Effect of growth temperature on InGaN films grown by MOCVD

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InGaN-based quantum wells have been used for ultra-violet, blue, green light-emitting and continuous wave laser diodes because it has a direct band-gap from 1.9 to 3.4 eV. But the indium incorporation into the alloy is a crucial point because it is difficult to grow high quality $In_xGa_{1-x}N$ films with high x value (x>0.1). Due to thermodynamic limit and high InN evaporate pressure, it is limited for increasing indium content by the indium flow rate. $In_xGa_{1-x}N$ films with higher x values were grown at lower growth temperature (≤500℃), but its optical properties became degenerate. So the growth of InGaN films used for optic-electronics devices were usually conducted at growth temperature from 780℃ to 820℃. Mastering the growth of the ternary alloy indium-gallium nitride (InGaN) as well as the choice of a suitable temperature, are both key issues in the worldwide effort to demonstrate light-emitting and laser diodes. Here, effect of growth temperature on indium content, quality and morphology of InGaN films were reported.

All samples were grown on sapphire substrates with (0001) orientation by low pressure MOCVD. The main procedures of materials growth are as following. The first, the substrate was heated to 1150℃ and under the stream of H_2 for 10 min. Then decrease temperature to 550℃ for growing a 20 nm GaN buffer layer. After this, growth temperature was elevated to 1060℃ for growing GaN layer. The GaN layer is very important to improve the quality of InGaN overlayer. Finally, InGaN films were grown on the GaN layer at growth temperature from 760℃ to 840℃. Ga, In, and N sources used in our experiments were TMGa, TMIn and NH_3 respectively. All materials growth was conducted at 0.1atm. Hydrogen or Nitrogen was used as carry gas. Typical growth rate is about 200 nm per hour.

Indium content in InGaN alloy was determined by x-ray diffraction according to Vegard's rule. The indium content in alloy of InGaN films grown at 760, 780, 800, 820 and 840°C were 0.31, 0.26, 0.14, 0.10 and 0.06 respectively. We can see the x values obvious decrease with increasing of growth temperature. Furthermore it was found that the relation between x values and growth temperature for two kinds reactor as well as nitrogen or hydrogen as carrier gas is an approximate exponential relation as

$$x_{In}=A\ \exp(E_a/kT),$$

as shown in fig.1. It was demonstrated that In content is sensitive to temperature and can be controlled by adjusting growth temperature. Of course, it also maybe bring x value fluctuation with non-uniform distribution of temperature and disturbance.

The FWHM of XRC for InGaN films decreased with increasing temperature, as shown in Fig.2. It demonstrated the quality of InGaN film improved by prompting growth temperature. We suggest that it is main reason for intensities of PL become stronger as prompting growth temperature.

Surface morphology also was found to be effected by growth temperature. The typical AFM image was given in fig.3. We can see from the fig.3 that the surface is not mirror level but rough as various size "cluster". Fig.4 show the effect of growth temperature on the surface roughness of

InGaN films. It can be seen that the roughness increases with growth temperature. However, this roughness can become smooth by growing a GaN overlayer. If we used an approximate average size to represent the cluster, the interesting thing is that the average size of "cluster" becomes larger when growth temperature increase. These means GaN and InGaN films have a different growth mechanism under our growth conditions. Increasing growth temperature, some InN will be streamed from the growth interface and result in decreasing of x_{In}. On the other hand, the separation effect of atoms on growth interface become stronger, which cause formation of the larger cluster on surface when nitrogen was used as carrier gas.

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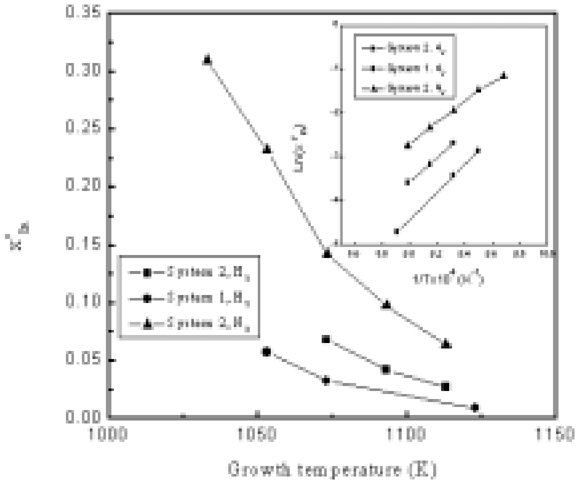

Fig.1 The relation between x values of $In_xGa_{1-x}N$ and growth temperature

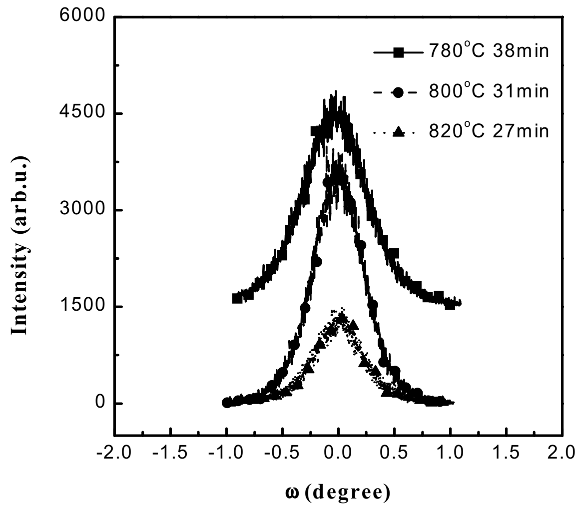

Fig.2 XRC of InGaN films grown at 1053K, 1073K and 1093K

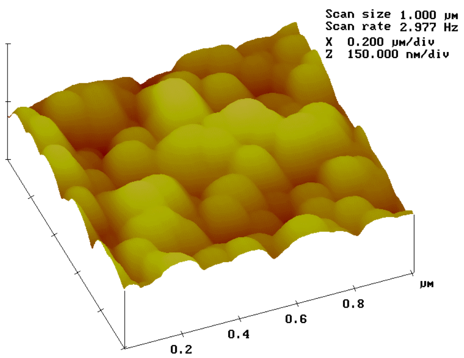

Fig.3 The typical AFM image of InGaN surface grown at 1113K

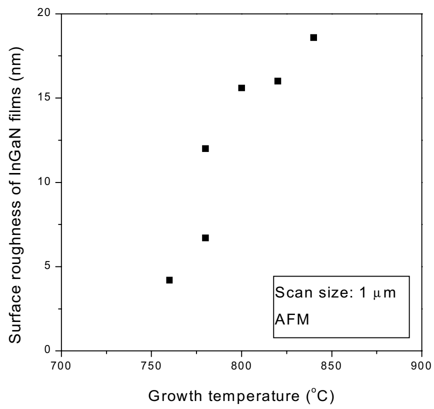

Fig.4 The effect of growth temperature on the surface roughness of InGaN films