Effects of Water Interactions with Polishing Pads on Wafer-Scale Chemical Mechanical Planarization Rates

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In a typical chemical-mechanical planarization (CMP) process, material is removed from the surface of a wafer through mechanical interactions with the polishing pad and through the combined chemical and mechanical action of a slurry containing abrasives and weak etchants. The polishing pad elastic properties are critically important to CMP, as they contribute to direct pad-wafer abrasion and also to indirect pad-slurry particle-wafer abrasion.

We investigated the effect of immersion in water on the polishing performance of typical IC1000 pads in silicon dioxide polishing using a dual-axis polisher. First, we immersed pads in deionized water for 24 hours or 10 days, and we measured the elastic modulus of the pads under loads representative of CMP. We found that the modulus of dry pads was ~370 MPa, while the pads immersed in deionized water had an average modulus of 280 MPa. In these results, the duration of immersion in water beyond 24 hours had no appreciable effect on the bulk elastic modulus of the pads.

It is believed that the penetration of water into the surface of the polishing pads during immersion in water led to the reduction in modulus. Specifically, the water in the pad is believed to disrupt hydrogen bonding between adjacent polyurethane chains, reducing the pad modulus. Infrared spectroscopy analyses of the pads following immersion confirmed a reduction in hydrogen bonding in the pads following immersion. When the pads were allowed to dry and the water left the interior of the pad, the elastic modulus increased again. Infrared spectroscopy confirmed the re-establishment of hydrogen bonds following pad drying (1).

It is generally accepted that harder pads will give higher removal rates during CMP than softer pads, and we expected that the reduction in the pad elastic modulus resulting from immersion in water would lead to lower polishing rates. A series of experiments was performed in which 5 wafers were polished sequentially over a 5 day period to test this hypothesis. Wafers 1, 3, and 5 were prime TEOS rate wafers, and wafers 2 and 4 were reclaimed wafers. On day 1, a new IC1000 pad was mounted on an IPEC 472 polisher, and the 5 wafers were polished using a non-optimized, non-commerical process. In-situ conditioning was applied during the polishing. At the end of day 1, the tool was set on 'wet-idle' mode for 24 hours. During this time, water was sprayed on the pad periodically to keep the pad surface wet at all times. On day 2, approximately 24 hours from the start of experiments on day 1, the sequence of wafers was polished again, and the same protocol was repeated on day 3. On day 5, approximately 48 hours after the onset of experiments on day 3, the sequence of wafers was polished. In situ conditioning was used at all times, but no conditioning was applied between the end of polishing of wafer 5 on one day and the onset of polishing of wafer 1 on the subsequent day.

The polishing results from day 1 were inconclusive. The 5 wafers polished and the in-situ conditioning during the polish simply served to break-in the pad. On days 2, 3, and 5, wafers 3 and 5 polished at a rate between 2550 and 2600 Å/minute. On days 2 and 3, wafer 1 polished at a rate between 2400 and 2450 Å/minute, representing a reduction in rate of ~6% compared to wafers 3 and 5. On day 5, wafer 1 polished at a rate of ~2340 Å/minute, representing a reduction in rate of ~10% compared to wafers 3 and 5. The only difference in the pad between wafer 5 of one day and wafer 1 of the subsequent day was the immersion in water. Therefore, it was concluded that the reduction in hydrogen bonding caused by water penetration into the pads, and the subsequent reduction in pad elastic modulus, caused the reduction in polishing rate. Since wafers 3 and 5 on days 2, 3, and 5 polished at roughly the same rate, it appears that by the time the 3rd wafer is polished, a steady-state has been reached. In this state, the rate of pad softening due to the penetration of water into the pads is balanced by the removal of the pad surface due to the combined conditioning and polishing processes.

As the surface of the pad softens with increasing water penetration, the pad asperities' ability to deform is increased. As a result, the area of contact between the pad asperities and the wafer surface will increase as the pad surface grows softer. The load on any individual asperity will be reduced as the area of contact increases, and this should produce a reduction in polishing rate. The Greenwood-Williamson microcontact model (2) is used to understand the consequences of the reduction in pad elastic modulus on CMP performance. Using this approach, it was determined a that as the pad elastic modulus drops from 11×10^6 Pa to 5×10^5 Pa, the area of asperity-wafer contact increases by nearly a factor of 10.

In addition to increasing the area of contact and reducing the load on individual asperities, asperity softening also will decrease the local separation distance between the pad and wafer. This potentially allows increasingly smaller particles to be pushed into contact with the wafer surface by the pad, perhaps raising the polishing rate. This effect will tend to offset the reduction in local pressure due to asperity softening.

References
1) Gold, S., Unpublished data (2001).
2) J. A. Greenwood and J. B. P. Williamson, *Proc. Roy. Soc. Lond.* A, **29**5, 300 (1966).