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High etching rate of GaN films by KrF excimer laser

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Abstract

A study of laser processing of gallium nitride (GaN) material is reported. A pulsed KrF excimer laser at 248 nm with 20-nsec pulse width and 1 Hz repetition rate is used to etch the GaN film. We establish the material etching parameters under different environmental conditions. By changing the pulsed energy at constant pulse numbers, ablation of GaN surface was observed at threshold laser fluence about 0.3 J cm^{-2}. Laser etching increase with reducing environment pressure. At 1.0 J cm^{-2} laser fluence, the etching rate is about 35 nm per pulse at atmosphere pressure and increases to 60 nm per pulse at low pressure. The etched depth also increases with increasing laser fluence. The surface morphology of the etched surface was also investigated.

Keywords: GaN; KrF excimer laser; Environmental conditions; Atmosphere pressure; Low pressure

1. Introduction

The gallium nitride (GaN) based wide band gap semiconductor is one of the most promising materials for blue light emitting diodes and diode lasers. One of the major challenges to build these high performance devices is the processing of GaN. Due to the rare chemical stability and high hardness of GaN, certain proper etching method is required. So far, various processing techniques for dry etching have been reported. These reports include plasma etching, reactive ion etching (RIE), electron cyclotron resonance, inductively coupled plasma, magnetron RIE, chemically assisted ion beam etching and reactive ion beam etching [1]. Recently, photoassisted dry etching and laser etching of GaN materials [2–6] were also reported. The reported laser etching for GaN materials showed good etched surface morphology and high etching rate of 50–140 nm per pulse. However, there are few reports on the effect of etching rate under different pressure conditions. In this paper, we report the etching of GaN materials using KrF excimer laser and establish the threshold laser fluence as well as etching rates under various etching conditions.

2. Experimental

Two GaN film samples were used for the experiment. One sample has film thickness of 2.5 μm grown on sapphire substrate by metalorganic chemical vapor deposition. Another sample with 14.9 μm thick was also grown on sapphire substrate by hydride vapor phase epitaxy.

Fig. 1 shows the schematic diagram of the laser etching setup. A KrF excimer laser (Lambda Physick LPX210) at wavelength, $\lambda = 248$ nm and pulse width of 20 ns at repetition rate of 1 Hz, was used. The laser beam is reshaped and homogenized using a special optic system to generate a highly uniform ($\pm 5\%$ RMS) beam profile of 12×12 mm^2 after the mask plane. A beam splitter then splits the laser beam into etching beam and monitor beam. The etching beam is projected by a lens system of $10\times$ with 0.2 numerical aperture and focused on to the sample with a square spot size of 1.2×1.2 mm^2. A sample was placed inside a stainless steel chamber with fused silica window, and a pump port to create vacuum condition inside the sample. The monitor beam is incident on a CCD camera to insitu

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monitoring of laser beam quality and etching behavior. The etching experiments were carried out in room temperature conditions under atmosphere pressure and low-pressure environment of 10^{-3} and 10^{-6} torr.

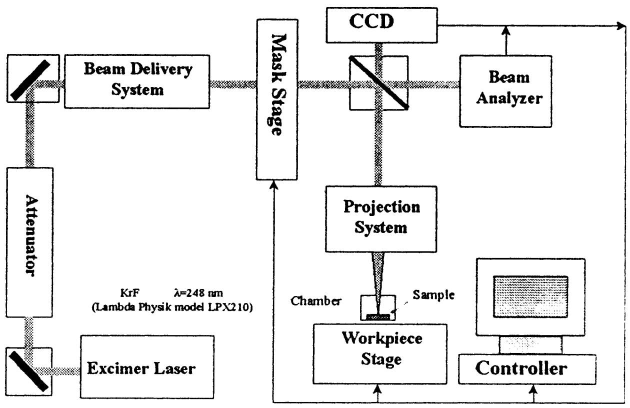

Fig. 1. The schematic diagram of KrF excimer laser.

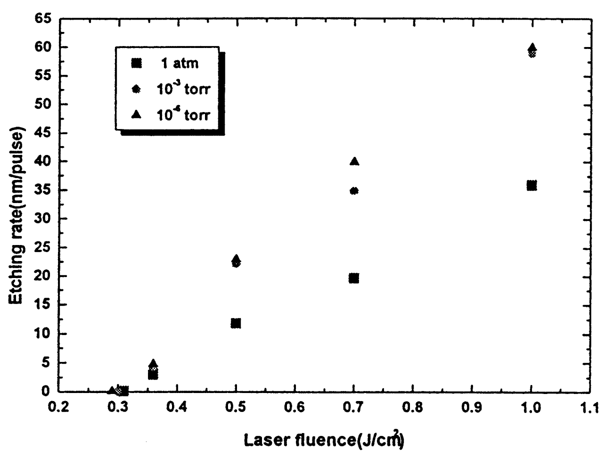

Fig. 2. The dependence of etched rate on laser fluence under different pressure conditions.

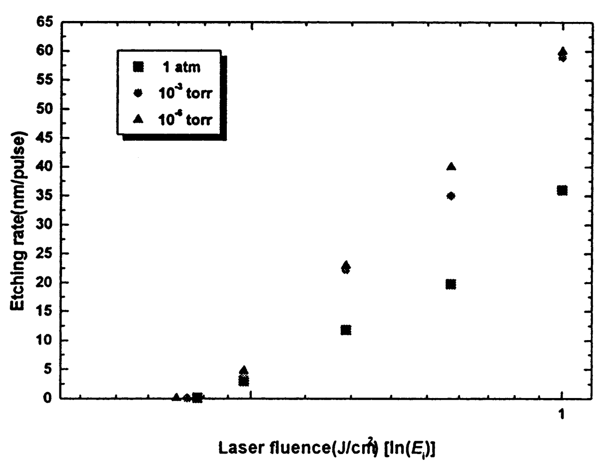

Fig. 3. Semilog plot of the etching rate as a function of laser fluence.

3. Results and discussion

The effect of laser etching environment condition on laser fluence and etching rate were investigated using the 2.5 μm thick sample under three pressure conditions; one atmosphere pressure, 10^{-3} and 10^{-6} torr. The sample after laser etching tends to show some material residues such as Ga, Ga oxide. These residues were cleaned by dilute acid solution such as HCl or H_2SO_4/H_2O_2 before measurement of etched depth. The laser fluence varied from 0.2 to 1.0 J cm^{-2} at constant number of pulses. Fig. 2 shows the etching rate as a function of laser fluence for the three different pressure conditions. In all conditions, etching rate increase with increasing laser fluence as expected with high etching rate for low-pressure condition. The etching rate is about 35 nm per pulse in one atmosphere pressure and 60 nm per pulse at 10^{-6} torr at the incident laser fluence of 1.0 J cm^{-2}. The threshold laser fluence from these results also show near similar value of 0.3 J cm^{-2}. The higher etching rate in low-pressure can be used for processing that requires high etching rate.

This data also allows the estimation of the GaN material absorption coefficient at KrF laser wavelength. Based on widely accepted formula of Beer's law; $d = (1/\alpha)\ln(E_i/E_{th})$; where d is the etched depth per pulse, α is the absorption coefficient, E_i is the incident laser fluence, and E_{th} is the threshold laser fluence for material removal. A plot of the etching rate versus logarithm of incident fluence E_i is shown in Fig. 3. We obtained a linear plot with a slope $1/\alpha$, the absorption length. From the slope, we can estimate the absorption coefficient to be 2.5×10^5 cm^{-1}, which is in agreement with the earlier reported absorption coefficient of GaN [7].

A relatively good quality of vertical edge was obtained. Surface morphology of etched surface was characterized by AFM in contact mode operation with a scan area of 5 μm^2. Fig. 4 illustrates a typical AFM image of the etched surface under low-pressure conditions. The root mean square values of etched surface for low-pressure etched samples varied from 14 to 34 nm. These results show that the relatively better etched surface morphology was obtained under the atmosphere pressure condition

4. Conclusion

In conclusion, we investigated the KrF excimer laser etching of GaN materials under various conditions. The threshold laser fluence for laser etching of GaN was 0.3 J cm^{-2} under different pressure conditions. At low laser fluence of 1.0 J cm^{-2}, the etching rate of 60 nm

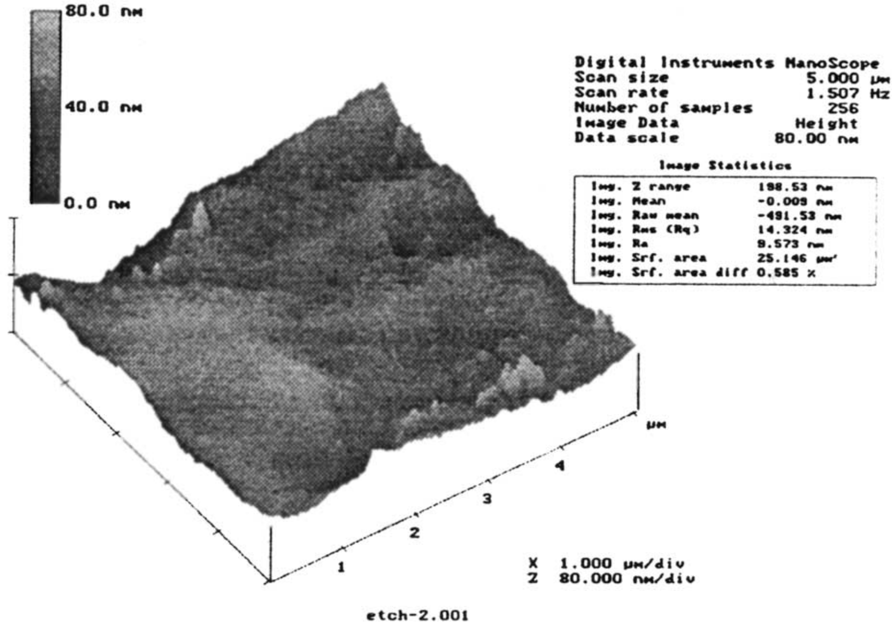

Fig. 4. AFM image of the etched surface under low pressure environment.

per pulse under low-pressure condition and 35 nm per pulse under atmosphere pressure condition were obtained. The laser etching processing seems to be a viable GaN etching technique, especially for high speed-deep etching

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