ASPERITY SIZE DISTRIBUTION NEAR WAFER FEATURES DURING CMP

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Abstract

Dual Emission Laser Induced Fluorescence (DELIF) is used to attain in-situ images of the slurry layer between the polishing pad and wafer during chemical mechanical planarization (CMP). The slurry layer under a flat wafer takes the shape of the polishing pad. As a wafer feature passes over the pad, the pad adapts to the wafer shape and expands into the well. Here, we present a comparison of the shape of the polishing pad inside and outside 14 um deep wafer wells. By comparing asperity size distribution histograms we see no asperity compression inside the wells. However, in the region outside the wells where the pad and the wafer are in contact, asperities are compressed approximately 2.5um with an applied pressure to the wafer of 6.0 psi. In addition to asperity compression we observe an increase in pad-wafer contact from the 0.5 psi to the 6.0 psi case.

Introduction

In-situ experimental evidence of pad behavior underneath the wafer during CMP is difficult to observe directly because both the polishing pad and wafer materials are often opaque. Pad properties and the corresponding planarization effectiveness of are often tested by ex-situ examination of the pad and the wafer (1). Over the past decade DELIF has enabled in-situ measurements of both slurry (2) and pad (3) behavior during CMP. Recent optical improvements have enabled acquisition of high spatial and temporal resolution images (4). In this report, we discuss an analytical technique that allows us to begin examining pad-wafer contact during the polishing process. We will observe how the polishing pad responds to a change in wafer profile under low and high pressure conditions.

Experimental Methods

A full discussion of DELIF theory can be found elsewhere (2, 5) and well as an overview of our experimental setup (6). However, a brief explanation will be presented here. A Nd/YAG laser emits light at a wavelength of 355 nm. The laser light is absorbed by the polyurethane polishing pad and reemitted at a peak wavelength of 390 nm. Some of the emitted light from the pad is absorbed by a dye (Calcein) that is dissolved in the slurry. The dye in the slurry emits light at 530 nm. The wavelengths of the pad and the dye in the slurry are separated by a beam splitter and filters into two separate cameras that collect 10 bit images. The ratio of the (dyed slurry image)/(pad image) yields an intensity map that is proportional to the amount of Calcein at each pixel location and independent of the non-uniformities in the light source producing the images. This intensity map images can then be calibrated to a fluid film thickness of the slurry layer. For
these data, 1 intensity unit corresponds to approximately 20 µm of slurry. A discussion of the calibration method can be found elsewhere (7).

The wafer and carrier of a typical table top rotary polisher is opaque and therefore cannot be used to make DELIF measurements. Our measurements are made using table top polisher we have modified to optimally enable DELIF measurements (6). The wafer and carrier head has been replaced by a 3” diameter, 0.5” thick piece of optical glass that has similar properties to silicon wafers. Square wells have been etched to a depth of 18 µm in the optical glass in a pattern as shown in figure 1a. The square wells range in area from 0.25 mm² to 4 mm². Figure 1b is a ratio map picture of the slurry film thickness between a wafer with etched square wells and a Freudenberg FX9 polishing pad. The Freudenberg FX9 is a polyurethane pad with a surface roughness of approximately 4.5 µm as measured by profilometer and is similar to the industry standard Rodel IC1000. Since the wafer has a surface roughness on the order of nanometers, the fluid film thickness reflects the topography of the polishing pad. Dark areas in Figure 1b correspond to the tops of the asperities where the pad and wafer are close to each other, and brighter areas correspond to valleys between asperities.

Results

Figure 2 shows a histogram of sub-regions from figure 1b both inside and outside the square well. Both histograms are normalized so they can be compared. This image was acquired with a pad-wafer relative velocity of 0.34 m/s, an applied down-force of 2psi, and a slurry injection rate of 70 cc/min. The shape of the histograms is not quite Gaussian and skewed towards lower intensities, or asperity peaks. The shape of the right side of the histogram is dominated by pad porosity; whereas the right side of the histogram is dominated by pad conditioning and polishing wear (8). The means are offset because there is more fluid under the well. While the pad does expand a small amount to adapt to the well edge, it does not expand fully into the well leading to an overall slurry thickness change. The well depth is 18 µm and the difference between the means of the histograms corresponds to approximately 15 µm indicating asperity expansion into the well of 3 µm. The standard deviation of the histogram inside the well is greater than outside the well indicating a wider asperity size distribution inside the well than outside the well. The left tail (low intensity) of the histograms corresponds to the tops of the asperities, and the right tail corresponds to valleys in the pad.

Figure 3 shows what happens to the histograms at low (0.5psi) and high (6.0psi) applied down-force. Unlike figure 2, the histograms in figure 3 are roughly calibrated using the calibration factor in the “Experimental Methods” section and are centered on the mean pad height. Figure 3a compares the region outside the wells where the pad and wafer are probably in contact, and figure 3b compares the region inside the wells where the asperities are most likely not in contact with the wafer. In figure 3b the histograms are roughly the same shape indicating that the asperity size distribution is unaffected by the increase in pressure inside the well of this depth. However, the histograms from the region outside the well in figure 3a show approximate 2.5 µm more compression than in the 6.0 psi case than the 0.5 psi case. In the 6.0 psi case, the valleys seem to be closer to the mean pad height. Any flattening of the asperities, and increased contact, would appear at the left extreme of the histogram. The left tail of the histogram in figure 3a is
steeper in the 6.0 psi case than the tail for the histogram in the 0.5 psi case indicating more uniformity in the peak height distribution at 6.0 psi.

Conclusion

DELIF has enabled the acquisition of in-situ high spatial and temporal resolution images of the slurry layer during CMP. With an optical glass wafer, we can study how the polishing pad responds to wafer features. By examining histograms from these DELIF images, we have compared polishing pad shape inside and outside the wells and discussed what happens at low and high down-forces. Asperities expand into the wells approximately $3\mu m$ during polishing. Asperities do not make contact with the bottoms of the wells, however, increased pad-wafer contact is observed between the 0.5 psi and 6.0 psi cases as indicated by a steeper left tail on the histogram.

References


Figure 1. (a) Wafer etch geometry. (b) An image of the slurry layer between a patterned wafer and a Fruedenburg FX9 polishing pad.
Figure 2. Slurry layer thickness distribution both inside and outside the square well.

Figure 3. Comparison of asperity size distribution at 0.5 psi and 6.0 psi (a) outside the well region and (b) inside the well region.