shorter bonds with respect to the *c*-plane. The polarization dependent X-ray absorption spectroscopy can be applied in order to determine anisotropy of bonds. This kind of experiment requires measurements in grazing and normal incidence angles: close to "in-plane" and to "out-of-plane" of growth.

InGaN QDs have been grown using a two-step growth method [1] consisting of two layers: first an InGaN nucleation layer (NL) and second an InGaN formation layer (FL) with a lower In content compared to the NL. The NL was grown at two different temperatures 600 and 650ºC with an intended thickness around 1.5 nm. The following FL was grown at 700ºC with an estimated thickness of 8 nm. Both uncapped and capped quantum dots (with 8-40 nm GaN cap) were studied.

The XAFS measurements have been performed at the K-edge of In: E = 27940 eV in the fluorescence detection mode for uncapped and capped QDs as well as the reference samples. The EXAFS spectra were gathered for two angles of incidence (70° and 10°) for the reference samples. In case of the QD samples, the intensity of the signal was too small for normal incidence. Therefore, we were only able to measure spectra in grazing incidence, in which configuration the signal is gathered from bigger volume of the sample.

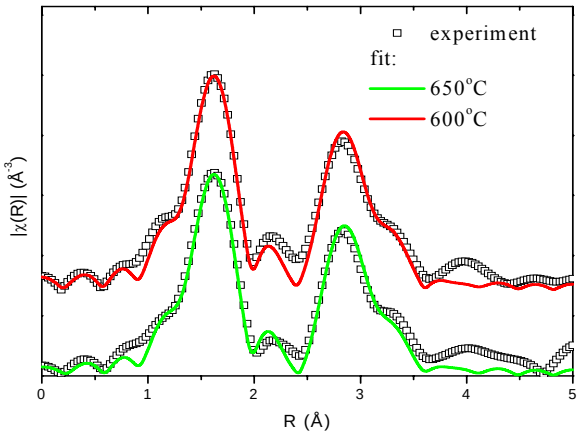

Figure 1: Fourier Transformed EXAFS oscillations of the uncapped samples and the fitting results. Spectra are shifted vertically for better clarity.

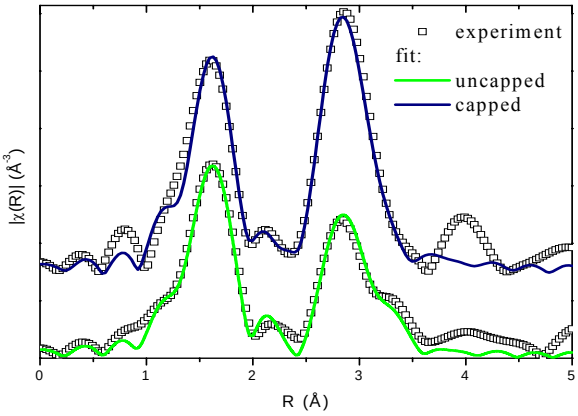

Figure 2: Fourier Transformed EXAFS oscillations of the uncapped and capped samples and the fitting results. Spectra are shifted vertically for better clarity.

In this report we focus on the influence of the growth temperature and the presence of the cap on the local atomic structure around In atoms. As the first example, two uncapped samples with 1.5 nm of InGaN NL and 7 nm of InGaN FL grown at 600°C and 650°C are shown. The fitting results are presented in Fig. 1 and Table 1 ("uncapped 600°" and "uncapped 650°"). The shapes of the Fourier Transforms of the spectra for both samples look similar. Also the fitting parameters are the same within the uncertainty limit. It appears that these two different growth temperatures did not influence significantly the structure of the quantum dots.

	uncapped 600º	uncapped 650º	capped 650º
$R_{N(1-3)}$ [Å]	2.08±0.01	2.07±0.01	2.08±0.01
$R_{N(4)}$ [Å]	2.14±0.01	2.13±0.01	2.14±0.01
σ^2_N [Å^2]	0.001±0.001	0.001±0.001	0.001±0.001
σ^2_{Ga} [Å^2]	0.009±0.002	0.010±0.002	0.007±0.001
σ^2_{In} [Å^2]	0.004±0.003	0.002±0.002	-

Table 1. Fitting parameters of the uncapped and capped samples.

The other important question is how the presence of the capping layer affects the dots. In this case as an example, the "uncapped 650°" sample is compared with the "capped 650°" one. In this capped sample, on top of the 1.5 nm of InGaN NL and 7 nm of InGaN FL, 36 nm of the GaN capping layer is added. As can be seen from Figure 2 and Table 1, the first shell containing N atoms didn't change in respect to the uncapped sample prepared in the same conditions. However, in the second shell the differences are clearly visible. In the uncapped sample, the second shell is a mixture of Ga and In atoms, while for the capped sample only Ga atoms are present. It seems that the GaN cap layer introduces serious changes in the local structure of the InGaN QDs. In summary, EXAFS technique is a good tool for characterization of this kind of systems because it enables to look below the capping layer without damaging the sample. This possibility gives very important information because the GaN cap layer seems to introduce the changes in the local structure of the InGaN QDs. In this report preliminary results are presented. Further studies are needed in order to understand the microscopic structure in detail.

References:

[1] T. Yamaguchi, K. Sebald, H. Lohmeyer, S. Gangopadhyay, J. Falta, J. Gutowski, S. Figge, D. Hommel, phys. stat. sol. (c), 3, 3955 (2006).