Growth optimisation of GaInN/GaN MQW RCLED structures. Device performances and reliability

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GaN based Resonant Cavity light emitting diodes(RCLEDs) have been developed for use with plastic optical fibre (POF) data communication systems, due to their suitable emission wavelength (Low POF attenuation at (λ=510nm), inherent temperature stability and short carrier life time.

In this paper, we report on the growth optimisation and characterisation of GaInN/GaN Multiquantum Well (MQW) RCLED structures emitting at 500nm. The device structures, which include GaInN/GaN MQW and GaAlN/GaN Bragg mirrors, have been grown by MOCVD, and their physical properties were optimised using High Resolution X−Ray Diffraction (HR−Xray) and room temperature photoluminescence mapping measurements.
The correlation of some physical properties of the epitaxial structures with the device characteristics, such as the optical performances or the reliability, has been investigated.
The growth of GaInN/GaN MQW heterostructures is not straightforward, and the well/barrier interface optimisation is a critical step of the RCLED MOCVD process due to the large difference in the growth parameters of GaN and GaAlN.
A drastic improvement of the luminescence efficiency of the GaInN/GaN MQW heterostructures has been obtained for MQW/Barriers grown at low temperature (700°C/980°C) with thickness around 8Å/90Å. This breakthrough in the optical properties can be explained by the fact that the thin quantum wells grown at low temperature may favour the quantum dot formation and a good lateral carrier confinement due to an inherent built in piezo−electric field across the well. The 300K photoluminescence efficiency obtained at 499nm was found to be 100 times higher as compared to the previous MQW heterostructures emitting at the same wavelength, with a different design (30Å/90Å) and grown at higher temperatures (820°C/1150°C).
Figure 1 shows a room temperature photoluminescence mapping of the peak wavelength (λ= 499nm) related to such a MQW heterostructure.

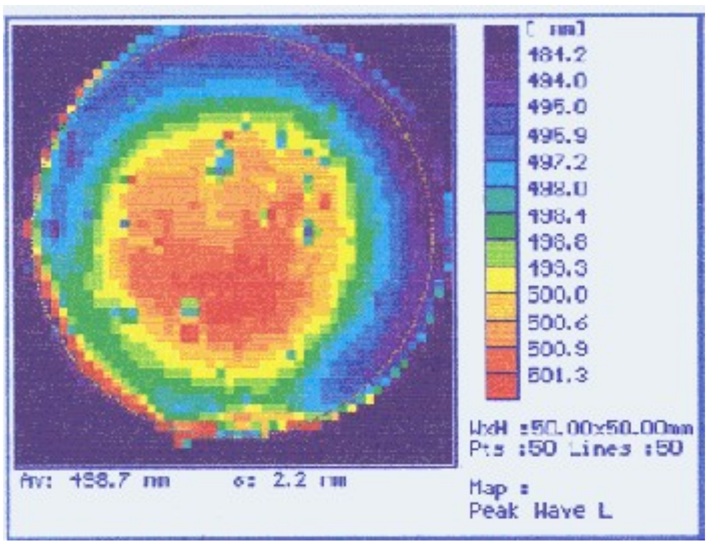

Fig1: 300K peak wavelength PL mapping of a MQW heterostructure

The wavelength standard deviation is close to σ_λ = 2.2nm on the two inch wafer, demonstrating a good composition homogeneity of the alloy.
The structural properties of these MQW heterostructures checked by high resolution X−Ray Diffraction and TEM are in good agreement with the high luminescence efficiency obtained. Sharp and well delineated interfaces were observed by TEM cross section, as depicted in figure 2 while X−Ray rocking curves exhibited satellite peaks well defined up to the 5^{th} order, as shown in Fig. 3.

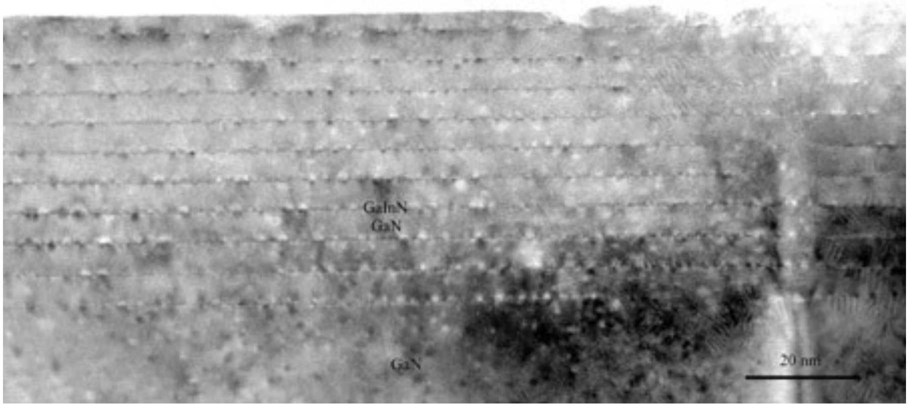

Fig 2:TEM cross section of a GaInN/GaN MQW heterostructure

The GaInN/GaN lattice period related to the angular shift $\delta\theta$ between two adjacent satellite peaks is calculated to be 92 Å, which is close to the period measured by TEM (~ 10nm).

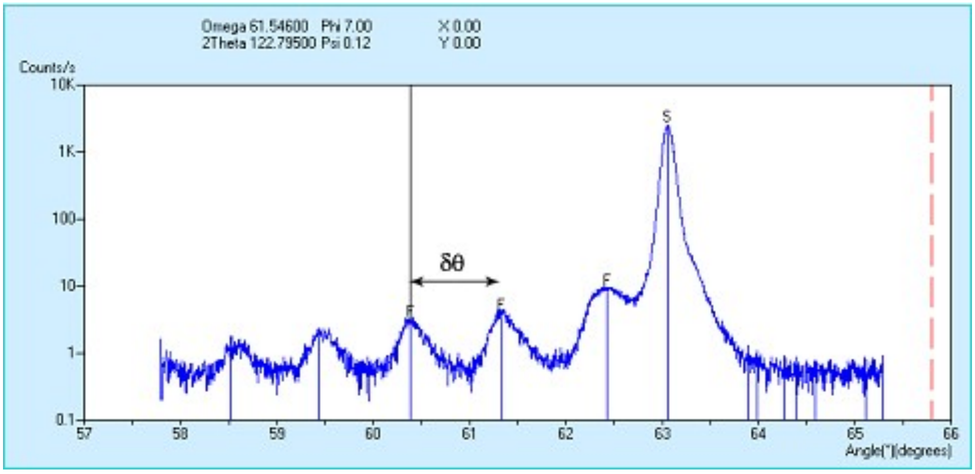

Fig 3:X−Ray rocking curve of a GaInN/GaN MQW heterostructure

A real impact of the p+ GaN cladding layer and of the n type Bragg−mirror on the optical properties of the RCLED structures (strong blue−shift of the emitting wavelength : $\Delta\lambda$=15nm) has been identified. In addition to the blue shift of the emitting wavelength, a reduction of the luminescence intensity has been observed closely related to the increase of the p+ type GaN cladding layer thickness. This behaviour may be due to Mg diffusion during the p+ type GaN re−growth process or induced by strain.
We have overcome the problem by implementation of a very thin Mg diffusion barrier at the p/n interface and by a fine optimisation of the alloy composition and thickness of the quantum wells and Bragg mirrors, as seen in Fig.4.

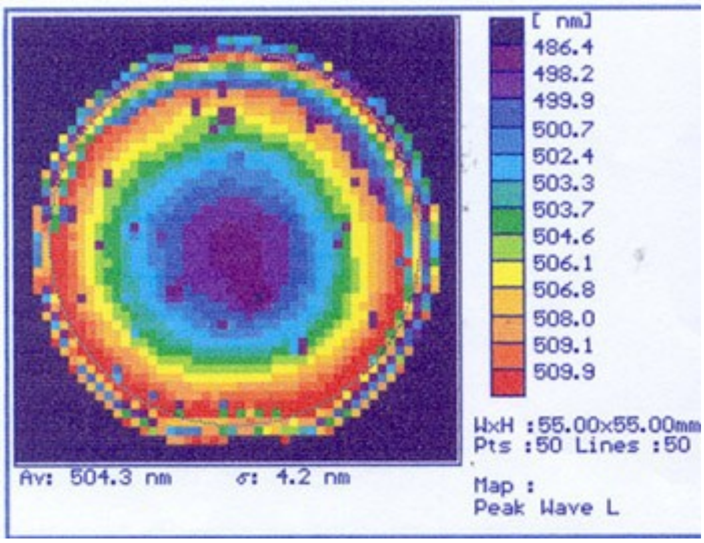

Fig 4:Room Temperature peak wavelength photoluminescence mapping of a MQW RCLED structure

The device performances of such RCLED structures have been found in good agreement with the physical properties of these structures. The total optical output power drops from 1050µW at 20mA for a RCLED with a 800Å thick p type GaN cap layer to 70µW at 20mA for a RCLED with a 2800Å thick p type cap layer.
The impact of the strain induced defects on the reliability of the devices has also been investigated.
A clear enhancement of the reliability of the devices has been observed, in line with the improvement of the structural and optical quality of the RCLED wafer materials.

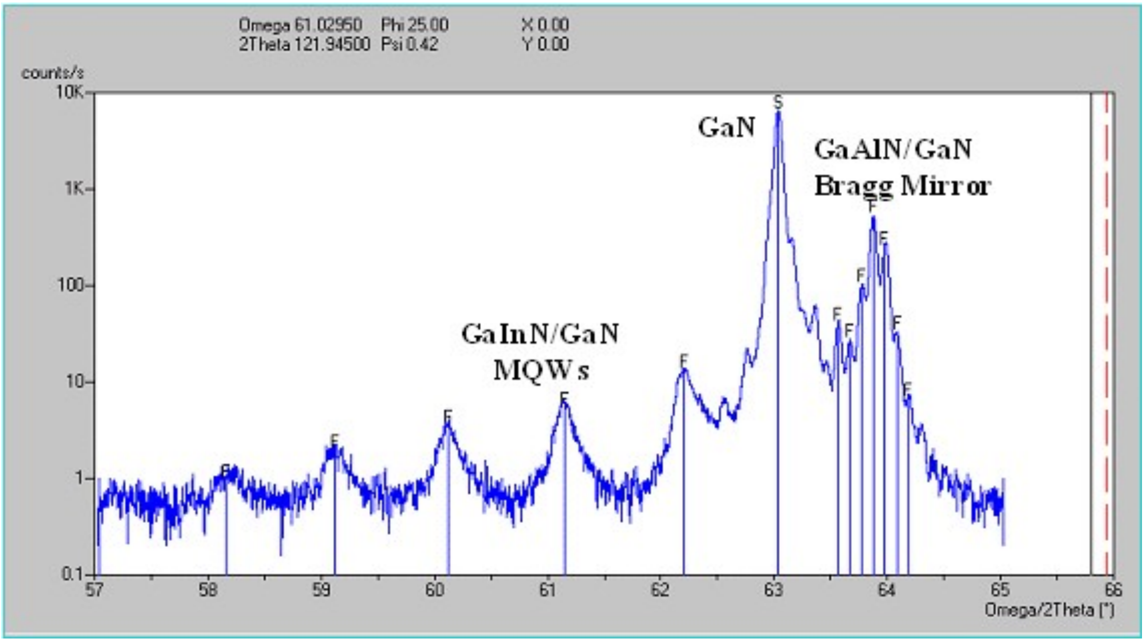

Fig.5:X−Ray rocking curve of a MQW RCLED structure

Figure 5 shows a High Resolution X−Ray rocking curve of a GaInN/GaN RCLED structure, grown on template GaN buffer, with a low density of misfit dislocations.
The rocking curve exhibit interference fringes related respectively to the GaInN/GaN MQWs and the GaAlN/GaN Bragg mirrors demonstrating a good quality of the interfaces.

The surface morphology roughness checked by AFM on such a wafer is very low (RMS =10Å, Rmax = 20Å) and a narrow line−width (FWHM=22nm) of the 500nm PL−emission peak has been obtained.
Bottom emitting RCLED devices have been fabricated on this RCLED wafer. Figure 6 shows the RCLED structure in cross−section while figure7 shows an array of completed devices in plane view.

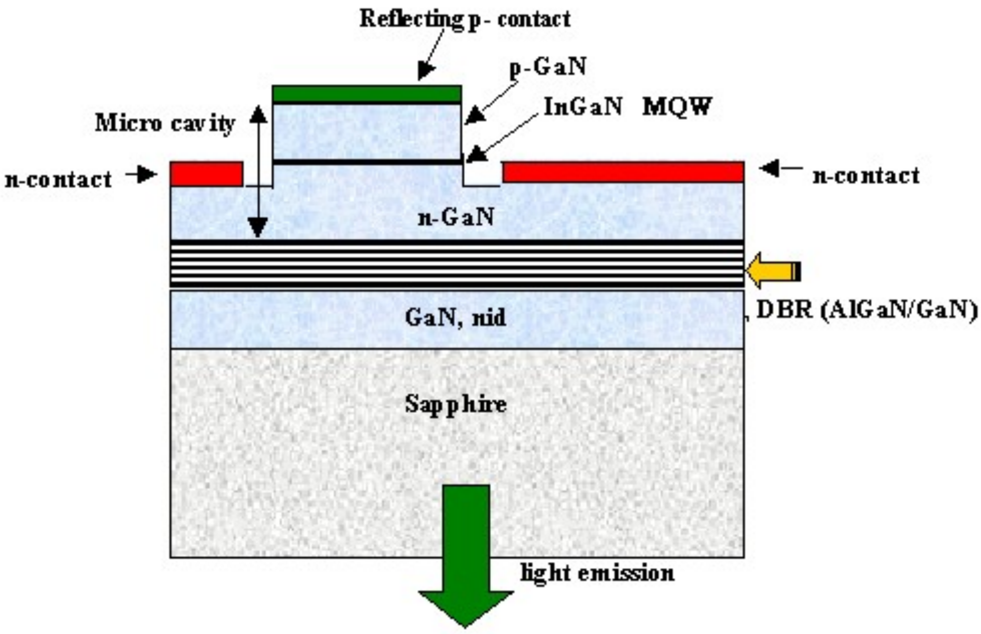

Fig 6: RCLED structure

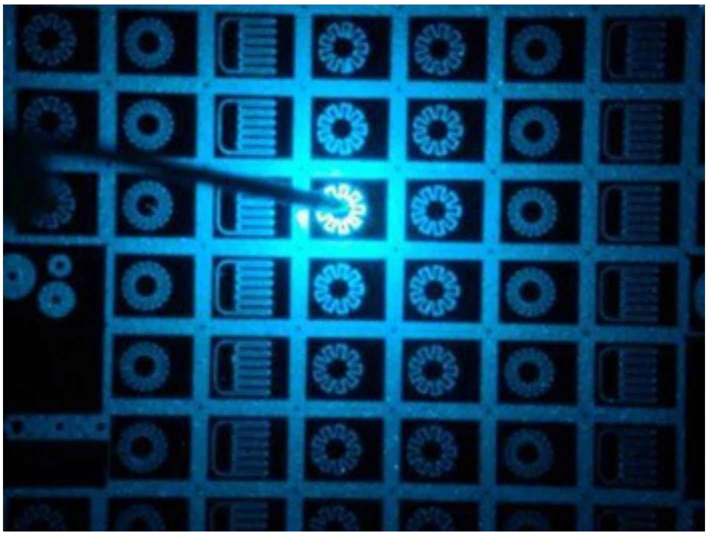

Fig7: Array of completed RCLED devices, on wafer

The EL−peak emission occurs at 499 nm, and the FWHM of the EL−peak measures 25 nm. The total light output for an encapsulated device, inside an integrating sphere, is 1.82 mW at 40 mA. Reliability tests achieved on such RCLED devices have demonstrated the improved stability of these devices: 93% of the optical intensity (1.8mW) remain after 600hrs at 30mA.

The research work presented here has been supported by the European Community (AGETHA, IST−1999−102292).