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Highly-efficient slurryless finishing of GaN by plasma-assisted polishing using a resin bonded grinding stone

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Abstract
GaN is a promising material for the next generation semiconductor power devices which operate at high temperature and have a small power loss since GaN has a wide bandgap and a high electric breakdown field. For device fabrication, the surface of GaN must be scratch-free, damage-free and atomically flat. Chemical mechanical polishing (CMP) is widely used as the finishing technique for GaN. However, its material removal rate (MRR) is very low due to the high hardness and chemical inertness of GaN. We proposed a novel polishing technique named plasma-assisted polishing (PAP) which combined surface oxidation by irradiation of atmospheric-pressure plasma and removal of the oxide layer by soft abrasive polishing. PAP is applied to difficult-to-machine materials such as GaN and SiC to realize a scratch-free and damage-free polishing with high MRRs. In our preliminary study, we developed a prototype PAP machine for polishing of 3 inch wafers and the fundamental polishing characteristics of the PAP machine were evaluated. In this paper, the relationship between the surface morphology of the grinding stone and the MRR of PAP was investigated. Intermittent dressing of the resin bonded grinding stone enabled us to obtain a high MRR of about 200 nm/h for GaN substrate, which was about 2.5 times higher than that of conventional CMP.

GaN, SiC, Plasma-assisted polishing, Pit-free, Damage-free

1. Introduction

Since GaN has a wider bandgap, a higher electric breakdown field strength and a higher saturation speed of electrons compared to Si, GaN is one of the promising materials for next generation semiconductor power devices. Also, since GaN has a direct bandgap, it is widely used as the substrate for light emitting diodes (LEDs). To realize the excellent properties of GaN, the surface of GaN substrate must be scratch-free, damage-free and atomically flat. However, it is difficult to obtain a scratch-free and damage-free GaN surface with high-efficiency using conventional polishing techniques due to its high hardness and chemical inertness. Chemical mechanical polishing (CMP), in which the chemical modification by chemicals in slurry and mechanical removal by abrasives are combined, is widely used for polishing of GaN. Although CMP is widely used nowadays, its material removal rate (MRR) is very low and the costs of slurry and the post-treatment of wasted slurry are expensive, and its influence on the environment has been a big problem. To obtain a scratch-free and damage-free GaN surface with a high MRR, plasma-assisted polishing (PAP) which combined surface oxidation by irradiation of atmospheric-pressure plasma and removal of the oxide layer by soft abrasive polishing was proposed. [1][2]

For polishing of large size wafers, a prototype PAP machine for polishing of 3 inch wafers was developed. In this paper, the relationship between the surface morphology of the grinding stone and the MRR of PAP was investigated.

2. Experimental

2.1. The prototype PAP machine

The prototype PAP machine is consist of a rotary and scanning stage, a pressurizing mechanism, and a hybrid polishing head which combined the electrodes for plasma generation and the grinding stones for polishing.

Figure 1 shows an image of the hybrid polishing head. Since grinding stones and electrodes are alternately arranged, oxidation of the surface by irradiation of plasma and removal of oxide layer by resin bonded grinding stone are simultaneously conducted by rotating the polishing head.

The process gas for plasma generation was introduced from the center of the hybrid polishing head. By applying a RF power (13.56 MHz) between the gap of the electrode and wafer substrate, atmospheric-pressure plasma is generated.

Pressurization is realized using a load cell, a servo motor and three damped springs. Before polishing, the desired pressure is input to the pressure control software. After the wafer substrate has set, the polishing tool moves downward to the substrate in a manual mode. Once the grinding stones are almost in contact with the substrate, the manual approach stops. Then the generation of AP-plasma and the rotation and scanning of the stage and the polishing tool are conducted in order. After that, pressure control starts and the value of the measured pressure on the load cell is reset to zero. The grinding stones move downward to come in contact with the substrate and the pressure gradually increases to the set value.

Figure 1. Photograph of the hybrid polishing head.

Table 1. Experimental parameters.

Sample	3 inch GaN (Epi)
Gas	Ar 10 slm
RF power	18 W
Rotation speed	Stage : 100 rpm, Electrode : 0 rpm
Scanning	Distance : 20 mm, Rate : 10 mm/s
Pressure	30 kPa
Polishing time	5 min
Tool	Resin-bonded SiO_2 grinding stone

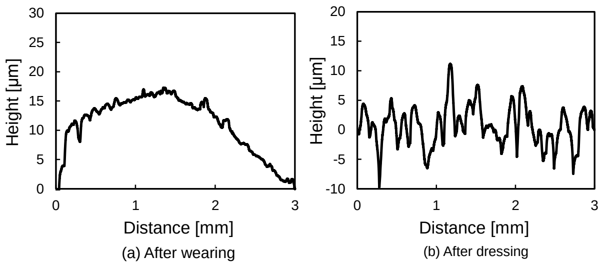

Figure 2. Cross-sectional view of grinding stones.

Table.2 Dressing parameters.

Tool	Diamond plate (#100)
Rotation speed	Stage : 50 rpm, Electrode : 100 rpm
Pressure	10 kPa
Time	30 s

2.2. Experiment methods

Experimental parameters are listed in Table 1. The resin bonded SiO_2 grinding stone was used, and the average diameter of SiO_2 abrasive was about 0.3 μm. To evaluate the relationship between the surface morphology of the grinding stone and the MRR of PAP for GaN (0001) grown on sapphire substrate, different morphologies of the grinding stone were prepared. Figure 2 shows cross-sectional views of two patterns of the morphologies of the grinding stone. Figure 2 (a) shows the morphology of the grinding stone after wearing. Almost no protrusions existed on the surface. On the other hand, Figure 2 (b) shows the morphology of the grinding stone after dressing. Many protrusions can be observed. On the grinding stone surface, the protrusions shown in Figure 2 (b) can be considered to behave as small cutting edges, resulting in material removal during polishing. Therefore, it was assumed that the MRR was greatly affected by the surface morphology of the grinding stone. Thus, the relationship between the two patterns of the surface morphology of the grinding stone and the MRR of PAP was evaluated.

To keep the surface morphology of the grinding stone rough as shown in Figure 2 (b) in polishing, PAP of 10 s and dressing of 30 s were alternately conducted. Dressing parameters are listed in Table 2. The MRRs of polishing of GaN with following conditions were evaluated: dry polishing of GaN using SiO_2 grinding stones without plasma irradiation, PAP of GaN without dressing and PAP of GaN with dressing alternately conducted. The MRRs were calculated from the mass reduction of GaN wafer by polishing.

3. Result & discussion

Figure 3 shows the MRRs of polishing of GaN under different conditions. The MRR of grinding stone polishing without irradiation of plasma was 34.2 nm/h. In contrast, the MRR of PAP

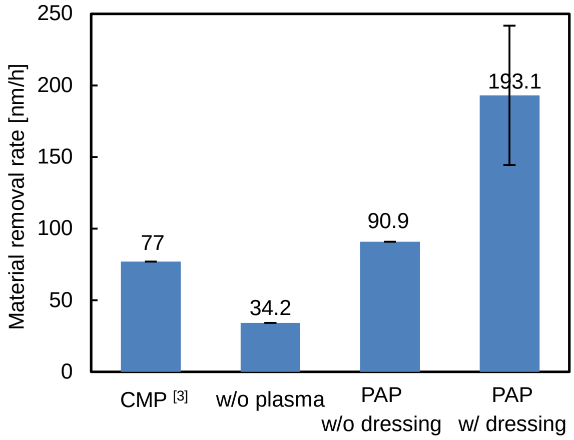

Figure 3. Material removal rate of GaN.

without dressing was 90.9 nm/h. It means that plasma modification was very effective to increase the MRR of GaN. In PAP, water vapor contained Ar plasma was used for surface modification. GaN surface was oxidized to Ga_2O_3 by reaction of OH radicals generated in water vapor contained Ar plasma. Ga_2O_3 was much softer than GaN and easier to be removed by polishing using soft abrasive [2]. Thus, the MRR of PAP was much higher than that of grinding stone polishing without plasma irradiation.

In the case of PAP with intermittent dressing, the MRR was calculated to be 193 nm/h, which was about 2.1 times higher than that of PAP without dressing. This means that dressing is very effective for obtaining a high MRR of GaN in PAP. Also, the MRR of PAP with intermittent dressing was about 2.5 times higher than that of conventional CMP process. In the future, the prototype PAP machine will be optimized to realize *in situ* dressing in PAP. On the basis of the above results, it is strongly expected that a higher MRR can be obtained with the application of in situ dressing, which will be experimentally confirmed in a future study.

4. Summary

Application of plasma-assisted polishing (PAP) was proposed for finishing of difficult-to-polishing materials and a prototype PAP machine for polishing of 3 inch wafer substrate was developed. In this PAP machine, oxidation of the surface by irradiation of water vapor contained Ar plasma and removal of oxide layer by resin bonded silica grinding stone were simultaneously conducted. The relationship between the surface morphology of the grinding stone and the MRR of GaN was investigated. Intermittent dressing of resin bonded silica grinding stone enabled us to obtain a high MRR of about 200 nm/h for GaN (0001) substrate, which rate was 2.5 times higher than that of conventional CMP. We concluded that it was possible for PAP to be an alternative polishing technique of CMP.

Acknowledgments

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