Laser Lift-Off of GaN Thin Film and its Application to the Flexible Light Emitting Diodes

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ABSTRACT

The high performance GaN light emitting diode (LED) from sapphire wafer has been transferred on a plastic substrate with 308nm XeCl laser lift-off (LLO) for next generation flexible lighting applications. SU-8 passivation with thermal release tape (TRT) adhesive enables structure coverage and adhesion so that it can be an excellent candidate for a carrier substrate for non-wetting transfer process using laser liftoff technology. The dimensions of the laser beam are also investigated in two types (3μm x 5cm and 1.2mm x 1.2mm) to reduce stress when decomposition of GaN occurs. With careful optimization of carrier substrate and laser beam conditions, we can fabricate flexible GaN LED on polyimide substrates which shows similar electrical properties to the GaN LED on bulk sapphire substrate.

Keywords: Laser Lift-Off, Flexible GaN LED, Carrier Substrate, SU-8, Thermal Release Tape, Polyimide

1. INTRODUCTION

For the last few years, the fabrication of lighting sources on flexible substrates has been studied vigorously to develop not only consumer electronics but also medical applications including body composition detectors and therapy devices.[1-6] From the first invention of flexible GaN III-V materials in 2005[7], several approaches have presented flexible inorganic light emitting diodes (f-ILEDs) by transferring micro-structured GaAs/GaN to flexible plastic substrates.[8-11]

Although the f-ILEDs show the remarkable applications such as flexible displays to waterproof biosensors, they have limitations in optical performance caused by epitaxial growth quality on a silicon substrate.[8-11] Recently, T. Kim et al. have demonstrated new fabrication protocol using conventional laser lift-off (LLO) technology to produce flexible and highly efficient GaN LEDs.[12] In LLO process, it is essential to laminate carrier substrates on the top of the GaN thin films for reducing stresses arising from GaN decomposition.[13] Generally, materials with structural support and strong adhesion have been used for carrier substrates such as $InPd_x$ alloys, epoxy on Si wafers and Cu substrates.[13-16] Therefore, the previous LLO fabrication of f-ILEDs requires additional wet etching of carrier substrates to transfer GaN LEDs to target plastic substrates, which inevitably results in process complication, inefficiency and performance reduction.[12]

Herein, we demonstrate LLO of the 5μm thick high power GaN LED thin film from sapphire substrates and its direct application to the flexible LEDs without any wet etching process. We achieve non-wetting transfer process by careful optimization of carrier substrates and laser beam condition. Superior GaN epitaxial layer on sapphire can be transferred without wet chemical etching to make 400μm x 400μm GaN LED arrays with 900μm spacing. Microscale flexible GaN LEDs will provide an opportunity not only new flexible LED display systems but also potential for various biomedical applications.

2. RESULTS AND DISCUSSION

Figure 1 shows schematic diagram of the fabrication steps for experiment for GaN thin film stability for conventional carrier substrate LLO process. GaN epitaxial layers are commercially grown 5μm thick on sapphire substrate (p-GaN/MQW/LT-GaN/n-GaN/u-GaN) by metal organic chemical vapor deposition (MOCVD) (Figure 1a). To make

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ohmic contacts, p-GaN/MQW/LT-GaN layers are etched by an inductively coupled plasma reactive ion etcher (ICP-RIE) (Figure 1b). Au/Cr (50nm/10nm thickness) layers are deposited as ohmic contact pads to both p-GaN and exposed n-GaN and annealed at 600 ºC by RTA for 3min (Figure 1c). Then three kinds of carrier substrates (Polydimethylsiloxane (PDMS) stamp, Thermal Release tape(TRT), TRT with SU-8 passivation on top of the GaN thin film) are attached on GaN layers(figure 1d) and XeCl laser (0.8J/cm^2, 308nm wavelength, 3μm x 5cm beam shape) is irradiated on the interface of u-GaN/Sapphire(figure 1e). Laser lift-offed interfaces are observed by optical microscope.

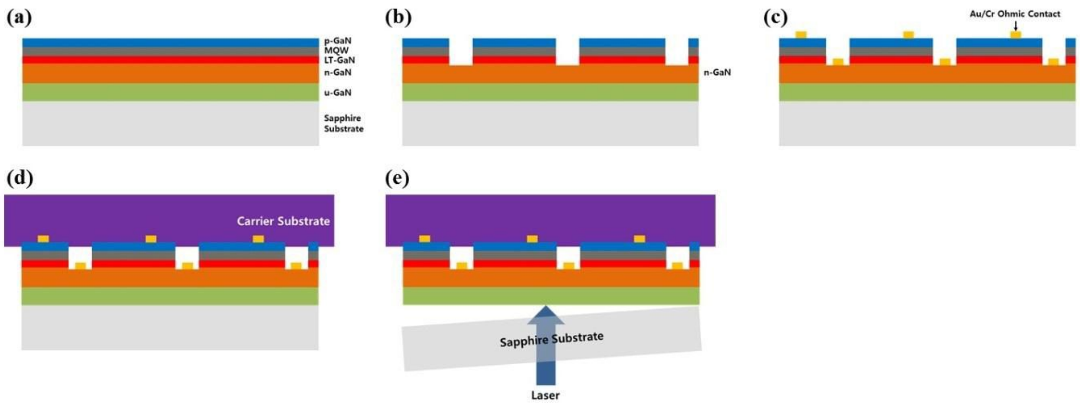

Figure 1. Schematic diagrams of laser lift-off for carrier substrate investigation

Figure 2 shows optical Images of the laser lift-offed surface of u-GaN with variation of carrier substrates. PDMS stamp carrier substrate shows partially fine surfaces with wrinkles (Figure 2a), TRT shows rough coverage (Figure 2b), and TRT with SU-8 passivation gives best lift off quality (Figure 2c). From the picture of Figure 2d, ~5mm x ~5mm GaN thin film is lift offed well. From this result, we decide carrier substrate for GaN LED LLO between three candidates.

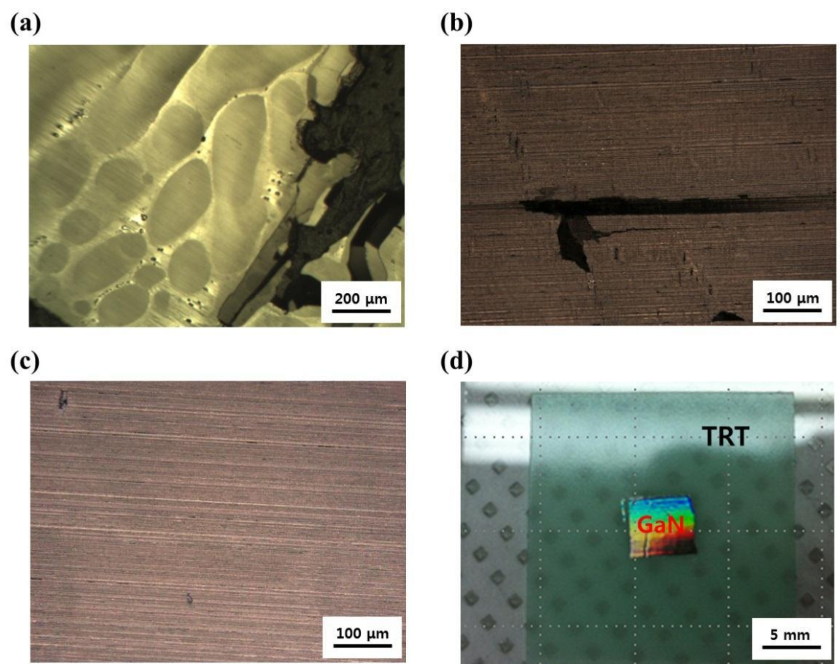

Figure 2. Optical Images of laser lift offed surface on different carrier substrates (a) on PDMS stamp (b) TRT (c) TRT with SU8 passivation. (d) photograph of the sample (c)

Figure 3 illustrates schematic diagrams of the process of GaN LED array LLO using SU-8 passivation with TRT adhesive carrier substrate. Figure 3a 3b 3c are same as Figure 1a 1b 1c which shows ohmic contact formation of GaN LEDs. Uniform layers of Al/PEO(plasma enhanced chemical vapor deposited oxide) /Au/Cr(500nm/2μm/100nm/20nm) are deposited as hardmask for dry etching (Figure 3d). Using conventional photolithography and ICP-RIE dry etching process, 400μm x 400μm square islands are formed (Figure 3e). Then residual PEO/Au/Cr layers are wet etched (Figure 3f). Mesa etched GaN LED arrays are patterned and passivated with 10μm thick SU-8 (Figure 3g) and structures are captured by TRT on glass (Figure 3h). Irradiation of 308nm XeCl laser releases GaN LED arrays from sapphire substrate (Figure 3i) and then LED arrays are transferred onto the Au/Cr(50nm/10nm) coated polyimide substrate(25μm) (Figure 3j). Electrical characteristics of flexible GaN LED are measured by Kiethley 4200(Keithley Instruments Inc.) through contact opening of patterned SU-8 passivation (Figure 3k and 3l).

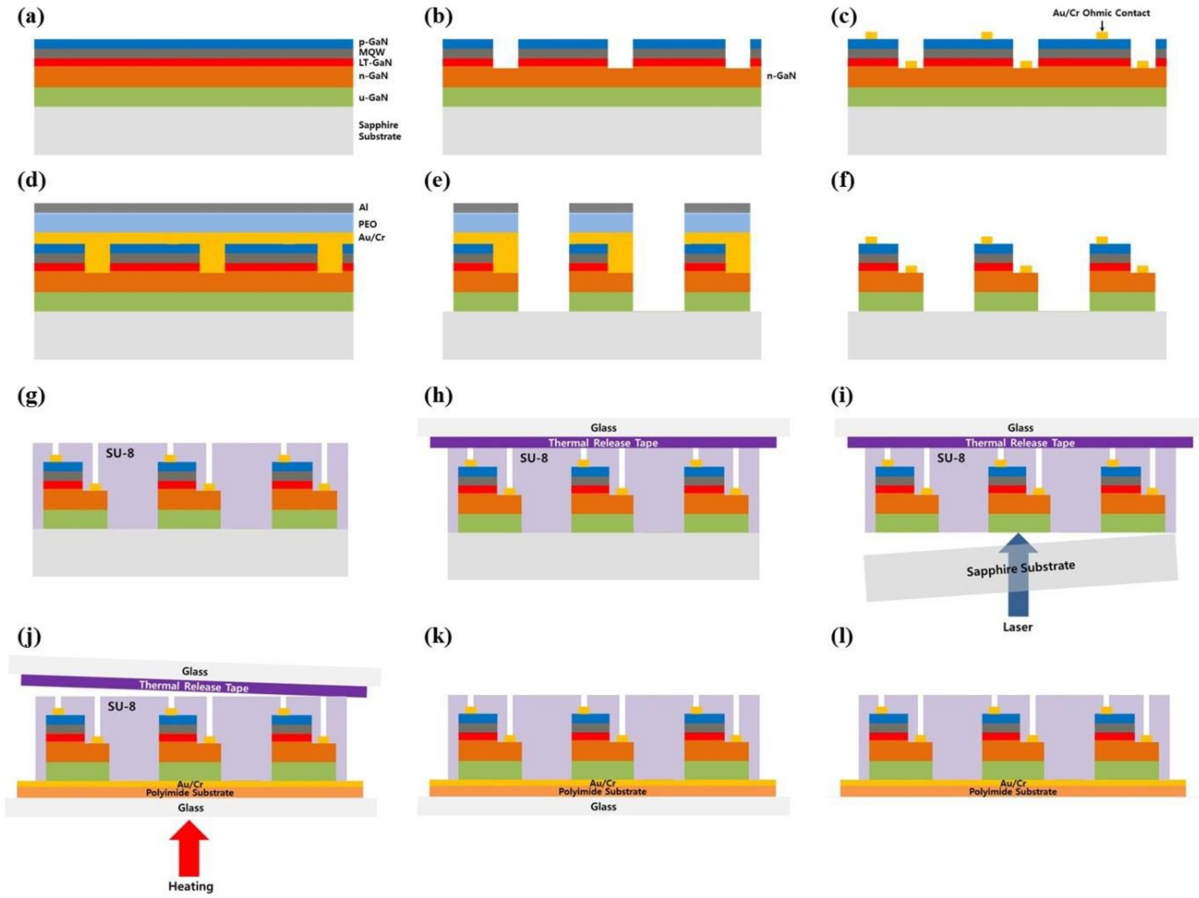

Figure 3. Schematic diagrams of the fabrication of high quality flexible GaN LED arrays from sapphire substrate.

Influence of XeCl laser beam dimension (3μm x 5cm and 1.2mm x 1.2mm) is examined (Figure 4, corresponding to Figure 3i). Each GaN LED arrays entirely exposed by 1.2mm x 1.2mm square laser beam (Figure 4a) produces undesirable cracks, while GaN LEDs exposed by 3μm x 5cm line shape laser beam makes just minor cracks on u-GaN surface (Figure 4b). These results represent the importance of irradiance area of laser flux and corresponding stress during LLO.

(a)

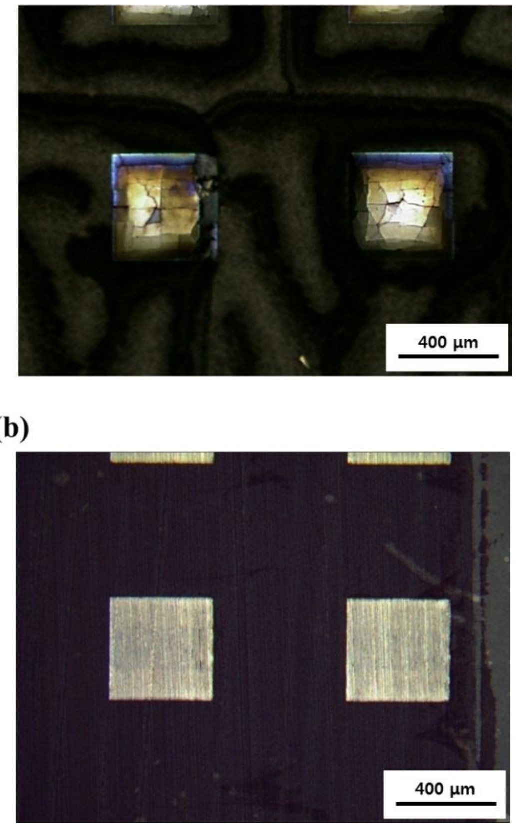

Figure 4. Laser lift offed surface of GaN LED arrays with different XeCl laser beam dimensions (a) 1.2mm x 1.2mm square laser beam (b) 3µm x 5cm line shape laser beam

I-V curve of bulk GaN LED and laser lifted flexible GaN LED is measured by semiconductor parameter analyzer (Keithley 4200) (Figure 5b, inset photograph shows turn-on state of flexible GaN LED). I-V curves show that electrical characteristic of flexible GaN LED is similar to GaN LED on bulk substrate.

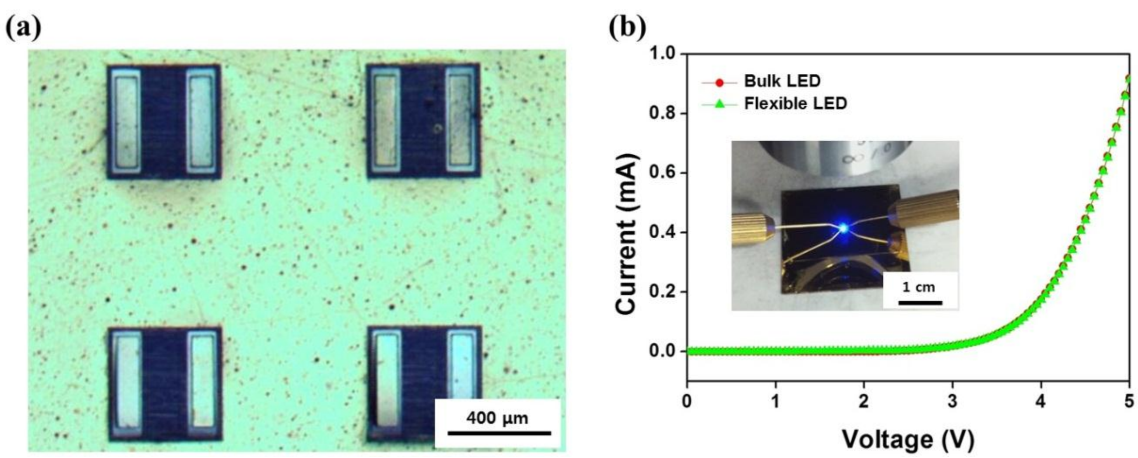

Figure 5. (a) Optical Image of GaN LED arrays on flexible substrate (b) I-V curve comparison between Bulk LED and Flexible LED

3. CONCLUSIONS

We have investigated the fabrication of flexible GaN LED using LLO technology. High quality GaN LED epitaxial layers grown on sapphire substrates can be transferred on flexible substrates which enables non-wetting transfer process. In the selection of a carrier substrate, SU-8 passivation with TRT adhesive can be a strong candidate for our innovative LLO protocol. Laser beam dimensions are also optimized to release GaN LED epitaxial layer without cracks. Line shape laser beam (3μm x 5cm) improves the quality of transferred LED structure. GaN LED arrays on flexible polyimide substrates and shows high electrical and optical performance.

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