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Stress analysis in GaN epilayer after chemical mechanical polishing (CMP) from sapphire substrates

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1 Introduction

Commercial GaN-based light-emitting diodes (LEDs) are epitaxially grown on c-plane sapphire substrates due to lack of a lattice matched and cheap substrate. Owing to large mismatch of lattice constant and coefficient of thermal expansion (CTE) between the GaN epilayer and the sapphire substrate, high compressive stress has risen in the GaN epilayer during the cooling procedure from high growth temperature to room temperature in the chamber of metal-organic chemical vapor deposition (MOCVD) system.[1] Strong internal piezoelectric field was found in the GaN epilayer caused by the high compressive stress.[2] Tilted energy band structure and quantum-confined stark effects (QCSE) caused by the piezoelectric field will shrink energy band gap of GaN epilayer and red-shift emitting wavelength of GaN-based LEDs. Furthermore, poor thermal conductivity and electrical isolation of sapphire substrate have also hindered the applications for LEDs operating at high electrical power injection. For solving the problem mentioned above, thinning down or removing the sapphire substrate is one of the possible solutions. Thin-GaN LED structure has been proposed by *wong et al.,* [3] and the sapphire substrate was removed by laser lift-off (LLO) technique. However, bad leakage current property was found in GaN LEDs after LLO process because leakage path was created by the high energy laser of the LLO system.[4]

In this study, instead of LLO technique, CMP process was used to thin down sapphire substrate and reduce the internal stress in the GaN epilayer. Compared to LLO process, CMP offers a faster and more efficient way to remove sapphire substrate without suffering damage from high energy laser. The stress states of GaN epilayers on different thickness of sapphire substrates thinned down by CMP process were investigated by micro-Raman scattering and photoluminescence (PL) spectra.

2. Experimental

Figures 1(a) and (b) show the schematic diagrams of the wafer bonding and sapphire removing process. A Ni (50 Å)/Ag (300 Å) reflective layer was deposited on conventional LED wafer by electron-beam evaporator. After the deposition of the reflection layer, the Cr (1000 Å)/Pt (1000 Å)/Au (15000 Å) bonding metallization layer was deposited on surface of both the LED wafer and a secondary p-type Si (100) substrate by Au-Au adhesive bonding. In the bonding process, the wafers were treated at 350 °C with the pressure 25 kg/cm^2 for 2 hrs. After bonding process, the sapphire was lapped down to 100μm and grinded slowly by CMP system (Logitech Tribo). The stress states of samples were analyzed by micro-Raman spectrometry (Jobin Yvon / Labram HR) with 532 nm Nd:YAG laser and room temperature PL spectra were obtained by a PL with 405 nm GaN laser as excitation light source.

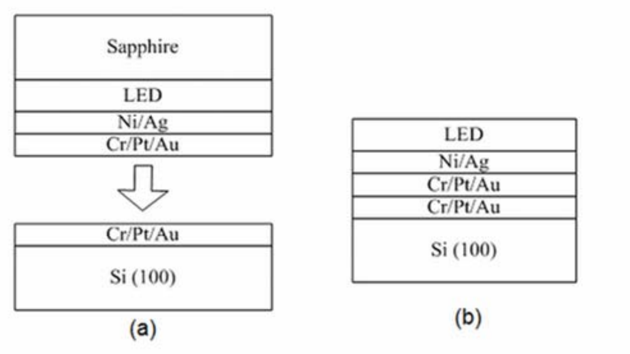

Fig. 1 Schematic diagram of (a) LED wafer transferred onto Si substrate (b) sapphire remove process.

3 Result and discussion

The sapphire thicknesses after CMP process were determined by field-emission scanning electron microscopy as 1.1, 3.6, 5.2, 7.9 and 20.3 μm for each sample, respectively. Figures 2(a) and 2(b) show cross-section image of scanning electron microscope (SEM) for GaN-based light emitting diode after CMP process with 1.1 μm and 20.3 μm sapphire substrates, respectively. Figure 3 shows the E2 (high) mode of Raman scattering spectra of GaN on epitaxial sapphire substrate, GaN transferred onto Si substrate and GaN with various sapphire thicknesses after CMP process. After wafer bonding process, the Raman peak position of GaN epilayer was redshift from 568.93 cm^{-1} to 569.48 cm^{-1}. This result indicated compressive stress in GaN thin film was increased. The Raman peak positions have a significant blueshift to short wavenumbers when the sapphire thickness was polished down to less than 20.3 μm. The sample with 1.1 μm sapphire substrate has a smallest Raman peak position at 567.94 cm^{-1}. This result represents the compressive stress in the course of CMP process to be released. A parabolic relationship between the Raman wavenumbers (ω) and

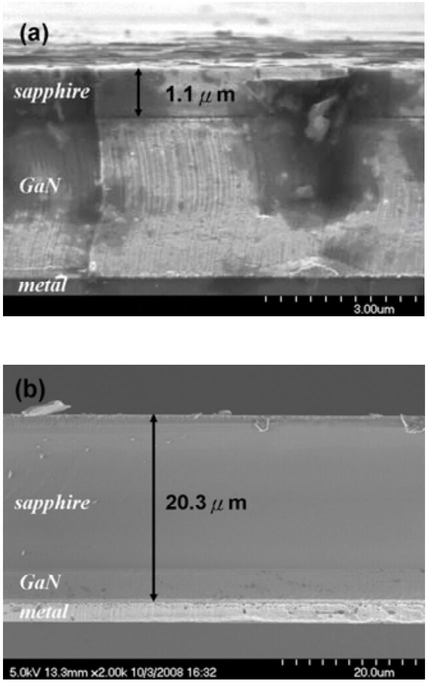

Fig. 2 Cross-section SEM image of GaN LED bonded to Si using Au metal layers at 350 °C and polished with CMP down to (a) 1.1μm (b) 20.3μm.

residual sapphire thicknesses (d) can be expressed like: ω=569.51-1.92 × exp (-d/5.81) (cm^{-1}). By using this equation can calculate the Raman peak of unstressed GaN is 567.58 cm^{-1}, which is very close to GaN bulk (567.6 cm^{-1}) obtained by the study of *Davydov et al.*[5] By analyzing the main scattering signal of E2 mode, the thinnest sample exhibit a 248.3 MPa (1.54 cm^{-1}) stress relaxation

As a result of sapphire thickness reduced to 25.1 μm below, the interaction between sapphire substrate and Si substrate seems aggravating. Four samples here have a different range of substrate thickness, they are 0.4~1.23 μm, 1.78~3.61 μm, 4.21~13.44 μm and 18.49~25.1 μm, respectively. With reducing the sapphire thickness, an almost linear relationship between sapphire thickness and PL peak position was found in these four samples. Figure 5 shows the PL peak change in accordance with the following equation : $\Delta\lambda_{PL}$= (0.54~0.62) $\Delta d_{sapphire}$ (nm). However, the emission wavelength decreased with reducing the sapphire thickness was attributed to the release of the biaxial stress.

4. Conclusion

The sapphire substrate was thinned down by using wafer bonding and CMP technology. By reducing the thickness of the sapphire substrate from 450 μm to the range between 1.1 μm and 20.3 μm, the compressive stress in GaN epilayers will be almost released. On the other hand, a blueshift phenomenon was observed during the CMP process using PL measurements. These results indicate that the stress which is enormously related to sapphire thickness will make great effect on the LED's performance.

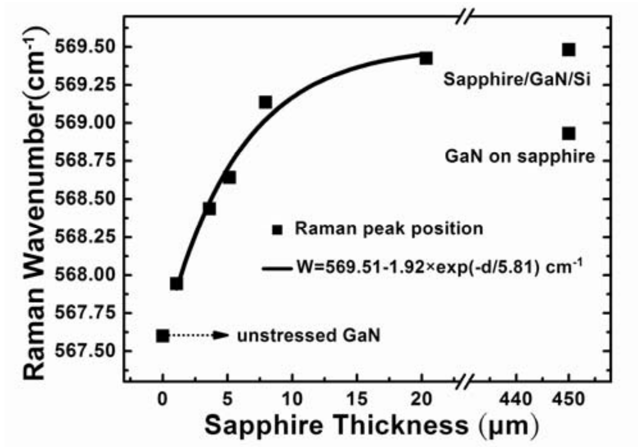

Fig. 3 The relationship between Raman wavenumbers and residue sapphire thicknesses.

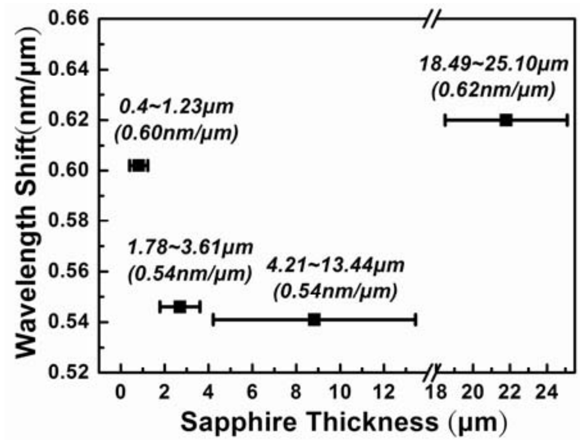

Fig. 4 The PL peak shift rate for the four samples with differe

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