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Contribution of ultrasonic traveling wave to chemical–mechanical polishing

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ABSTRACT

The ultrasonic vibrators are introduced into the chemical–mechanical polishing devices, and in this polishing system, the ultrasonic vibrators generate ultrasonic traveling wave and keep coaxial with the polished silicon wafer rotating at given speed so as to compare the texture of the polished silicon wafers. And the experiments on the chemical–mechanical polishing with assisted ultrasonic vibration are accomplished in order to investigate the effect of the ultrasonic vibration on the chemical–mechanical polishing. Via comparing the roughness average of the two silicon wafers polished with assisted ultrasonic vibration and without assisted vibration, it is found that the morphology of the silicon wafer polished with assisted vibration is superior to that without assisted vibration, that is, this series of experiments indicate that the ultrasonic vibration is beneficial to the chemical–mechanical polishing. Aiming at understanding the contribution of the ultrasonic vibration to chemical–mechanical polishing in detail, the model of the chemical–mechanical polishing with the assisted ultrasonic vibration is built up, which establishes the relationship of the removal rate and the polishing variables such as the rotary speed of silicon wafers, the amplitude and the frequency of vibrators, the particle density of polishing slurry and the characteristics of polishing pad etc. This model not only could be used to explain the experimental results but also to illuminate the roles played by the polishing variables.

1. Introduction

The chemical–mechanical polishing is a physicochemical process used to make wafer surfaces locally and globally flat [1]. It can be regarded as a hybrid of chemical etching and free abrasive polishing. With the development of semiconductor technology, it has been accepted wildly [2], and as the rising of ultra large scale integration chips in recent years, it gains ever increasing attentions [3] and appears to be the only available method for global planarization [4,5]. In order to widen the application area and lower the manufacturing cost of chemical–mechanical polishing, many scholars have made efforts to research this polishing technology experimentally and theoretically [6–11], to date, it is also the point at issue [4,12].

Generally, in process of chemical–mechanical polishing, the slurry with abrasive particles suspending makes the surface of the polished object produce chemical change and the relative movement between the polishing pad and the surface of the polished object also makes the abrasive particles grind the surface of the object [13]. These two processes are the main mechanism of the chemical–mechanical polishing. Thus, the variables describing this system roughly consist of the following four categories, namely, tool process parameters, wafer variables, slurry variables and pad variables. The tool process parameters include pressure applied to the wafer and pad, relative speed between wafer and pad, polishing time, etc; the wafer variables refer to film type and pattern density; the slurry variables involve chemistry, particle size, and other properties; and the pad variables are hardness, roughness, and other properties of the pad [14]. The further development of the chemical–mechanical polishing requires an insight into the roles played by these parameters in the polishing process, which is still ongoing work at this moment [4,12] and also the aim of this paper.

The engineering application of ultrasonic technology arose in 1920s [15], it is the synthesis technology consisting of the electric technique, measurement technique, mechanical vibration and material science etc [15]. It has been attempted for many years to introduce the ultrasonic technology into the process of the hard and brittle material's planarization [16–19]. The early ultrasonic machining mostly relies on the ultrasonic vibration of the

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instrument which makes the suspending abrasive particles gain sufficient energy to impact the polishing object aiming at removing the rougher part of the surface. But the efficiency of this type of technology is very low. In recent years, a type of advanced instrument combining the vibration of ultrasonic frequency and the rotation at high speed of 1000–5000 r s^{-1} came into being, which have been wildly applied in the areas of aviation and atomic energy [16,17]. Then more and more technologies of the ultrasonic combined machining emerge in response to the need of times, which are regarded as the most effective method to machine the hard and brittle material and rapidly become a research hotspot [20,21]. The chemical–mechanical polishing with ultrasonic vibration assisted discussed in this paper just belongs to this type of technology.

As a promising polishing technology, the chemical–mechanical polishing with ultrasonic vibration assisted has become an important subject of many researchers and be applied to the polishing of silicon wafer, copper and sapphire and so on [22–25]. However, at present the effects of the ultrasonic vibration on the polishing process are still being discussing on basis of the experimental researches, and there is not an exhaustive theory to analyze the roles played by the ultrasonic vibration in the chemical–mechanical polishing so far. In this paper, the experiments of chemical–mechanical polishing with assisted ultrasonic vibration is analyzed, and the roughness average of the silicon wafers polished with assisted ultrasonic vibration was compared with that without assisted vibration so as to investigate the role played by the ultrasonic vibration. In addition, the contribution of the ultrasonic vibration to the chemical–mechanical polishing is also theoretically analyzed in detail, and it is found that the theoretical results qualitatively agree with the experimental results.

2. Experiments

2.1. Experimental devices

Aim at investigating the contribution of the ultrasonic vibration to the chemical–mechanical polishing, the author's team conducted a series of polishing experiments. In these experiments, the ultrasonic vibrators are introduced into the chemical–mechanical polishing system. The polishing effect with assisted ultrasonic vibration was compared with that without assisted vibration, so as to analyze the role of the ultrasonic vibration in the chemical–mechanical polishing.

The polishing experiments were accomplished on the precise grinding and polishing machine UNIPOL-802, as shown in Fig. 1. During polishing, the silicon wafer fixed on the platen rotates synchronously with the platen, and the polishing pad adheres to the working face of vibrator which generates ultrasonic traveling wave without macroscopic rotation and swing. The polishing slurry is injected into the area between the silicon wafer and the polishing pad in advance, and further injected into the polishing pad in the process of the polishing experiment. The gravity of the vibrator and the weights serves as the polishing normal force, which can be precisely measured. Considering that the polishing pad and the vibrator must not rotate freely due to high-frequency voltage loaded on the vibrator, three clamps are used to ensure that vibrator don't rotate and swing. The axis of the vibrator approximately coincides with the axis of the silicon wafer in order to compare the polishing texture of the corresponding area. The other conditions of these experiments are listed in Table 1.

2.2. Experimental results

The first experiment is conducted to investigate the polishing effect varying with the measured sites. In this experiment, the vibrator is shown as Vibrator I in Fig. 1, which has a diameter of 0.02 m and could generate a traveling wave composed by a series of second-order bending vibrations and a series of first-order longitudinal vibrations. During experiment, the input voltage is 100 V, the frequency is 27.99 kHz, the polishing normal force is 8.212 N, the rotary speed is 60 r min^{-1} and the polishing time is 4 min. The morphology of the silicon wafers polished with assisted ultrasonic vibration and without vibration is both measured by NV5000 5022S 3-D surface profiler, and the schematic diagram of the measured sites is shown in Fig. 2. The effective measurement

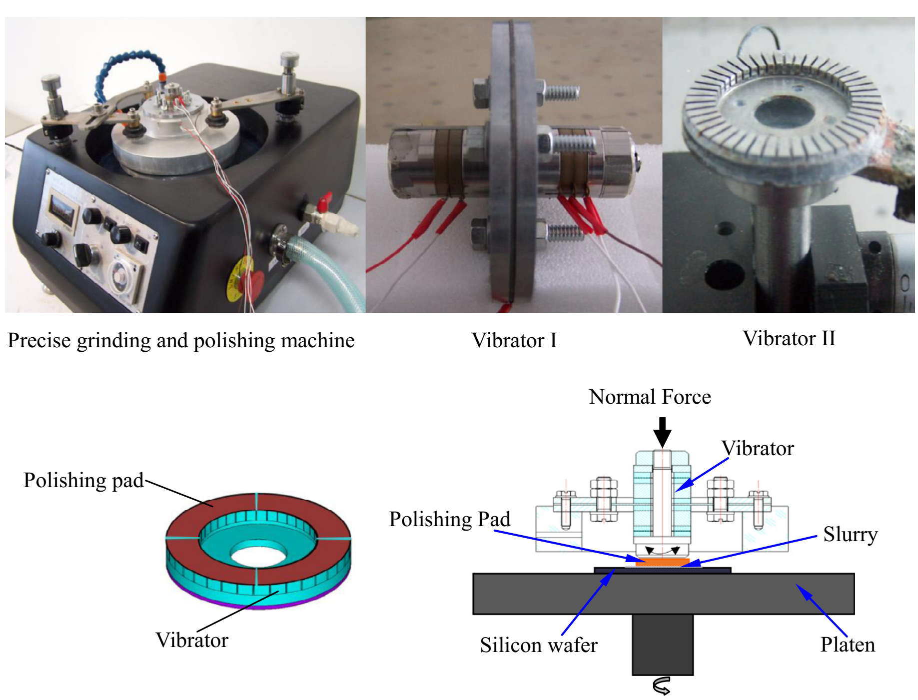

Fig. 1. The photos and schematic diagrams of the experimental devices.