Tribology International 105 (2017) 37–41

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Comparative study of the lubricating behavior between 12-in. copper disk and wafer during chemical mechanical polishing

Dewen Zhao, Yongyong He, Tongqing Wang, Xinchun Lu[*]

State Key Laboratory of Tribology, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Keywords:
Chemical mechanical polishing
Hydrodynamic lubrication
Carrier structure
Fluid pressure

ABSTRACT

In this study, a specially designed carrier with a one-zone pneumatic loading system that uses a thick copper disk as the workpiece was developed. Comparative studies of the fluid pressure and workpiece orientation between the disk and wafer carriers during chemical mechanical polishing were conducted. The results reveal that the copper disk leans down toward the leading edge and produces a negative-dominated (approximately 70%) fluid pressure, which differs from the multi-zone carrier but agrees with other studies in which the fluid pressure is measured from the disk side. Different balancing statuses and wedged gaps are formed in these two structures.

1. Introduction

Chemical mechanical polishing (CMP) has become one of the crucial processes in the manufacture of multilevel integrated circuits (IC), the purpose of which is to produce a smooth and global planar surface for the wafer [1]. Fig. 1 illustrates the schematic diagram of CMP [2]. A carrier with a wafer chucked in and a platen with a pad pasted on the top surface rotate in the same direction to generate a relative motion. During CMP, the slurry injected to the top surface of the pad enters into the wafer–pad interface. The chemicals and particles in the slurry produce a chemical–mechanical action on the wafer surface and promote the material removal at the wafer surface. Besides, the slurry causes a fluid lubrication effect on the wafer–pad interface [3,4].

In our previous studies [5–7], we have developed an in situ measurement system for a 12-in. CMP equipment. We used ten pressure sensors and five distance sensors to monitor the interfacial fluid pressure and the wafer orientation, respectively (Fig. 2b). The sensors are embedded in the platen, and the measurement system is integrated into a self-developed 12-in. CMP equipment (Fig. 2a). When the sensors rotate beneath the wafer surface, they measure the fluid pressure and wafer orientation across the entire surface of the wafer. The details of the in situ measurement system and measurement method can be obtained from our previous papers.

Using the above measurement system, we observed a fluid pressure distribution different from that of the disk during the CMP process of a 12-in. wafer with a multi-zone carrier. The results reveal a positive-dominated fluid pressure at the wafer–pad interface [5], which differs from some simulation results [8,9] and other simplified test rigs that use a disk as the polishing head (carrier) and measure the fluid pressure from the disk side [10–12]. Conversely, a negative-dominated fluid pressure was observed at the polishing interface using the simplified test rigs. We suggested that the structure of the carrier and the workpiece might be the cause for the difference. However, the idea was not proved because our measurement system was integrated into a large industrialized CMP equipment; it is quite difficult to use a disk directly as the polishing head.

To confirm the results of our previous studies further and to reveal the mechanism of fluid lubrication during CMP, a special carrier was designed based on the multi-zone carrier and its loading system. Thicker copper disk which is more rigid than thin wafer was used as the workpiece. This paper gives a comparative study of the fluid lubrication behavior between two different carrier structures using the same measurement system.

2. Experiment

2.1. Comparative measurement system

Fig. 3b illustrates the schematic view of the carrier structure used in our previous studies. It has a five-zone pneumatic loading system and a floating retaining ring. A flexible five-zone membrane loads the back surface of the wafer using compressed air. This type of carrier is normally used in industries as it can apply different pressures to each zone to obtain a better polishing uniformity [13]. Fig. 3a illustrates a specially designed carrier, which has a single zone pneumatic loading

---

[*] Corresponding author.
E-mail address: xclu@tsinghua.edu.cn (X. Lu).

http://dx.doi.org/10.1016/j.triboint.2016.09.019
Received 14 June 2016; Received in revised form 9 September 2016; Accepted 12 September 2016

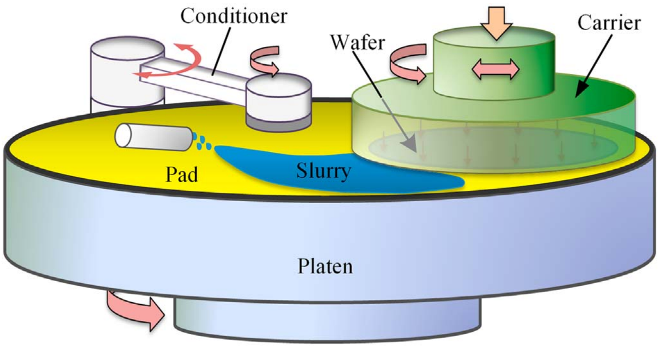

Fig. 1. Schematic diagram of chemical mechanical polishing equipment.

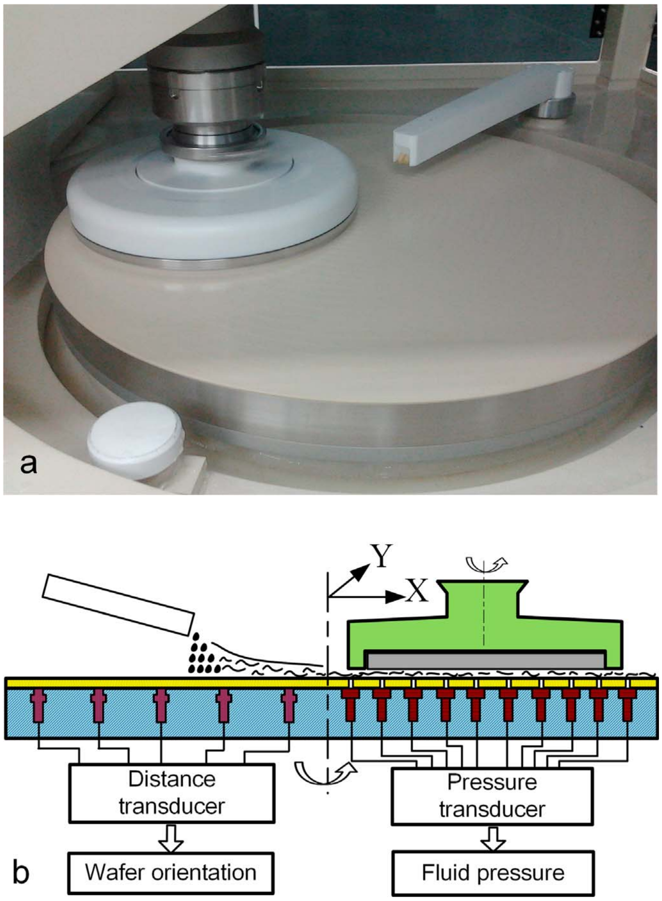

Fig. 2. In situ measurement system integrated in 12-in. CMP equipment.

system and uses a copper disk as the workpiece. A flexible ring is used to connect the disk to the base plate of the carrier. As a result, a cavity is formed between the disk and the base plate, and the compressed air can be applied to the back surface of the disk.

A flat copper disk of diameter 300 mm and thickness 10 mm was machined, as shown in Fig. 4a. The top surface of the copper disk was grinded and polished to a flatness of 2 µm. Although the elastic modulus of copper is much smaller than silicon, adequate thickness make the copper disk be much more rigid than the wafer. The copper disk and the carrier with a one-zone pneumatic loading system (Fig. 4b) were assembled. The same retaining ring was used to surround the copper disk. Further, the new carrier and the spindle were assembled for replacing the multi-zone carrier (Fig. 4c). The diameter and height of the new carrier were the same as that of the traditional carrier. The rotation and loading abilities were tested, and it was observed that the new carrier functions well compared to the traditional carrier.

2.2. *Experiment condition*

To ensure the same polishing pressure in the two carrier structures, the pressure induced by the weight of the disk was deducted from the loading pressure. As the distance sensors use the eddy current effect to detect the distance between the sensor and the metal layer, deionized (DI) water was used as the slurry to eliminate the influence of the material removal of the metal layer on the distance measurements.

A silicon wafer of thickness 750 µm deposited with a blanket copper layer of 2 µm was used in the multi-zone carrier. All the experimental parameters were set to be the same for the two carriers. The polishing pressure was 0.5 psi (3.5 kPa), the ring pressure was 3.5 psi (24 kPa), the rotating speed of both the carrier and platen was 80 rpm (the relative speed was approximately 1.7 m/s and uniform across the wafer surface [14]), and the slurry flowing rate was 250 mL/min. The fluid pressure and the wafer orientation were measured during each rotation. After data processing, the desired data across the wafer surface can be obtained. The details of the data processing can be obtained from our previous studies [5,6].

3. Results and discussion

3.1. *Comparison of fluid pressure distribution*

Fig. 5a illustrates the contour maps of the fluid pressure distribution. When the disk slides against the polishing pad, approximately 70% of the contact region has a negative pressure. The trailing edge has a slightly positive pressure. The maximum negative pressure is approximately −1.2 kPa, and the average pressure across the entire contact region is −0.24 kPa. The result is quite different from that of the previous study which tested the wafer when sliding against the pad using a multi-zone carrier, in which the positive pressure occupies the majority of the contact region (approximately 70%, see Fig. 5b). In the case of the wafer and disk, although the ratios between the negative and positive pressures are different, the locations of the high-pressure and low-pressure regions are similar.

For a better comparison, Fig. 6 illustrates the pressure curves along the arrows in Fig. 5 from the leading edge to the trailing edge. The pressure trend is similar in both the cases—negative pressure appears

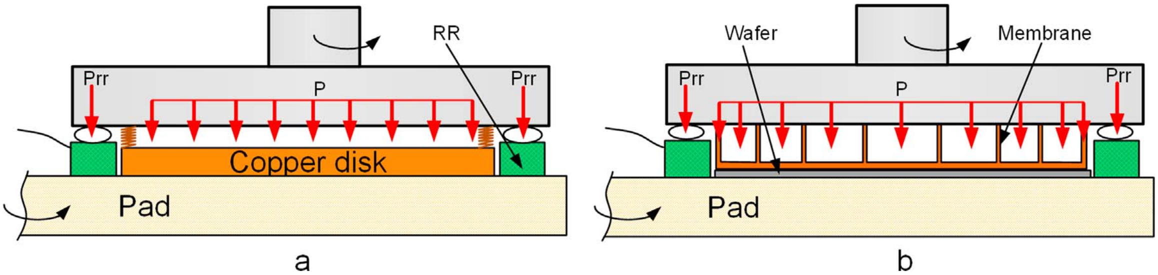

Fig. 3. Comparison of carrier structures: (a) simplified carrier with a single zone using a disk as the workpiece, and (b) industrialized five-zone carrier.