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A Review on the CMP of SiC and Sapphire Wafers

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Abstract. Chemo-mechanical polishing (CMP) has been a useful method to produce superior brittle wafer surfaces. This paper reviews the CMP of silicon carbide and sapphire wafers, focusing on efficiency of the polishing rate. The effects of slurry type, slurry pH value and mixed abrasives will be discussed in detail.

Introduction

Like silicon wafers, SiC and sapphire wafers are also important materials in the semiconductor industry [1-4]. While the CMP of silicon wafers has been investigated relatively more extensively, reports on SiC and sapphire wafers are not so comprehensive. Similar to the fabrication of silicon wafers, the initial polishing of SiC and sapphire wafers has been mechanical which uses hard abrasives (e.g., diamond) to remove materials in surface finish. This process is easy to introduce a damaged subsurface layer. In order to improve the process, CMP has been introduced, in which the key is to promote the combined chemical and mechanical interactions to maximise the material removal rate in polishing and to minimise the possible damages to the wafer. Various CMP methods have been proposed, but the process has been trial-and-error such that the CMP for SiC and sapphire wafers to date is still uneasy to control. This paper aims to provide a relatively comprehensive review on the CMP of SiC and sapphire wafers. Polishing temperature can influence the material removal in CMP; but due to the pages limit, the temperature effect will not be addressed in the present paper.

CMP of SiC Wafers

There are some challenges for an efficient CMP of SiC wafer. One is to produce a damage-free SiC wafer, while having a high material removal rate, because SiC is hard and chemically inert [5].

Additives. To enhance the polishing rate, White et al [6] developed the CMP slurry formulations to polish single crystal SiC wafer. It was reported that slurry without chemicals could provide a material removal rate of 2 nm/h, and slurry without particles could give a polishing rate of 16 nm/h. The combined effect was a polishing rate of 0.2 μm/h with the obtained surface roughness of less than 0.4 nm. Since the slurry composition is commercially confidential, White et al [6] only clarified a number of chemicals, pH and abrasives. Recently, Takemiya et al [7] obtained a much higher removal rate using a polishing compound composed of some colloidal silica particles, an organic solvent, a nitric acid, a citric acid, H_2O_2 and a viscosity additive. The pH was around 12 buffered by KOH. To accelerate the polishing efficiency, diphosphorus pentaoxide was added to the slurry to reach the material removal rate of 6μm/h. However, the surface quality was not mentioned in this patent.

Minamihaba et al [8] studied acid slurry to abrade the SiC surface with colloidal silica abrasives. The acid was selected from the group consisting of an amino acid and an organic acid having a benzene ring and a heterocycle, respectively. With optimizing the particle sizes (5 to 30 nm) and pH values (1 to 12), they claimed that if the primary particle size of colloidal silica exceeded 30 nm, it became difficult to remove SiC effectively. The influence of pH value on the material removal rate indicates that the polishing slurry becomes incapable of material removal as pH fall within the neutral region. Preferable conditions would be in an acidic (pH =1~3) or an alkaline state (pH =8~11). At pH = 10, the polishing rate was the highest (3 μm/h).

Kerr et al [9] provided slurry to produce a smooth, damage-free SiC wafer using ozonated water and hydrogen peroxide in a colloidal silica or alumina solution. It was considered that the dissolved ozone in the slurry was able to promote chemical reactions. The pH was buffered up to 8~14. To enhance the oxidation rate of SiC, the slurry temperature was increased, either by directly heating the slurry through chemical reactions. An acidic or base solution in their polishing process, such as H_2SO_4, KOH and NH_4OH, was added o stimulate an exothermic reaction to increase the temperature at the wafer surface. It was reported that by doing so the polished surface roughness reached 0.33 nm, but the removal rate was not presented. Matsui et al [10, 11] applied oxygen gas or light to the polishing process to promote the oxidation rate of SiC with H_2O_2, and claimed that this method could polish SiC at a low pressure. The surface roughness achieved was on the order of 0.5 nm. However, the material removal rate was not mentioned either.

Use of mixed abrasives. Polishing slurries containing mixed abrasives have become popular to improve the material removal rate and to minimise or eliminate damage. Following the traditional KOH-based colloidal silica CMP process of SiC wafer [12], An et al [13] added NaOCl and diamond abrasives (25nm) to the conventional silica slurry. The pH value was 10.23. The polishing was carried out with the polishing pressure 80 KPa at the platen speed of 120 rpm. It was reported that the oxidizer (NaOCl) promoted the chemical reaction on SiC surface and led to the increase in the thickness of SiO_2 layer. The diamond particles added increased the polishing rate, reaching 0.1 μm/h. The surface roughness of the wafer was around 0.1 nm.

CMP without abrasives. To avoid using abrasives, Lin et al [14] used a metal disc to replace a polymeric pad to polish a SiC wafer in the slurry with water and kerosene. The experimental results demonstrated that using a cast iron or a stainless steel disc could produce a better surface quality than that of using a copper disc. The hardness of a polishing disc was not a dominant factor. They speculated that the iron oxide formed when using ferrous metal discs might reduce the activation energy and thus the threshold temperature of the tribo-chemical reaction between SiC and water. Although this method could avoid chemical pollution, the material removal rate was low, at about

0.06 μm/h, and the surface roughness obtained was high, at about 20 nm. The polishing of SiC wafers using a metal disc is similar to the dynamic friction polishing of diamond and diamond composites [15-17].

CMP of Sapphire

Effective CMP of sapphire wafers is still unavailable [18, 19]. This section reviews some of the current methods.

Slurry. Moeggenborg et al [20] fabricated a sapphire surface in CMP using colloidal silica abrasive particles. The pH value of the slurry was 10~11, adjusted by KOH. Inorganic salt compound, such as NaCl, KI and NaI, was added into the aqueous medium solution. The polishing experiment was carried out on a Logitech CDP machine with the pressure of 79.35KPa at the platen speed of 65 rpm. The removal rate of sapphire was 5.28 μm/h. However, without the salt, the removal rate was reduced to 2.7 μm/h. The surface quality was not mentioned in this patent. Cherian et al [21] also applied the salt-additive to the slurry to promote material removal rate. Zhu et al [22] used an alumina slurry. The experiment was conducted on a precision polishmaster (Stras-Baugh) at the plate speed of 60 rpm with an IC1000 pad (Rodel). The effects of the pH value and pressure were optimized. It was noted that the highest removal rate was approximately 0.89μm/h with a RMS = 0.3 nm in a 20×20 μm area. It was believed that a coupling effect of the chemo-mechanical reaction between the sapphire and alumina accelerated the material removal. However, the performance in terms of material removal rate still needs to be further improved. Wang et al [23] achieved a RMS of 0.23 nm for sapphire wafer by a step-wise technique (CMP plus a subsequent chemical etching); but the removal rate was not mentioned. Sun [24] obtained a destructive removal rate of 7.25μm/h with the pressure of 13.78 KPa and platen speed of 50 rpm at pH = 11. The conductivity of the silica slurry was adjusted by pH value and complex chemicals, such as EDTA. However, the surface quality was not reported.

To enhance the chemical reaction between sapphire and slurry, Liu et al [25] provided a chemical solution composed of a chelating agent, which has 13 EDTA chelate rings such as a mixture of EDTA and KOH, and a strong propensity for complexation with aluminium ions and for forming a water-soluble chelating product. To avoid the damage from the hard abrasives, silica abrasives were used. The experiment results showed that the removal rate was 9.96~18μm/h and the surface roughness was 0.1~0.3 nm. However, the details of the polishing parameters, such as pressure and plate speed, were not mentioned in this patent.

Use of mixed and coated abrasives. Hu et al [26] polished sapphire wafer using micrometer B_4C and nanometer silica abrasives. The pH value was 12, adjusted by NaOH. It was observed that the removal rate was 2.27μm/h at the polishing pressure of 55 KPa and plate speed of 60 rpm, which is comparable to the others published in the literature (e.g., removal rate = 2.4μm/h, pressure = 80 KPa, plate speed = 65 rpm and pH = 10 [27]). The surfaces before and after polishing were characterized by XRD. The full width at half maximum (FWHM) of diffraction peak reduced from

63.8s before polishing to 21.2s after polishing, indicating that the surface quality was remarkably improved. Meanwhile, the RMS was reduced from 99.36 nm before polishing to 0.71 nm after polishing.

Bakshi et al [28-30] developed a slurry mixture composed of silicon carbide and alumina particles with an aqueous medium. When using a platen speed of 400 rpm, the material removal rate reached 11.4μm/h. The surface roughness was sharply reduced after 60 minutes. It was thought that the surfaces of the SiC abrasives were slightly oxidized and, thus, reacted with the sapphire surface to facilitate the material removal. However, since both of the SiC and Al_2O_3 abrasives are hard particles, it is likely that the hardness of the particle promoted the polishing rate of the sapphire wafer. This seems to be aligned with the higher surface roughness (~1nm) after polishing [22, 23, 25].

Apart from the simple mixture of two-types of abrasives, coated abrasives (CAs) were recently proposed for the CMP of sapphire. CAs are synthesized by the following process: (i) adding certain amount of micro hard abrasives, such as SiC, to deionized water, followed by an ultrasound treatment; (ii) adding certain nano soft abrasives, such as silica and ceria, to the suspension obtained in step (i), followed by an ultrasound treatment again; and (iii) adjusting the slurry by chemicals or pH value. Wang et al [31] used the coated abrasives, such as B_4C and SiO_2, B_4C and α-Al_2O_3, B_4C and CeO_2, to polish sapphire wafers to improve the removal rate and surface quality. The experiments were designed on a CMP tester (Cetr CP-4) with the pressure of 70 KPa at the plate speed of 150 rpm. The removal rates of the above three coated-abrasives were 6 μm/h, 10.8 μm/h and 9 μm/h, respectively. Meanwhile, the RMS of the wafer surface after polishing was less than 0.75 nm. Compared to the size of ceria and boron carbide particles, the distance of their interaction in light of chemical bonds and electrostatic force could be ignored. In addition, since the size of boron carbide is much larger than that of ceria, it seems that the ceria particles rightly seats on the surface of boron carbide core. It can be considered that, with the gradual increase in ceria particle on the core particle surface, the interaction between particles becomes more and more complete, leading to a more adequate chemical reaction between the outer ceria particles of the CAs and the sapphire hydration layer formed in CMP. Meanwhile, a severe mechanical tear appeared when using the hard B_4C core. Due to the dualistic function with respect to the direct contact between a soft particle and the sapphire hydration layer and a fierce indirect mechanical removal of hard particle, desired performance in terms of high removal rate and surface quality can be reached.

Concluding Remarks

It is clear that the main strategy to improve the polishing rate and surface quality is to effectively couple the mechanical factors (e.g., polishing pressure, speed, abrasive hardness and size) with the chemical ones (e.g., oxidizers, pH). However, the usage of chemicals leads to pollution.

Damage-free polishing without using any chemicals has been successfully demonstrated in polishing silicon wafers [32], where the mechanism is the re-crystallisation [33]. We believe that to achieve damage-free polishing without chemicals for SiC or sapphire wafers, methods based on different mechanisms must be established. Fundamental investigations into the mechanisms of material removal and subsurface damage [34-37] will be useful.

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