Microelectronic Engineering 149 (2016) 37–40

Contents lists available at ScienceDirect

Microelectronic Engineering

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

Method for accelerated diamond fracture characterization in chemical mechanical planarization

Ruochen Han [a,*], Xiaomin Wei [a], Yun Zhuang [a,b], Yasa Adi Sampurno [a,b], Ara Philipossian [a,b]

[a] Department of Chemical and Environmental Engineering, University of Arizona, 1133 E James E. Rogers Way, Tucson, AZ 85721, USA
[b] Araca, Inc., 2550 East River Road, Suite 12204, Tucson, AZ 85718, USA

ARTICLE INFO

Article history:
Received 8 April 2015
Received in revised form 14 September 2015
Accepted 14 September 2015
Available online 15 September 2015

Keywords:
Diamond fracture
Aggressive diamond
Chemical mechanical planarization

ABSTRACT

An accelerated method for diamond fracture characterization in chemical mechanical planarization processes was developed and several practice examples were described showing that the accelerated fracture test was appropriate for differentiating among typical diamond conditioner disks. First, the top ten aggressive diamonds for each of the three conditioner disks tested were identified and imaged using scanning electron microscopy (SEM). Next, the three disks were subjected to a 30-min accelerated fracture test against an aluminum plate on an Araca APD-800 polisher. SEM images were taken again on the same ten most aggressive diamonds. Even though the accelerated fracture test was designed to be analogous to conventional pad conditioning, significant changes to the diamonds could be seen only after 30 min of conditioning. Image analysis demonstrated that diamond fracture occurred in all three cases, but to very different extents.

1. Introduction

Chemical mechanical planarization (CMP) has been widely used in the integrated circuit (IC) manufacturing industry to achieve both local and global planarities. In CMP processes, diamond conditioner disks are used to regenerate pad asperities and remove used slurry and pad debris from the pad surface [1–3]. During pad conditioning, diamonds embedded in the disk plow and cut the pad surface to impart and maintain adequate pore structure and surface roughness. Physical contact with pad asperities and slurry abrasives causes the diamonds to wear thus leading to a drop in the cutting effectiveness of the disk. More importantly, any possible diamond pull-out, fracture and associated debris and fragments are known to cause catastrophic scratches on the wafer surface.

In general, the useful life of a diamond conditioner disk is about 100 h [4]. Mechanisms that determine end-of-life for conditioner disks include diamond micro-wear, partial fracture and complete pull-out. Previously reported work on diamond fracture describes a high-pressure water jet employed to demonstrate the failure mechanism in the diamond bonding and to quantify the effective strength of the bond [5]. Subjecting individual diamonds to a "pick" test is another method for measuring the force necessary for diamond pull-out which involves the release of a particular diamond from its bond matrix [5]. Tan and Cheng [6] conducted a wear–corrosion test on three types of conditioners. All disks were first immersed in a slurry with pH value of 7.7 for 50 h and then polished against Al_2O_3 rings. Results showed that electroplated disks were prone to diamond loss while brazed disks left the diamonds intact. It is important to note that all of the above studies focused on diamonds in general and made no effort to isolate and study whether any of these diamonds were "active" or "inactive" as described below.

In a recent work, Borucki et al. [7,8] found that among the several tens of thousands of diamonds present on the surface of a conventional diamond conditioner, the percentage of "active diamonds" (*i.e.*, those diamonds that actually work and do the pad cutting) was typically less than 1%. The remaining diamonds, which either did not touch the pad surface or merely supported the load of the disk, were referred to as "inactive diamonds". The work also reported that all "active diamonds" were not the same as only a small fraction of them, referred to as "aggressive diamonds" did more than 80% of the cutting of the pad.

Borucki's work underscored the importance of undertaking a new study to investigate and quantify whether and how "aggressive diamonds" maintain their integrity during pad conditioning and the extent of pull-out, fracture and micro-wear that may happen during CMP processes. However, as one may expect, any such studies would have to last 100 or more hours in order to see any appreciable micro-wear or fracture on the diamonds, which would be quite costly in terms of consumables and time, and also impractical. As such, instead of using a polishing pad, this study employs a pad-sized thin aluminum plate as the surface of contact with the diamond conditioner disk. Details of the aluminum plate and the procedures and equipment involved in the accelerated fracture tests are described in the next section.

* Corresponding author at: Department of Chemical and Environmental Engineering, University of Arizona, USA.
E-mail address: hanr@email.arizona.edu (R. Han).

http://dx.doi.org/10.1016/j.mee.2015.09.006
0167-9317/

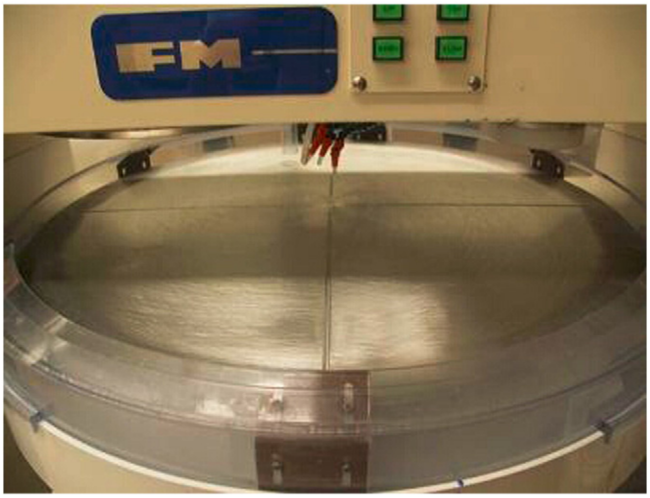

Fig. 1. The aluminum plate attached to the Araca APD-800 polisher's platen.

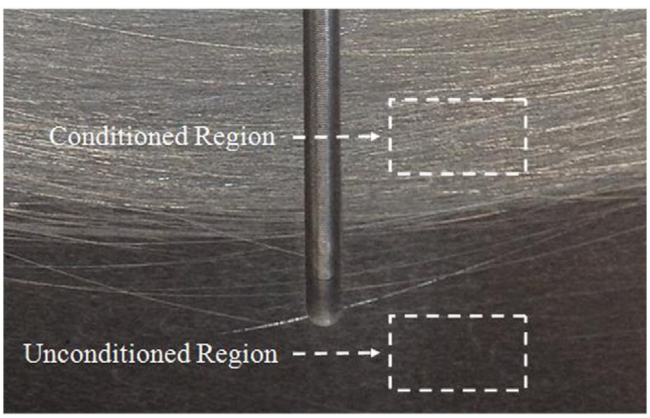

Fig. 2. Examples of conditioned and unconditioned regions of the surface of the aluminum plate.

2. Experimental

All accelerated fracture tests were performed on an Araca APD-800 polisher. The polisher and the associated accessories have been described in details elsewhere [5,9]. A thin aluminum plate (34 in. in diameter) was used instead of a polishing pad. Four grooves (1 mm in depth) were machined in a cross-shaped pattern on the surface of the aluminum plate as shown in Fig. 1. The plate was attached to the platen with a Dow® Electronic Materials Suba™ IV sub-pad such that the plate covered the entire surface of the platen. Prior to each accelerated test, the aluminum plate was conditioned with a 3 M A165 diamond disk and deionized water at a flow rate of 300 mL/min for 10 min. The conditioner rotated at 95 RPM and oscillated 10 times per minute with a down force of 44.5 N. The rotational rate of the platen was kept constant at 42 RPM. Both platen and conditioner rotated in a counter-clockwise fashion. This break-in step was done prior to performing any accelerated fracture tests. Its purpose was to keep the aluminum plate encountered by each subsequent diamond conditioner disk (*i.e.*, the disks that were to be tested for diamond fracture) at a similar surface micro-texture (*i.e.*, roughness). Fig. 2 shows the differences between the typical surface of a conditioned (*i.e.*, broken-in) region of the plate as well as a non-conditioned region where break-in was not done.

The same rotational rate and oscillation frequency, as well as down force, were used for the accelerated fracture tests. After the 10-min break-in, the 3 M A165 diamond disk was replaced with one of the three different types of disks to be tested. Prior to installation of each disk, the top ten aggressive diamonds were identified and imaged using SEM. The aggressive diamond identification process has been described in details elsewhere [4]. Next, each disk was subjected to a 30-min accelerated test with deionized water and SEM images were taken again on the same ten most aggressive diamonds. It should be noted that among the three diamond conditioner disks (referred to as disks D1, D2 and D3) tested in this study, disks D1 and D2 were the same type of disks as investigated in a previous study [1], which showed that disk D1 had minor substrate corrosion and micro-wear on the aggressive diamonds' cutting edges while disk D2 had significant substrate corrosion and aggressive diamond fracture after 24-h static etch and wear tests. For purposes of comparison, two inactive diamonds were also randomly selected from each disk and imaged using SEM before and after each test.

3. Results and discussion

Fig. 3(a) and (b) shows the SEM images of an aggressive diamond for disk D1 before and after the accelerated 30-min test. It can be seen that this particular aggressive diamond has undergone a major fracture as the bulk of the protruding diamond above the surface of the disk substrate which has gone missing after the test. On the other hand, the embedded part of this aggressive diamond remains in the disk substrate, suggesting that the bond between the aggressive diamond and substrate is sufficiently strong to prevent the diamond from being fully pulled out from the disk substrate.

Among the ten most aggressive diamonds, five of them show similar major fractures after the accelerated test. The remaining five aggressive diamonds, however, show minor fractures. As an example, Fig. 4(a) and (b) shows the SEM images of an aggressive diamond with a minor fracture. The bulk of the diamond remains unchanged while the tip of the diamond is fractured as indicated by the white dashed circle in Fig. 4(b). The reason that fracture occurs on all of the ten aggressive

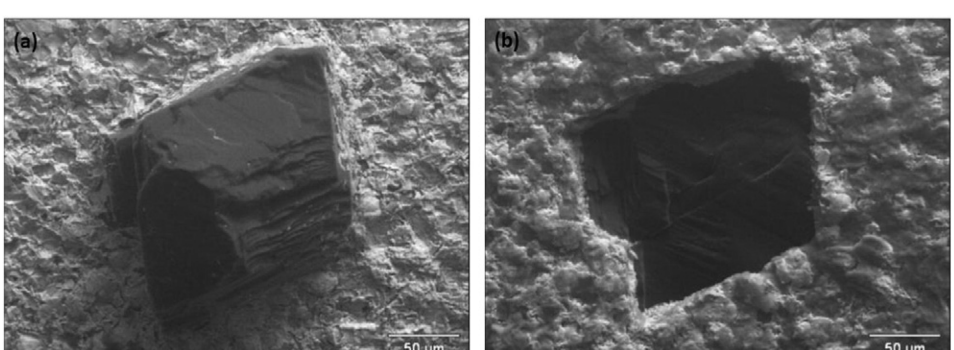

Fig. 3. SEM images of an aggressive diamond of disk D1: (a) before and (b) with a major fracture after the accelerated test.