Laser cutting of GaN/Al₂O₃ structures

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Abstract. We report on intra-volume laser scribing process developed for GaN layers grown on single-side and double-side c-plane sapphire structures by hydride vapor phase epitaxy. Dies of 10 mm × 10 mm and 15 mm × 15 mm were cut from 2-inch wafers using a 1.064-µm Nd:YAG pulsed laser. The impact of laser cutting on the mechanical properties of GaN/Al₂O₃ structures is discussed.

1. Introduction

Gallium nitride (GaN) and related III-N materials are widely used for applications in optoelectronic, high power and microwave devices. A post-growth processing is an essential part to manufacture semiconductor devices. One of the main processes at a final step is dicing of GaN-based epitaxial structures on a common substrate into small-size individual chips while keeping crack-free, clean, smooth chips surface. When processing the sapphire substrates usually used to grow III-N LED structures, the chip separation using a diamond scriber and breaking is near common standard. However, there is a strong demand for improved throughput and yield ratios of the processing using a laser micro machining technology. The laser processing has rapidly become more prevalent because it reduces chance of damage to process material due to shock or handling, reduces waste handling costs, provides one-step alternative to chemical etching process, allows removal of one type of material without damage to the underlayers.

Laser micro machining technology implies a variety of processes including hole drilling, ablation, milling, and cutting (scribing, dicing). Lasers with various parameters of emitted light (pulse energy, shape and width, wavelength) combined with precise positioning (stepper) system are used for this technique. Typically a UV laser is used for dicing or ablation (laser lift-off) of GaN based structures grown on sapphire (Al₂O₃) substrates having optically polished back side (double-side polished (DSP) sapphire) [1-4]. However single-side polished sapphire (SSP) substrates, that are cheaper than DSP ones, are also widely used in the III-N growth technology.

In this work we apply a 1.064-µm Nd:YAG laser to cut chips of 1-3 cm² from 2-inch GaN/sapphire wafer. These large-size chips (or plates) were used to fabricate GaN working electrodes for water...
splitting experiments [5]. We report on intra-volume laser scribing process developed for GaN/sapphire structures grown on SSP or DSP sapphire substrates.

2. Experimental

GaN layers of a 2-10 µm thick were grown by chloride hydride vapor phase epitaxy (HVPE) on c-plane 2-inch SSP and DSP sapphire substrates. Thickness of SSP and DSP substrates was 430 µm and 330 µm, respectively. The growth procedure included in-situ sapphire substrate treatment and an AlGaN buffer layer deposition followed by GaN layers growth. Details of the structure growth and characterization can be found elsewhere [6].

The precise laser machining system used in this work is schematically given in Figure 1. It consists of diode-pumped solid state pulsed Nd:YAG laser emitting in near-infrared spectral range (1064 nm) with repetition rate up to 10 kHz and average power up to 1 W, a stepper system to position precisely a substrate under the laser beam (not shown in Figure 1), a dichroic mirror, a recording unit comprising a microscope with a camera. The stepper has two horizontal orthogonal coordinates with 2.5 µm precision, one vertical coordinate with positioning precision 1 mm and rotation stage for orientation of a sample in horizontal plane. The recording unit is connected with a computer to monitor the material processing with 2-µm resolution in real time.

Figure 1. Schematic of the precise laser machining system.

The laser machining system may implement a traditional method of the sample surface ablation or a method of intra-volume laser scribing depending on the laser radiation parameters (wavelength, pulse duration, optical power density in the pulse, duty cycle, and beam divergence). The system has also a capability to process a wafer from both front and back sides adjusting a quality of the dice edges.

In this work we applied intra-volume laser scribing to fabricate 10 mm × 10 mm or 15 mm × 15 mm chips from 2-inch GaN/sapphire wafer. This scribing technique is associated with a plasma breakdown in transparent dielectric media under irradiation by a short pulse of high power density laser beam [7]. Under a very strong electric field of the laser wave, which is of hundreds of MV/cm, valence electrons are accelerated to energy sufficient for impact ionization of host atoms in the crystal lattice. As a consequence of the atoms ionization, electron avalanche is quickly developed reaching a critical density. Breakdown in transparent media is connected with rapid increasing of electron density to a critical level needed for strong absorption of the laser radiation by emergent plasma. As a result, the media is collapsed in local areas under blast waves in the plasma that results in the rupture of the material lattice leading to cracks and cavities formation.

GaN layers grown on a 350 µm thick DSP sapphire substrates were processed from the back side of the substrate to fabricate 10 mm × 10 mm and 15 mm × 15 mm chips. Short pulses of the focused laser beam with adjusted duration and power density created micro-cavities and micro-cracks inside the sapphire substrates. A spacial set of these cavities fabricated in the substrate promoted to cut (to break) the wafer into chips.
The same approach was used to process GaN layers grown on a 430 µm thick SSP sapphire substrates but the laser beam was focused into sapphire substrate through the GaN layer. Special attention was paid to avoid destroying of the GaN layer by adjusting the laser beam spot. The fabricated chips were studied by means if scanning electron microscopy (SEM).

3. Results and discussion

GaN layers grown on a 350 µm thick DSP sapphire substrates were processed by laser scribing from the back side of the substrate. Figure 2 shows cross section of GaN layer grown on DSP sapphire substrate. During the scribing process, the laser beam was firstly focused in a point positioned at distance of 310 µm from the substrate back side. The short impulse of the laser irradiation (5 ns, 2 mJ) creates a carrot-like or ellipsoid-like cavity (~15 µm (height) × ~6 µm (width)) in the focused point of the substrate. The cavity pulls out across the substrate. After that, the machining system stepper shifts the wafer in other position and new cavity creates. By this way a row of cavities can be formed as shown in Figure 2a.

An average distance between the cavities is 20 µm. Each cavity is surrounding by micro cracks that form a destroyed area between the cavities shown in Figure 2b. The micro cracks are spread in-plane the substrates (along the cavities row). To form another row of cavities, the laser beam was focused in a point positioned at a distance of 210 µm from the substrate back side. Two rows of cavity with destroyed area between them are clearly seen in Figure 2a. These two rows of cavities formed in two orthogonal directions in the GaN/sapphire wafer found to be sufficient to break the wafer easily into rectangular dies of 10 mm × 10 mm and 15 mm × 15 mm.

Figure 2. Scanning micrographs of cross section view of a 3.6 µm thick GaN layer grown on DSP sapphire substrate after the laser scribing from the backside of the substrate (a) and cavities under high magnification (b). In-plane cracks surround the cavities. A spacial set of cavities resulted in a net of cracks that promote to break the structure after the laser scribing.

Damaged area of dice edge found to be a 25 µm wide without any ablation. The GaN layer surface pollution (contamination) by products of the scribing process was not observed. Cracks in the GaN layer attributed to the scribing process were not observed too.

The main advantage of the intra-volume laser scribing is the process requiers low-power laser. Depending on the laser impulse duration and the laser beam focusing the radiation power density can exceed the threshold level of the rupture of the material. It gives selectivity of the scribing process and avoids destroying of transparent layers of the structure by laser radiation passing through.

GaN layers grown on a 430 µm thick SSP sapphire substrates were processed by laser scribing through the GaN layer. Figure 3 shows cross section of GaN layer grown on SSP sapphire substrate. Three cavity rows were formed by the intra-volume laser scribing process on a distance of 100 µm, 280
µm, and 370 µm from the layer surface. The cavity dimensions are 10 µm (height) × 3 µm (width). The SSP sapphire substrate is thicker than SSP substrate. Our experiments had shown that three rows of cavities formed in two orthogonal directions in the GaN/SSP sapphire wafer are sufficient to break easily the wafer into rectangular dies of 15 mm × 15 mm.

Figure 3. Scanning micrographs of cross section view of a 3.6 µm thick GaN layer grown on SSP sapphire substrate after laser scribing through the GaN layer (a, the insert shows the ellipsoid-like cavity at higher magnification) and a plain- view of the same die (b, inserts show specific of the die edges at higher magnification.) The GaN layer appears as a thin light area on the top of the Figure 2a.

The plain-view of the die edges shown in Figure 3b. Two orthogonal edges have different sharpness that can be associated with two crystallographic directions (axes) on the c-plane sapphire surface: along a-axis and along m-axis. Typically 2-inch sapphire has a flat along a-axis. The laser cribbing in our experiments was performed in a direction parallel and perpendicular to the flat. It looks that rougher edge of the die in Figure 2b having fluctuation up to 25 µm is along the m-axis of sapphire. The other die edge has the sharpness of 2-3 µm. The similar results were observed for dies cutting from GaN/DSP sapphire wafers. More experiments are required to optimize the die edge sharpness.

4. Conclusions
An intra-volume laser scribing process with 1,064-µm Nd:YAG laser was applied for dicing of 3-10 µm thick GaN layers grown by HVPE on SSP and DSP c-plane sapphire substrates. The laser scribing process is associated with a plasma breakdown in transparent dielectric media under irradiation by a short pulse of high power density laser beam.

GaN layers grown on a 430 µm thick SSP sapphire substrates were processed from the front side (from the GaN layer surface) to fabricate 15 mm × 15 mm dies. GaN layers grown on a 350 µm thick DSP sapphire substrates were processed from the back side of the substrate to fabricate 10 mm × 10 mm and 15 mm × 15 mm chips. Surface damaged area of a dice edge found to be a 25 µm wide without any ablation in both set of dies. A surface pollution (contamination) of the GaN layers by products of the scribing process was not observed. Cracks in the GaN layers attributed to the scribing process were not observed also.

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