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High Precision Finishing Process for Sapphire Substrate Surface*

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Abstract: We studied the design of experiments in order to obtain optimized chemical mechanical polishing (CMP) equipment variables and treated sapphire substrate surfaces using the CMP method on a C6382I-W/YJ single side polisher. According to sapphire substrate and its product properties, we chose alkali slurry and took SiO_2 sol as abrasive. Various process parameters, such as table speed, slurry flow rate, temperature and down force, were investigated from the viewpoint of high removal rate. Through the experiment results, we determined the optimal CMP process parameters.

Key words: sapphire substrate; high precision finishing; chemical mechanical polishing; alkali slurry; process
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1 Introduction

Sapphire (α-Al_2O_3) single crystal combines many good mechanical and optical properties[1~3] that make it the material of choice in a variety of modern high-technology applications such as space and military optical systems, high-power laser optics, blue emitting diodes, laser diode devices, visible-infrared windows, substrates for semiconductor devices, and high-pressure components. In addition, (0001) sapphire crystal wafers can be used as substrates for growing photoelectric materials such as GaN thin films[4]. Sapphire wafer is also widely used for GaN-based III-nitride device fabrication[5].

In many of these applications, there are stringent requirements for the surface quality of the wafer in terms of finish and flatness. The generation of high-quality surfaces with a fine surface finish and low surface and subsurface damage is also important. The crystal structure of epitaxial films is strongly influenced not only by the substrate material and its orientation, but to a great extent also by the surface quality of the substrate[6]. The cost of fine surface machining and polishing of ceramics for opto-electronic applications may exceed 80% of the total production cost. The use of chemically assisted polishing techniques such as chemical mechanical polishing (CMP) may produce high quality surface finishes at low cost and with fast material removal rates[7]. CMP has been widely and effectively applied to a variety of materials in the last two decades, including semiconductors, crystals, glasses, special metals, plastics, and computer disks. CMP is becoming popular because of the advantages of CMP over other surface finishing techniques: little or even no surface and subsurface damage, elimination of surface defects, high removal rates, high efficiency, and low cost[6~10].

However, many ceramics such as sapphire are noted for wear and corrosion resistance due to their high chemical and thermal stability and high hardness, and in many cases effective CMP processes are not available or not understood[11~13]. In particular, among the CMP components, process variables are very important parameters in determining the removal rate. In this paper, we report the design of experiments in order to obtain optimized CMP equipment variables (downforce, slurry flow rate, table speed and temperature) and the treatment of sapphire substrate surfaces using the CMP method. According to the experiment results, we determined the optimal CMP process parameters.

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2 Material preparation and experiment

2.1 Material preparation

The sapphire crystals were obtained by the Czochralski (CZ) method. Their diameter was 50mm. The crystals were grown using a [0001] direction seed under a high pure flowing argon gas atmosphere with a pulling rate of 1.5～2mm/h and a rotation rate of 10～30r/min. After the edges were rounded, the sapphire crystal wafers, with the thickness of 0.4mm, were cut perpendicular to the growth direction from the equant section of crystal-bar for testing. The surfaces were lapped using diamond powders and polished by chemical mechanical polishing (CMP).

2.2 CMP experiment

The CMP experiment was performed on a C6382I-W/YJ single side polisher. We chose alkali slurry and took nano-SiO_2 solution as abrasive. The particle size was 15～25nm, as measured by a Malvern Zeta Sizer HS3000 particle size analyzer. The parameter ranges of design for the optimized process were as follows: down force 0.10～0.18MPa, table speed 30～60r/min, slurry flow rate 100～200mL/min, and temperature 25～50℃. When studying the influence of one of the factors on removal rate, the other factors were kept at the center point. The polishing time was 30min each time. The aim of designing the CMP experiment was to determine the change of removal rate caused by different down forces, table speeds, slurry flow rates, and temperatures, and to determine the optimized process parameters.

3 Results and discussion

The most frequently referenced expression for polishing rate is the Preston equation: $RR = KPS$[14], where RR is the removal rate, P is the down force, S is the relative velocity of the polishing pad and the wafer, and K is the Preston constant. This equation mainly shows the influence of mechanical action caused by down force, rotation speed, pad, and other factors that affect the polishing rate. It only presents the relation between removal rate and down force or rotation speed through mechanical action. But from the experiments, we find that the polishing rate is not the simple sum of mechanical and chemical action, but $V_t \gg V_m + V_c$. Thus we can see that CMP is a complex reaction process. The key of determining the optimized process (down force, slurry flow rate, table speed, and temperature) is to achieve a high removal rate and surface quality.

3.1 Down force

Polishing pressure or down force is an important parameter in the polishing process. Figure 1 shows the removal rate variation as a function of down force. According to the Preston equation, as the down force increases, the polishing rate also increases. But from Fig. 1 we can see that at a certain pressure range, the removal rate linearly increases with increasing down force. When the pressure is over 0.14MPa, the removal rate decreases linearly. The reason is that with increasing pressure, friction action is enhanced, which causes the temperature between the wafer and pad to rise, and then the chemical action is enhanced. But the slurry content between the wafer and pad decreases when the pressure reaches a certain value, which influences the transmission action of slurry. Then the reaction product cannot break away from the finished surface, which holds back the chemical action process. Then the mechanical and chemical action cannot reach a balance, and the slow process (mechanical process) takes the control of action, leading to a decreased removal rate. From Fig. 1 we can see that with a down force of 0.14MPa, we obtained a relatively high removal rate of 15μm/h, which is satisfactory for sapphire CMP characteristics.

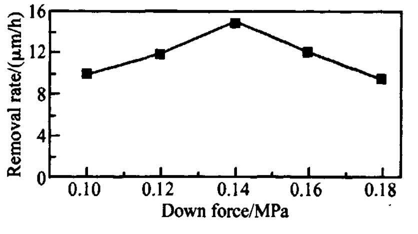

Fig. 1 Removal rate as a function of down force

3.2 Slurry flow rate

Figure 2 shows the removal rate as a function of slurry flow rate. The slurry flow rate changes from 120 to 200mL/min. As the slurry flow rate increases, the removal rate increases and then decreases slightly. In other words, the excess slurry supply deteriorates the removal rate. With increasing slurry flow rate, the transmission action of the slurry is enhanced. With the reaction product breaking away from the wafer surface, a part of the slurry flows away too and there is no action with the wafer, which leads to a slight decrease in the removal rate. From Fig. 2 we can see that with a slurry flow rate of 150mL/min, a relatively high removal rate of 13.6μm/h is obtained. Although a high slurry flow rate can result in a relatively high removal rate, it also leads to the waste of slurry and increasing cost. We choose a slurry flow rate of about 150mL/min as the optimized value.

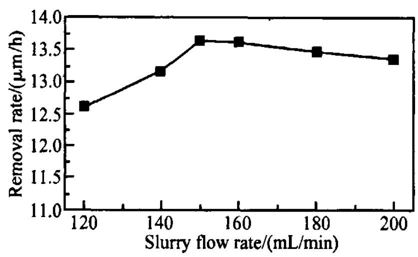

Fig. 2 Removal rate as a function of slurry flow rate

3.3 Table speed

Table speed is also an important parameter in the processing of sapphire, which influences the speed of reaction product breaking away from the wafer surface and surface quality. Figure 3 shows the removal rate as a function of table speed. The table speed changes from 30 to 60r/min. With increasing table speed, the removal rate linearly increases. For a table speed of 60r/min, the removal rate can reach about 15μm/h. With increasing table speed, the friction force between the wafer and pad increases, which induces mechanical action enhancement and a rise in temperature. As the temperature rises, the chemical reaction velocity increases. At the same time, the mass transport is increased. The increased mass transport and mechanical and chemical action leads to an increase in the removal rate. Thus we choose 60r/min as the optimized value.

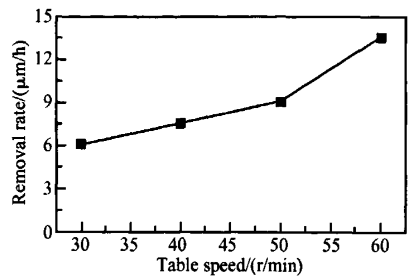

Fig. 3 Removal rate as a function of table speed

3.4 Temperature

Polishing temperature takes more important action in the CMP process. It influences the chemical action as well as the mechanical action. Figure 4 shows the removal rate as a function of polishing temperature. The range is from 25 to 50℃. With increasing polishing temperature, the chemical reaction rate increases. Chemical and mechanical action reaches equilibration gradually. Then the increasing of the removal rate becomes milder. Thus we choose a polishing temperature of 45℃ as the optimized value.

Table 1 summarizes the optimized process variables obtained by the designed experiment.

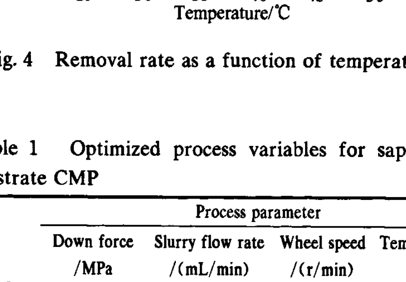

Fig. 4 Removal rate as a function of temperature

Table 1 Optimized process variables for sapphire substrate CMP

	Process parameter			
	Down force /MPa	Slurry flow rate /(mL/min)	Wheel speed /(r/min)	Temperature /℃
Optimum value	0.14	150	60	45

4 Conclusion

The process variables of the CMP equipment were apparently dependent on removal rate and surface quality. In this paper, according to the characteristics of sapphire substrate material, we finished the sapphire substrate using the CMP method on a C6382I-W/YJ single side polisher. The slurry is alkali and the abrasive is nano-SiO_2 sol. Under the designed experimental condition, we obtained a relatively high removal rate of over 10μm/h and the optimized process variables of a down force of 0.14MPa, wheel speed of 60r/min, slurry flow rate of 150mL/min and temperature of about 45℃, which will contribute to advanced CMP process developments because it can save cost and time due to trial and error.

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蓝宝石衬底表面的高精密加工工艺*

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摘要: 为了获得优化的CMP参数变化,对实验进行了设计,并采用CMP方法在C6382I-W/YJ单面抛光机上对蓝宝石衬底表面进行了加工.根据蓝宝石衬底特性,选择了碱性抛光液,并选用SiO_2胶体作为磨料.依据高去除的目的,对如底盘转速、抛光液流量、温度及压力等不同工艺参数进行了研究.根据实验结果,确定了蓝宝石衬底表面的CMP最佳工艺参数.

关键词: 蓝宝石衬底; 高精密加工; 化学机械抛光; 碱性抛光液; 工艺
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