Effect of skin layer of PVA brush on static and dynamic contact area during post CMP cleaning

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INTRODUCTION

The post-CMP cleaning process is one of the most critical steps in semiconductor device manufacturing. Among several types of post-CMP cleaning processes, polyvinyl acetal (PVA) brush cleaning has been widely used in industries due to its better cleaning performance as a result of the physical forces imposed by direct contact between the brush and wafer surface [1]. The contact condition between the PVA brush and the scrubbing surface has paramount importance, which affects the cleaning mechanism and particle removal efficiency (PRE) of the substrate. Mainly with and without skin layer brushes are commonly used in brush scrubbing processes. However, in this study, we modulated the real contact area evaluation method between different types of brush nodules (skin and without skin layer, and half-cut) and scrubbing surfaces under actual operating conditions using high-speed photography, and data were analyzed by MATLAB. The effect of rotation of brush nodules and gap distance on real-time contact area during brush scrubbing was evaluated. It was found that the contact area with surfaces is highly dependent on the PVA brush surface topography and gap distance. This study aims to understand the role of PVA brush integrity and lifetime in the process of post-CMP cleaning.

BACKGROUND

Polyvinyl acetal (PVA) brush is composed of soft polymer material and a porous-like structure that is hydrophilic and can absorb a significant amount of water due to molecular structure and capillary action [1-2]. Based on the nature of the skin, the two major classes of brush used in the post-CMP cleaning process are with and without skin [1]. The post-CMP cleaning plays a crucial role in semiconductor device cleaning to remove CMP residual components and different types of particle contaminants from the surfaces. The efficiency of the post-CMP cleaning process greatly depends on the contact area between the brush and wafer surfaces [3].

The real-time contact area between the PVA brush and the surface can be studied with the help of images captured by passing the collimating LED light through a prism [4]. The actual contact area between the PVA brush and substrate can be analyzed from the brightness of the images captured by a high-speed camera. However, the brightness of the image depends on the light source brightness and recording conditions [5-6]. The contact area increases by increasing the brush rotation speed at the dynamic condition [3-7]. However, the contact area decreases rapidly right after the PVA brush starts rotating from the static condition. The literature also reported that the shear force between the brush and scrubbing surface during post-CMP cleaning increases with the rotational speed of the PVA brush [8]. The average contact pressure and contact area are functions of brush rotation speed in wet conditions where the downforce decreases, and the contact area increases with brush rotation speed [9].

EXPERIMENTAL

A total internal reflection optical device coupled with a high-speed camera was used to visualize the interaction of the brush surface with the substrate under stationary or moving conditions, as demonstrated in fig.1. Furthermore, the experiments were performed to visualize the changing shape of the nodules during contact. Based on the analysis of the images, the change in volume and contact area of the nodule were evaluated. The brush nodules of approximately 10 mm were cut from a commercial 300 mm PVA brush (AION, received from KCTech) to perform the experiments. The nodules were soaked in DIW for 24 h to ensure the proper wetting of the brush nodules before the experiments. The brush nodule interaction was studied on the surface of a prism (with a contact angle of 28°) made up of borosilicate glass (BK7) to obtain clear images of the brush surfaces.

The experimental setup was built by upgrading CSY (Company Succeed with You, Korea) pencil-type nodule scrubber by incorporating a high-speed camera (Phantom VEO710, at a frame rate of 1000 fps and 1280 × 800 pixels) as shown schematically in Fig. 1. To obtain the images during the brush contact, an LED light was passed through the prism, and the light reflected due to the total internal reflection while passing through the prism was directed to the high-speed camera. This refracted light produces images that give the real contact area of the PVA brush, as shown in Fig. 1. The white space in the image indicates the brush contact surface, while the dark area represents the non-contacted surface. The brightness of the image captured by the high-speed camera is directly proportional to the brush contact area and this was estimated by processing the image with the help of MATLAB software. The experiments were also performed under various brush gap distances from the surfaces (0, -1, -2, and -3 mm).

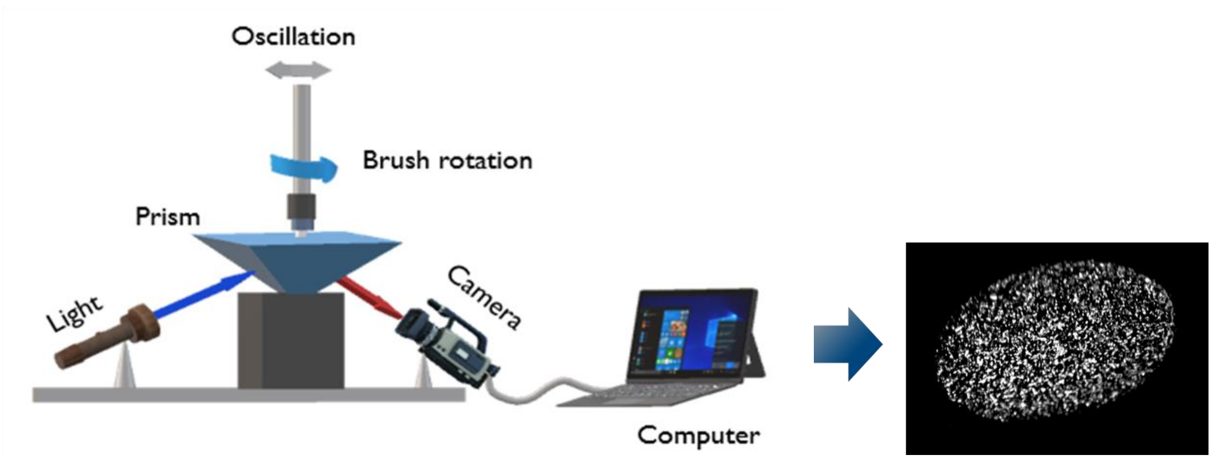

Fig. 1 Schematic representation of the experimental setup and a sample image captured with the high-speed camera

DISCUSSION

The contact area measurements were performed with different types of brushes at static and dynamic conditions to evaluate the brush and substrate interaction. The experiments were also performed at different gap distances. Figure 2 shows the FE-SEM images of the brushes, and the image captured by the high-speed camera during contact with the prism. It is clear from the images that the brush with the skin layer (Fig. 2a) exhibited a smooth surface while without the skin layer (Fig. 2b) showed a rough top surface with a dome-shaped structure. On the other hand, the half-cut PVA brush nodule (Fig. 2c) showed a comparatively rough and flat surface. Figure 3a shows the brightness of the images captured under static conditions with various types of brush nodules at different brush gap distances. Based on the brightness value, the real-time contact area was increased by decreasing the gap distance with all types of brush nodules under static conditions. However, the brush contact area with the skin layer under static conditions was significantly higher than the other types of brushes.

The brightness of the image under dynamic conditions, after 0.5 seconds, with various brush nodules at different gap distances is shown in Fig. 3b. Irrespective of the brush type, the contact area of the brush increased with a decrease in the brush gap distance. The contact area of the brush with the skin layer under dynamic conditions was significantly lower than that under static conditions. When the PVA brush started moving from static to dynamic conditions, initially, the contact area decreased drastically due to local brush deformation. However, a stable contact area was observed over time during the scrubbing process [4]. The same trend of contact area was observed by varying gap distances from 0 to -3 mm, the stabilized contact area is shown in Fig. 3b.

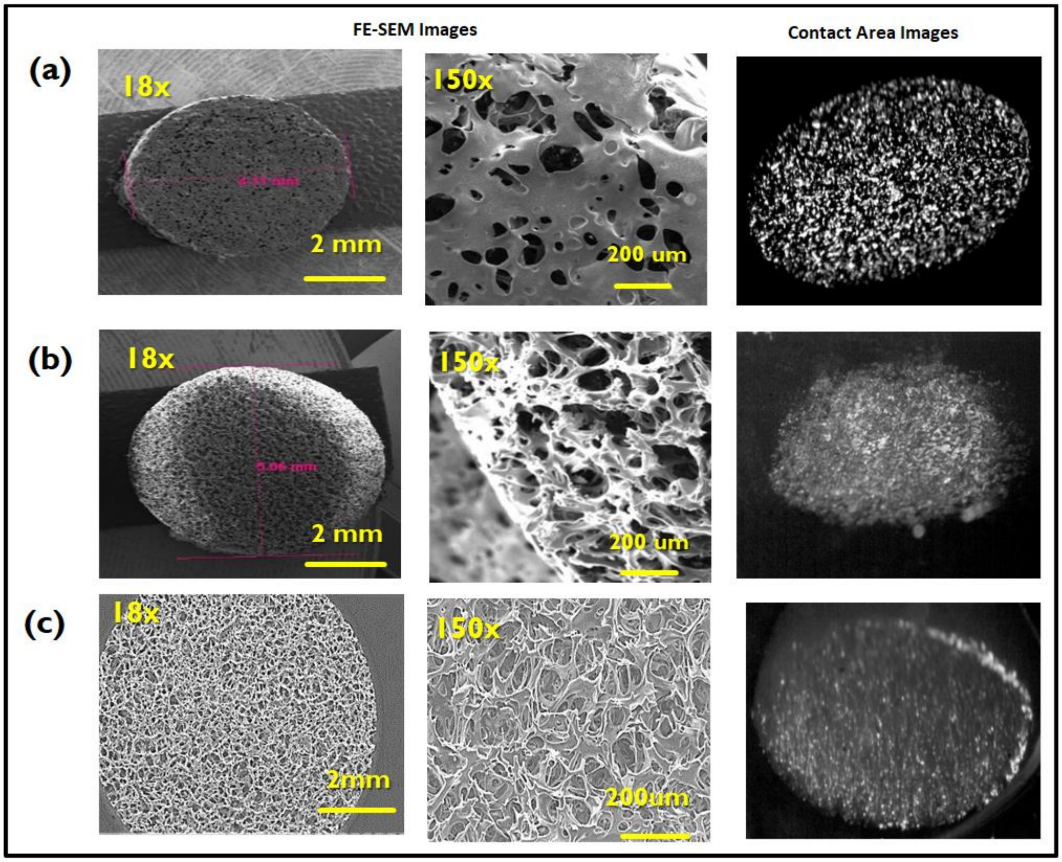

Fig. 2 Surface analysis by FE-SEM and contact area images at static condition by High-speed camera for (a) skin layer, (b) without skin layer, (c) self-removed skin layer (half-cut) PVA brush nodules.

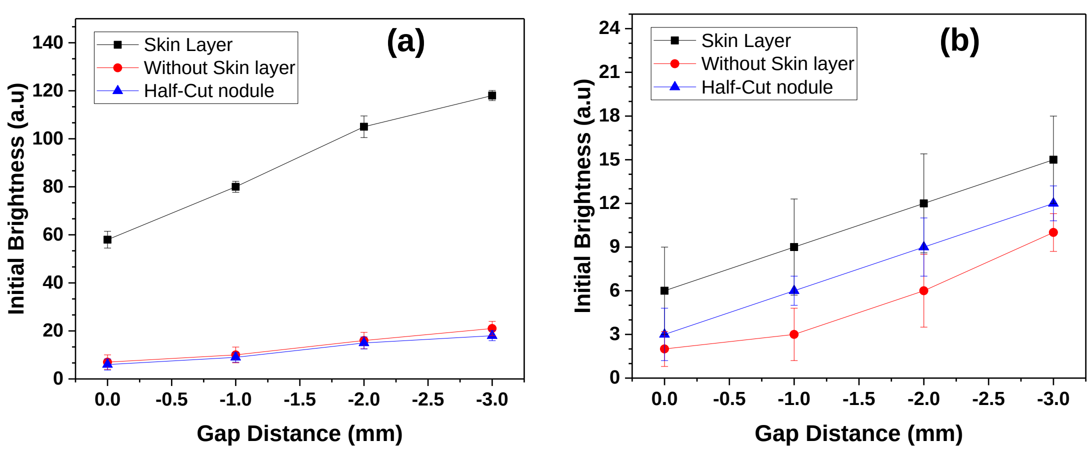

Fig. 3 Variation of initial brightness with gap distance using with skin layer, without skin layer, and half-cut brush nodules at (a) static and (b) dynamic conditions after 0.5 seconds.

The contact area of the brush with the skin layer showed a higher contact area in all conditions. Under dynamic conditions, the brush without the skin layer showed a lower contact area compared to the brush with the skin layer and half-cut nodules as a result of the high frictional force due to the rough surface topography of the brush without the skin layer.

CONCLUSIONS

In this study, we experimentally investigated the interaction of brushes with the substrate under various brush gap distances at static and dynamic conditions. This study studied the contact area between the brush and substrate based on the brightness of the brush surface images captured with a high-speed camera. The studies were extended to brushes with different surface conditions. The study showed that the contact area increased by decreasing gap distance, and the skin layer brush has a higher contact area than the without skin layer and half-cut nodules under static and dynamic conditions. It is also found that the initial contact area decreases when the brush started rotating from static to dynamic conditions. Under the dynamic condition, the brush without the skin layer showed low contact area compared to half-cut nodules due to the deformation of the brush and high frictional forces arising from the rough brush surface.

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REFERENCES

1. Hosaka A, Mizushima Y, Hamada S, Koshino R, Fukunaga A, and Sanada T. Static and dynamic interaction between polyvinyl acetal brushes and flat surfaces-Measuring near-surface brush volume ratio and nodule volume change for moving brushes, Microelectronic Engineering, 2022, 256,111721.
2. Ein-Eli, Y., and Starosvetsky, D. Review on copper chemical–mechanical polishing (CMP) and post-CMP cleaning in ultra large system integrated (ULSI)—An electrochemical perspective, Electrochimica Acta, 2007, 52, 1825-1838.
3. Lee JH, Ryu HY, Hwang JK, Yerriboina NP, Kim TG, Hamada S, Wada Y, Hiyama H, and Park JG. A breakthrough method for the effective conditioning of PVA brush used for post-CMP process, ECS Journal of Solid State Science and Technology, 2019, 8, 307-312.
4. Sanada T, Hanai M, Fukunaga A, and Hiyama H. An Observation Method of Real Contact Area during PVA Brush Scrubbing, Solid State Phenomena, 2018, 282, 73-76.
5. Ito M, Sanada T, Fukunaga A, and Hiyama H. Brush deformation effects on polyvinyl acetal brush scrubbing. ECS Journal of Solid State Science and Technology, 2018, 7, 201-208.
6. Miyaki T, Sanada T, Mizushima Y, Fukunaga A, and Hiyama H. Contact Area Distribution during PVA Brushes Scrubbing, ECS Transactions, 2019, 92, 183-189.
7. Philipossian A and Mustapha L. Tribological attributes of post-CMP brush scrubbing. Journal of the electrochemical society, 2004, 151, 456-460.
8. Sun T, Zhuang Y, Li W, and Philipossian A. Investigation of eccentric PVA brush behaviors in post-Cu CMP cleaning, Microelectronic engineering, 2012,100, 20-24.
9. Gu X, Nemoto T, Teramoto A, Ito T, Sugawa S, and Ohmi T. Reduction of scratch on brush scrubbing in post CMP cleaning by analyzing contact kinetics on ultra low-k dielectric, ECS Transactions, 2009, 19, 103-109.

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