PS-11-10

Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp1017-1018

Laser Slicing Lift-Off Process for GaN-on-GaN Technology

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Abstract

Laser slicing process was developed to lift-off a thin GaN film with epitaxial device structure from a bulk GaN substrate, that allows reusing the expensive GaN substrate many times.

1. Introduction

Gallium Nitride substrates are crucial for the production of reliable high-power GaN devices: LEDs and lasers, high-voltage diodes and transistors, and microwave HEMTs. Widespread use of GaN substrates is currently limited by their high cost. Separation of the epitaxial device structure from the bulk GaN substrate allows the reuse of the expensive substrate multiple times and thus reduces the manufacturing cost of GaN-on-GaN devices.

Several approaches were proposed to separate a GaN film from a native GaN substrate: chemical lift-off process [1]; porous release layers [2-4]; controlled spalling [5]; laser lift-off with an InGaN release layer [6]; ion implantation [7]. The lift-off methods based on intermediate release layers require a complicated epitaxy process. The ion implantation-based process results in the formation of a large number of point defects and does not allow separating epitaxial device structures.

The laser slicing lift-off (LSLO) process has been developed [8,9] that does not require any specific release layers and can be used to lift-off GaN films with front-end processed device structure from the bulk GaN substrate. The method allows to use The application of such a process allows to reuse the expensive bulk GaN substrate many times and thereby reduce the cost of the devices.

2. Laser slicing method

Laser slicing method is based on the effect of GaN decomposition caused by an ultrashort laser pulse focused inside a bulk GaN material (fig. 2). An ultrashort-pulse laser is focused inside bulk GaN, several microns under the surface. The laser pulse energy is chosen such that the laser breakdown threshold is exceeded only in the focal volume. The substrate is scanned by the laser beam until a continuous layer of decomposed material is formed under the surface

A proof-of-concept LED chip was fabricated using the laser slicing lift-off to demonstrate the feasibility of the proposed method (fig. 1). First, a bulk GaN layer was grown by hydride vapor phase epitaxy method. After that the surface of the bulk GaN layer was epi-polished. A 5-µm thick GaN film with an InGaN LED structure was grown homoepitaxially by MOCVD. After that, the 5-um thick GaN film with the LED structure was lifted-off from the substrate and transferred to a copper carrier. The electroluminescence of the LED chip after the lift-off was demonstrated (fig. 3).

3. Conclusions

Critical stages of the GaN-on-GaN device manufacturing using laser slicing lift-off were implemented. The bulk GaN crystal was grown by the HVPE, epi-polished and a blue LED InGaN device structure was grown. After that, GaN film with a thickness of 5 µm, containing the LED structure, was lifted off from the GaN substrate using the laser slicing process. The operation of the LED structure, lifted off from the bulk GaN substrate and transferred onto a copper carrier, was demonstrated.

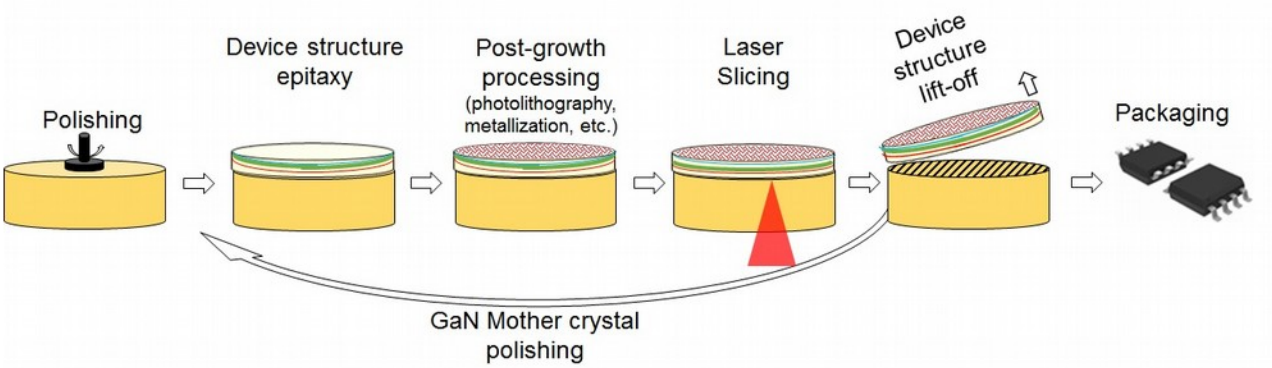

Fig. 1: Schematic diagram of GaN-on-GaN device fabrication using the laser slicing lift-off process

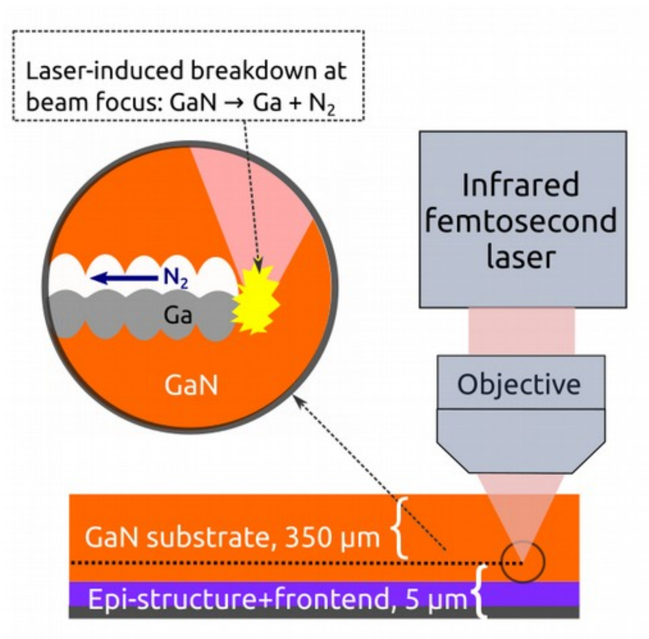

Fig. 2: Laser slicing lift-off process: a beam of a near-infrared femtosecond laser is focused inside a GaN wafer, 5 µm below the surface. The decomposition of GaN takes place in the focal volume of the laser beam. The wafer is scanned in the XY plane until a continuous layer of decomposed material is created inside the wafer.

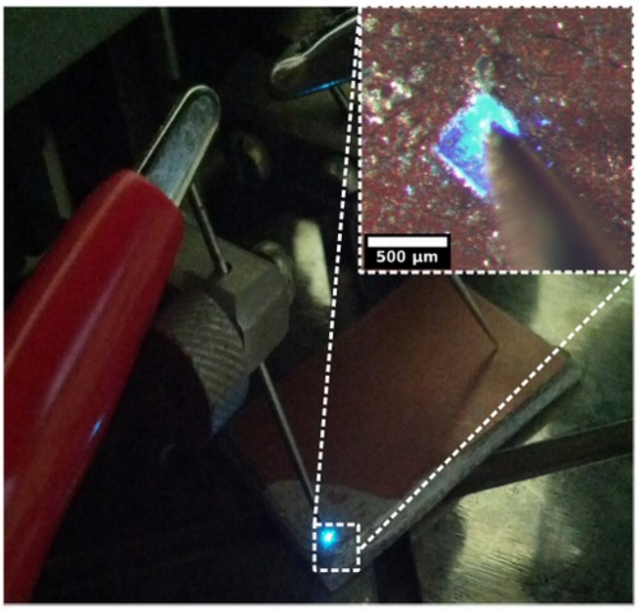

Fig. 3: Photograph and a microphotograph (inset) of the InGaN LED chip lifted off from a bulk GaN substrate and transferred on a copper substrate with a current probe connected, electroluminescence at 1 mA operating current.

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