Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 850-851

G-8-2

Thin GaN on Sapphire with Reduced Bowing by Large Area Laser Lift-off Technique

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1. Introduction

Sapphire has been the most suitable substrate material for the epitaxial growths of GaN-based devices. Currently, visible LEDs and proto-type ultraviolet lasers on sapphire are available on the commercial basis[1,2]. Although the better quality devices are easily obtained, the epitaxial wafer bows in a convex manner at room temperature after the growth due to the thermal and lattice mismatch between GaN and sapphire. The bowing has made the subsequent wafer processing difficult or not reproducible. Practically, the wafer processing in a large size wafer has been very difficult on the bowed wafers. In particular, stripe widths of the laser diodes and gate lengths of the field effect transistors need to be precisely defined in the photolithography process. However, the pattern width varies over a large size wafer resulting in the poor yield in the production. Thus, to reduce such bowing has been desired for the reproducible wafer processing of GaN-based devices.

This paper describes a new technique to reduce the bowing utilizing so-called laser lift-off technique[3,4]. The wafer bowing of GaN thin film on sapphire is significantly reduced by forming the metal Ga at the interface by the high power laser irradiation from the backside of the sapphire. The high power laser is irradiated uniformly over a 2-inch wafer resulting a GaN template with reduced bowing.

2. Experiments

GaN films up to the thickness of 5μm are grown on c-plane sapphire ($Al_2O_3(0001)$) by Metal Organic Chemical Vapor Deposition (MOCVD). After the epitaxial growths, high power, short pulse 3-rd harmonic Q-switched Nd:YAG laser (λ=355nm) is irradiated from the backside of the sapphire. The high power laser heats up the interfacial GaN layer and decomposes very thin portion of the GaN resulting the formation of the metal Ga at the interface. The laser beam is scanned over a 2-inch wafer. Note that the used laser lift-off system is applicable up to 4-inch wafer.

3. Results

Crack-free thin GaN films with metal Ga underneath are successfully obtained through the optimization of the process parameters. Fig.1 shows the optical microscope images of the GaN films after the laser irradiation. The surface remains very smooth and the transmission image appears in black suggesting the Ga formation at the interface. 2-inch diameter GaN templates with the metal Ga are successfully obtained through optimization of process parameters such as laser power. The optimized condition prevents the thin film from blowing up from the substrate with cracks due to the uniform relaxation of the film stress. The photo of thus obtained a 2-inch template shown in Fig.2. The color of the film changes from transparent to gray because of the Ga formation.

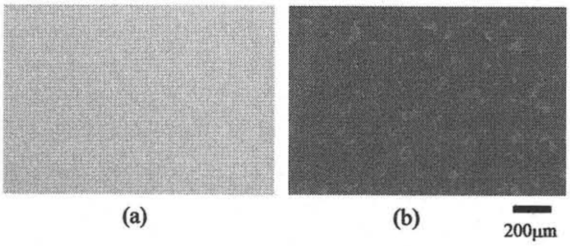

Fig.1 Microscopic images of GaN on sapphire after laser irradiation.
(a) surface morphology, (b) transmission image (black area corresponds to metal Ga)

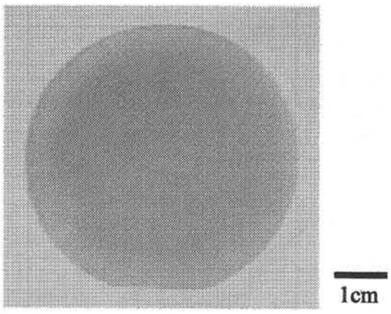

Fig.2 A 2-inch GaN film on sapphire substrate after laser irradiation

In addition, the interfacial structures are characterized by transmission electron microscope (TEM). Cross sectional analysis reveals that no crystal defect is induced by the lift-off process. Note that the formation of Ga is also confirmed as shown in Fig.3. The thickness of the decomposed GaN layer is approximately 200nm or less.

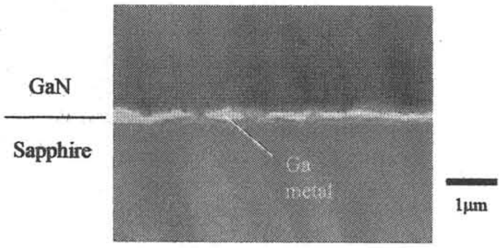

Fig.3 Cross sectional TEM image of laser irradiated GaN thin film on sapphire

Most importantly, the laser processing is found to reduce the wafer bowing of the GaN film on sapphire with metal Ga at the interface. The wafer curvatures are measured for the area of approximately 1cm^2 using optical interference technique. The measured wafer curvature is around 0.1 m^{-1} after the laser irradiation, which is far reduced from the original value of 0.3 m^{-1} for the as-grown wafer. Fig.4 shows the typical image of optical interference measurements, in which the less number of the lines implies the reduced bowing. Assuming only the thermal mismatch between GaN and sapphire[5], the curvature of the original wafer before the laser irradiation is calculated to be 0.26 m^{-1}.which is well close to the measured original value. This suggests that the original bowing is caused mainly by the thermal mismatch and the stress caused by the mismatch is relieved by the formation of metal Ga at the interface. The process flow to form such a nearly bowing free wafer is illustrated in Fig.5.

4. Conclusions

In conclusion, the wafer bowing of GaN thin film on sapphire is significantly reduced by forming the metal Ga at the interface by using laser lift-off technique. Through the optimization of the process parameters, a 2-inch diameter 5μm-thick GaN film on sapphire with reduced bowing is successfully obtained. This technique would enable the uniform and reproducible wafer processing of GaN-based devices on a large wafer.

Acknowledgments

The authors would like to thank Dr. Daisuke Ueda, Director of Semiconductor Devices Research Center, and Dr. Hirokazu Shimizu for their technical advice and continuing support for this work.

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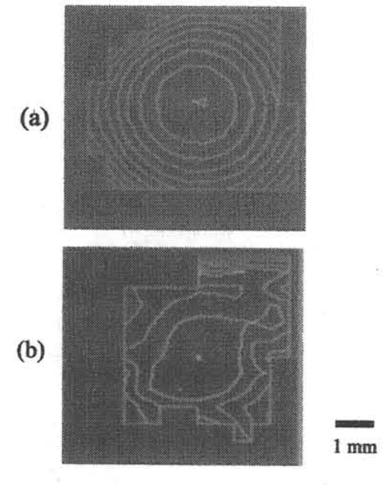

Fig.4 Optical interference measurements results on 5μm-thick GaN film on sapphire
(a) before laser irradiation (curvature 0.3 m^{-1})
(b) after laser irradiation (curvature 0.1 m^{-1})

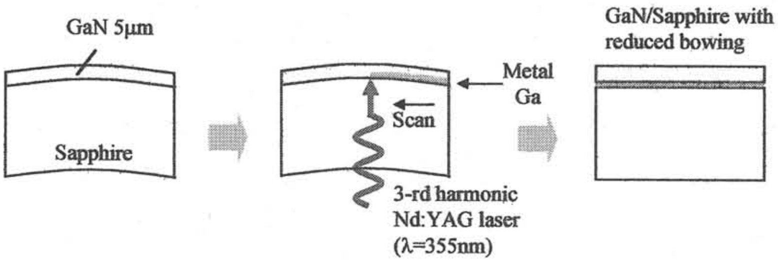

Fig.5 Schematic process flow of the bowing reduction using laser liftoff technique