Innovative relaxed InGaN engineered substrates for red-green-blue µLEDs applications

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Abstract

The Smart Cut ™ technology enables the layer transfer and strain relaxation of patterned InGaN films. Pattern size can extend up to 1mm. According to the In content of the donor InGaN layer, lattice parameter can be tuned at least up to 3,205Å. Full InGaN LED containing InGaN/InGaN multiple quantum wells structures are grown by metalorganic vapor phase epitaxy (MOVPE) on this engineered substrate. Long wavelengths have been reached, up to 630nm with FWHM of 48nm at 0.8 A/cm², thanks to the reduced strain in the overall structure which enable a higher In incorporation during the MOVPE growth.

INTRODUCTION

Micro displays targeting virtual and augmented reality applications require pixel size in the range of 10x10µm or below. As pixel size is reduced, transfer processes are getting more and more challenging. Having a single material able to emit directly over the full red-green-blue (RGB) spectrum is an enabler. In addition to their ability to produce the three primary colours, InGaN based LEDs have advantageous properties such as low power consumption, long operation lifetimes, and the ability to be safely operated in harsh temperature regimes, which make them optimal candidates for micro displays using micro-LEDs.

Green and red InGaN based LEDs initially suffer from low internal quantum efficiencies (IQE) and external quantum efficiencies (EQE) as compared to blue LEDs. These problems arise for three main reasons. First is the presence of threading dislocations that result from the lattice mismatch between GaN and the growth substrate and act as nonradiative recombination centers. Second is the deterioration of the crystal quality due to indium phase separation. Third is the existence of piezo-electric polarization fields within the quantum wells (QWs), which can cause band bending and a decrease in the overlap of the electron and hole wave functions due to the quantum-confined Stark effect (QCSE), resulting in low radiative recombination rates. One solution could be to reduce the strain in the overall structure to limit the compositional pulling effect and thus increase the In incorporation rate. It will in the same time reduce the QCSE considering same In content, as in InGaN based QWs it is due to piezoelectric polarization. One solution could be to reduce the strain in the overall structure to limit the compositional pulling effect and thus increase the In incorporation rate. It will in the same time reduce the QCSE considering same In content, as in InGaN based QWs it is due to piezoelectric polarization. To obtain this strain reduction one of the best ways is to dispose of an InGaN pseudo-substrate.

Soitec's Smart Cut™ technology is used to achieve this goal by transferring and relaxing a thin InGaN layer on a handle wafer.

EXPERIMENTAL

The starting material can be either epitaxially grown InGaN-GaN-on-sapphire template or InGaN-on-bulk free standing GaN. In this work, the experimentation was performed using 100mm diameter strained InGaN-GaN-on-sapphire templates. First, bonding layer is deposited on the InGaN substrate and hydrogen implantation is performed [1]. A first temporary bonding is done on a carrier. As a result, an InGaN/GaN layer (<1µm) is transferred on the carrier and the starting material can be reused. We have experimentally demonstrated full Smart Cut™ cycle and subsequent GaN wafer reuse with no degradation. After this first layer transfer on the carrier wafer, the film relaxation is carried out. The InGaN film is patterned to enable the relaxation without inducing any film's buckling (fig.1).

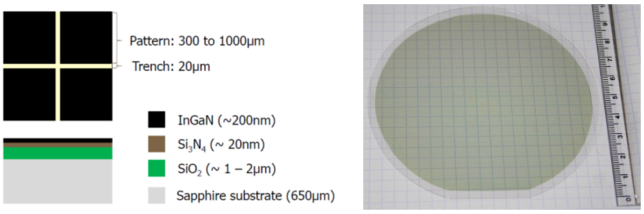


Fig. 1: Description of the product with relaxed InGaN layer on top (left) and photo of a 100mm sample (right).

Due to the wafer transfer process, crystal polarity is flipped and hence temporary bonding of the film is used in order to transfer on the final carrier wafer the InGaN film with a Ga polarity. This product is called InGaNOS (InGaN-on-Sapphire). This process is today available on 100mm and could easily be extended to 150mm wafers. The process has been developed and allows today to produce thin (50nm to 500nm thick) InGaN films.

Full InGaN structures grown by metalorganic vapor phase epitaxy (MOVPE) on three flavors of InGaNOS with different lattice parameters have been tested. The structure consists of an InGaN buffer layer grown on InGaNOS substrate, followed by 5 InGaN/InGaN multiple quantum wells. Wells (resp. barriers) have a thickness of 2.5nm (resp. 6nm) as measured by TEM.. pInGaN must have been used as the p contact layer to overcome crack formation. A conventional chip process has been then applied on the LED structure using thick Ni/Au contact for the p contact and Ti/Al/Ni/Au for the n contact. The emission arises from the back side of the LED chip. Electroluminescence was used to record spectra under electrical injection.

RESULTS

Pattern size can extend up to 1mm for the highest lattice parameter. According to the In content of the donor InGaN layer lattice parameter can be tuned up to 3,205Å (fig.2). For this lattice parameter, typical pattern lateral size is 500µm by 500µm as imaged on figure 3.

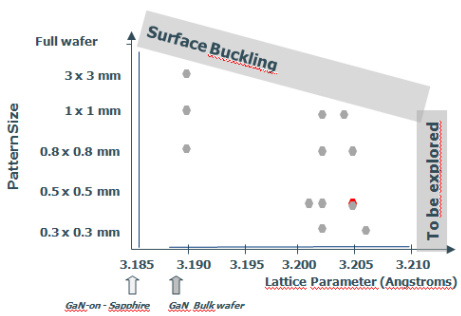


Fig 2: Description of the different substrate design prepared by Soitec.

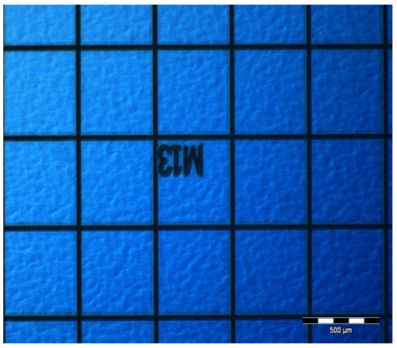


Fig 3: Microscope image of patterned and relaxed InGaN-on- sapphire substrate.

The last one is the most promising for red emission and it has been used to obtain red electroluminescence. The InGaN crystal quality has been shown to be maintained, as seen by AFM (fig.4). The V_pit density is ~3E8/cm² with pit width around 100nm. The surface roughness has an Rms between 2,7 and 3,7 nm for 5x5µm fields.

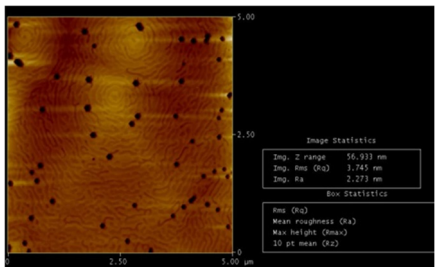


Fig 4: AFM image of the surface of the relaxed InGaN-on- sapphire substrate.

Cathodoluminescence has been used to get a direct measurement of the active defect density (fig.5). This measurement is performed after the growth of the InGaN multiple quantum. We have measured a defect density of 3e8/cm² on 5x5µm field. No additional threading dislocation is introduced through Smart Cut™ with ion implantation and realxation. Hence the crystal quality of the engineered substrate depends only on the starting material crystal quality.

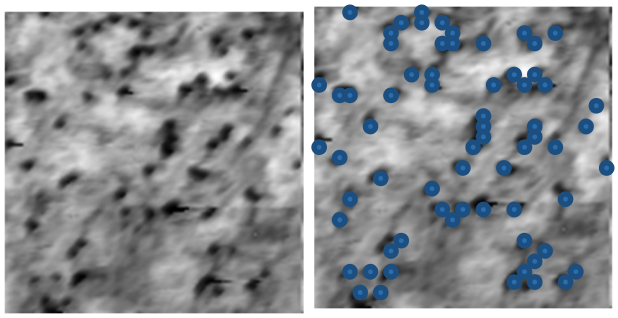
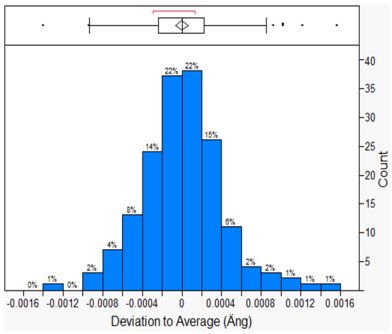


Fig 5: Cathodoluminescence of InGaNOS substrate following InGaN MQW growth: pan chromatic image (left) and color revealed active defects (right).

XRD evaluation was performed for (003) symmetric ω scans (rocking curve) of relaxed InGaN layer and measured on 9 points per wafer. The on wafer distribution shows a total range of +/- 0.0016 Å for a total number of 19 wafers (Fig.6).



100.0%	maximum	0.00156
99.5%		0.00156
97.5%		0.00099
90.0%		0.00048
75.0%	quartile	0.00022
50.0%	median	0
25.0%	quartile	-0.0002
10.0%		-0.0005
2.5%		-0.0008
0.5%		-0.0014
0.0%	minimum	-0.0014

Fig 6: Distribution of lattice parameter (all points all wafers).

It has been shown that the In incorporation rate is increased with the a (in-plane) lattice parameter of the substrate for same growth conditions [2]. Full InGaN LED structure has been grown on InGaNOS substrate. The emission arises from the back side of the LED chip through sapphire. 3 LED patterns are designed inside the patterned epi wafer at 100µmx100µm, 50µmx50µm and 30µmx30µm. Long wavelengths have thus been reached, up to 630nm, thanks to the reduced strain in the overall structure. Fig. 7 presents an electroluminescence spectrum, and exhibits a picture of a 50x50µm µLED. Red electroluminescence has been then demonstrated with central emission wavelength of 630 nm and FWHM of 48nm at 0.8 A/cm².

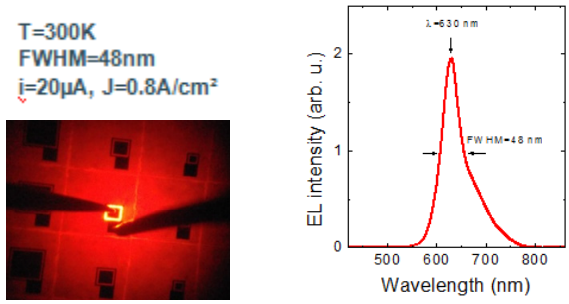


Fig. 7: EL red emission at 630nm with FWHM=48nm for the 50µmx50µm microLED.

Soitec's engineered substrate technology offers innovative solutions to the current challenges facing the microLED industry today by eliminating the need for phosphor converts through efficient nitride-based red LEDs with direct emission, and nitride/phosphide LED mixing through enhanced color quality consistency with full InGaN blue, green and red LEDs.

Additionally, Soitec's InGaNOS technology could be used to create substrates with mixed lattice parameters, enabling growth of different colored LEDs on the same substrate. This innovation can significantly reduce the cost of microLED mass transfer within microdisplay fabrication.

Conclusions

The InGaNOS innovative relaxed InGaN engineered substrate enable a higher In incorporation during MOVPE growth. Red electroluminescence has been demonstrated with central emission wavelength of 630 nm and FWHM of 48nm at 0.8 A/cm².

Acknowledgements

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