Planarization Efficiency of Copper Protrusion

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Planarization efficiency of Cu protrusion on a 0.175/0.175 μm feature was investigated with polishing tests on a hard pad, a medium pad, and a soft pad. Slurries with two different chemistries and two abrasive particles were formulated to study the planarization efficiency and its improvement. The results proved that the planarization efficiency of Cu protrusion decreased dramatically with decreasing pad hardness. The planarization efficiency on the hard pad was satisfactory and Cu protrusion could be reduced to near zero. The planarization efficiency on the soft pad was low and little improvement was obtained by changing the slurry formulation. The planarization efficiency on the medium pad was intermediate but could be improved significantly by changing chemistry and/or abrasive in the slurry. One of the improved slurries produced planarization efficiency on the medium pad that exceeded the planarization efficiency by a commercial slurry on the hard pad. Effect of H_2O_2 concentration in the working slurry on planarization efficiency on the medium pad was also observed. It was interpreted by changes in the characteristics of the protective film on Cu surface with H_2O_2 concentration.

Keywords: Chemical-mechanical Polishing (CMP), Cu protrusion, Planarization efficiency

1. Introduction

In Cu electroplating of patterned wafers, super filling of narrow trenches occurs and results in Cu protrusion over arrays of fine lines [1]. As the fine lines become increasingly narrower in the newer generations of IC devices, Cu protrusion becomes more pronounced and planarization of the protrusion in Cu CMP becomes more challenging. Planarization of Cu protrusion is difficult because of a very small height-to-width ratio (to an order of 1-to-10^4). Ideally, we want to polish off Cu in the protruding area only. In reality, however, Cu on both protrusion and surrounding field will be polished at different rates.

Effective planarization can be produced on a hard pad because of its small compressibility, but it is not true for polishing on a soft pad because it can easily conform over the protrusion [2-6]. It has been reported that polishing on a hard pad may cause mechanical defects such as scratches whereas polishing on a soft pad will likely reduce mechanical defects but produce low planarization efficiency [7-9]. Therefore, polishing on a medium pad may result in an optimal compromise between planarization efficiency and defectivity. Slurry formulation (chemistry and abrasive) has direct impacts on the planarization efficiency through formation and abrasion of the protective film that forms on Cu surface during the CMP process. It is also known that other factors such as substrate and polishing process will affect the planarization efficiency [9-13]. The purpose of this work was to study the planarization efficiency of Cu protrusion on a medium pad and improve it by changing abrasive and chemistry in the slurry.

2. Experimental

The colloidal silica slurries investigated in this study contains a Cu chelating agent, a Cu corrosion inhibitor, other proprietary components, and uses H_2O_2 as the oxidizer. Working slurry was prepared by dilution of the slurry with DI water followed by addition of H_2O_2. Two chemical formulations (denoted C1 and C2) and two abrasives (denoted A1 and A2) were tested in this study. Slurry formulations and pathways for slurry improvement are shown in Figure 1. Slurry C1A1 is a commercial slurry which can be considered as the baseline slurry. In slurry C2A1+2, a mixture of two abrasives (A1 and A2) was used. From slurry C2A2 to slurry C2′A2, the concentrations of some chemical components were optimized.

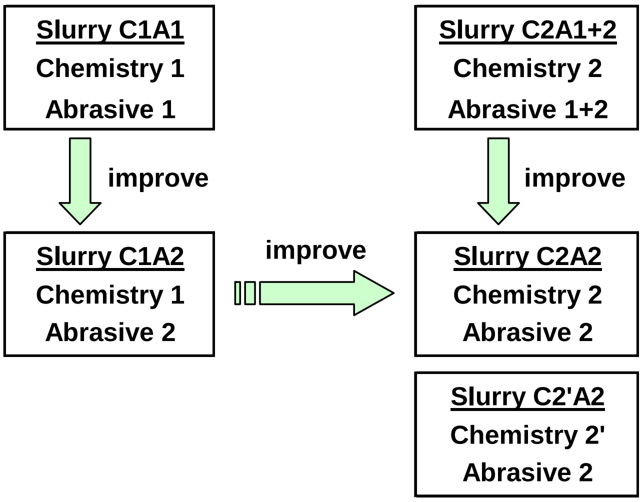

Figure 1. A flow chat for slurry formulation and changes of chemistry and abrasive in slurry to improve planarization efficiency of Cu protrusion.

Polishing tests were performed using commercial 200 mm Cu patterned test wafers (Sematech 854 mask) on an IPEC Westech 372M polisher. The hardness values of the pads used were: hard pad, Shore D of ~60; medium pad, Shore D of ~53; and soft pad, Shore A ~61. (Please note that there is not a direct correlation between Shore D and Shore A hardness scales for the pads made of different materials.) Typical polishing process conditions were: platen/head rotational speed, 85/80 rpm; pressure, 1.5 psi; and slurry flow rate, 200 mL/min. For the hard and medium pads, conditioning was done using a 3M A165 diamond disk. For the soft pad, a 3M PB52A nylon brush was used. The polishing with slurry was followed by 10-sec buffing with DI water and rinsing with DI water. The step height for Cu protrusion was measured on a Veeco DEKTAK 8 profilometer.

3. Results and Discussions

Figure 2 shows typical profiles of some 50% dense structures on the patterned test wafers used in this study. Recess was found on the structures with line width ≥1 μm while protrusion on the fine line arrays of ≤0.5 μm. The Cu protrusion on the 0.175/0.175 μm feature had a maximum height of about 2500 Å and a width of about 1250 μm. This corresponds to a height-to-width ratio of 1:5000, making the planarization of Cu protrusion very challenging. In this work, Cu protrusion on 0.175/0.175 μm feature was selected for evaluation of the planarization efficiency and its improvement. The maximum step height was measured to generate the planarization plot for Cu protrusion vs. remaining Cu thickness.

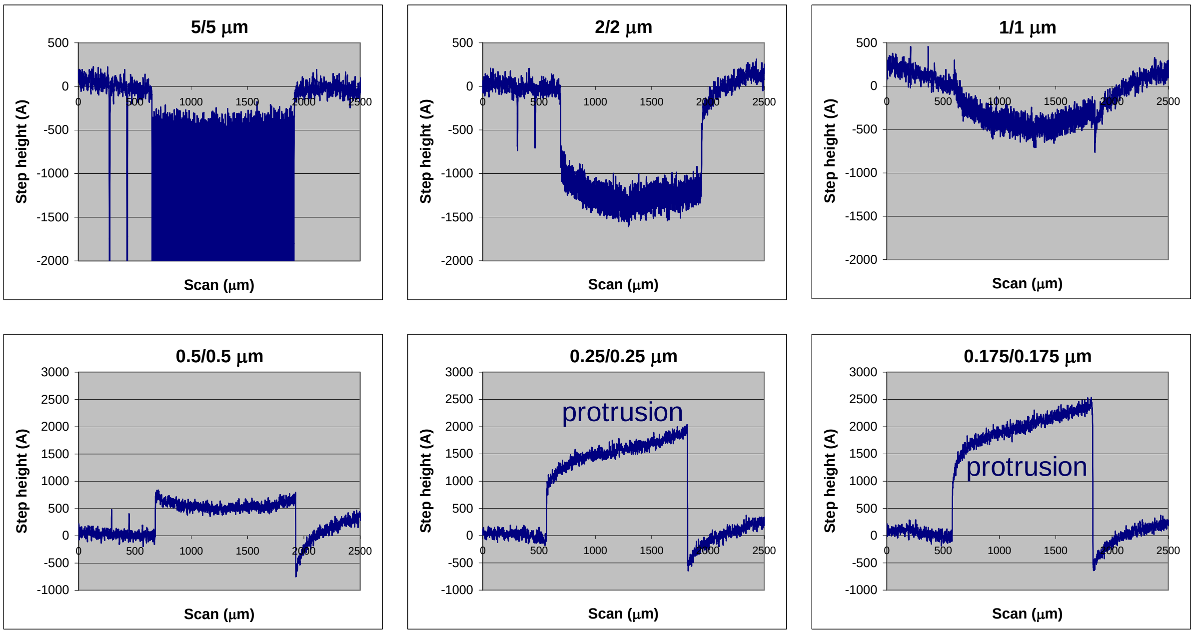

Figure 2. Cu protrusion on fine line arrays.

Figure 3 shows the effect of pad hardness on planarization efficiency of Cu protrusion with slurry C1A1. The planarization on the hard pad was effective and the Cu protrusion was reduced quickly to near zero. However, the planarization efficiency on the soft pad was very low and the overall reduction in Cu protrusion was less than 20%. In between, the medium pad produced an overall reduction of about 45%. Since slurry C1A1 was a commercial slurry, the planarization efficiency by this slurry on the hard pad was considered to be the benchmark for the improvement of slurry for polishing on the medium and soft pads.

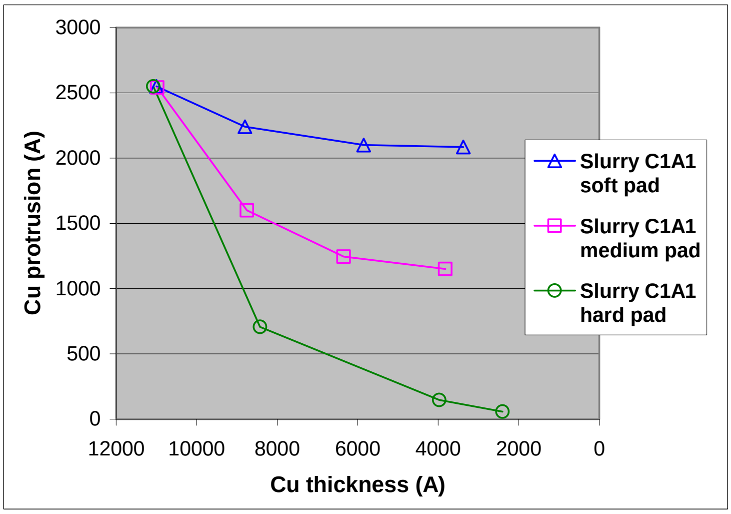

Figure 3. Effect of pad hardness on planarization efficiency of Cu protrusion by slurry C1A1.

The effect of pad hardness can be explained by difference in pad compressibility. A hard pad has small compressibility and does not conform much over the Cu protrusion. It exerts higher pressure and produces higher removal rate on Cu protrusion than on the surrounding field. Therefore, high planarization efficiency is achieved. In contrast, a soft pad has high compressibility and easily conforms over the Cu protrusion which has very small height-to-width ratio. It produces little or no difference in the pressure and Cu removal rate between the Cu protrusion and the surrounding field. Therefore, low planarization efficiency is resulted.

Improvement of planarization efficiency for polishing on the medium pad was attempted by changing the slurry formulation. As can be seen in Figure 4, the planarization efficiency was improved by changing the abrasive (from A1 to A2), and further improved by also changing the chemistry (from C1 to C2). These results demonstrate the ability to improve planarization efficiency on the medium pad by changing the slurry formulation.

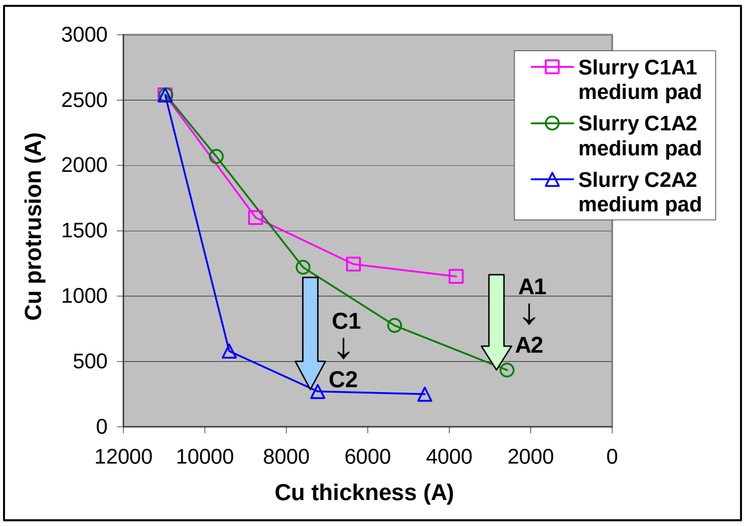

Figure 4. Improvement on planarization efficiency by changing abrasive and chemistry

Figure 5 compares the improvement of planarization efficiency on the medium and soft pads. It shows that the improvement is significant for polishing on the medium pad but minimal on the soft pad. This seems to indicate a potential limitation on the improvement of planarization efficiency on the soft pad. The improvement on a soft pad is difficult because a soft pad conforms very easily over the Cu protrusion.

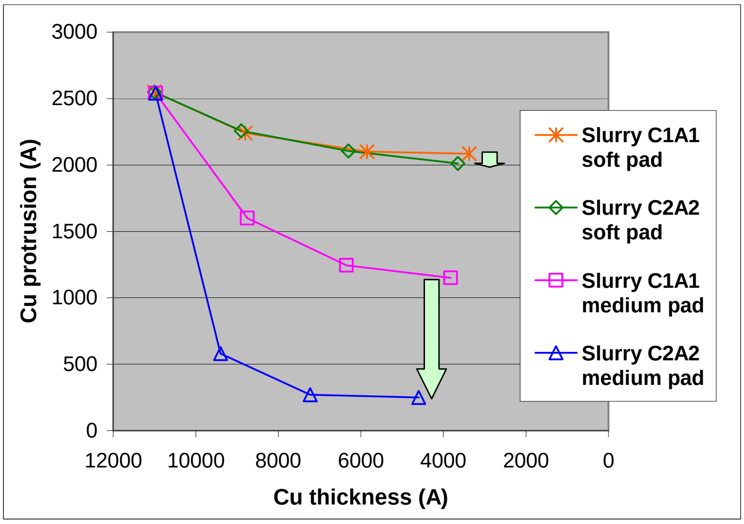

Figure 5. Effect of pad hardness on improvement of planarization efficiency by changing slurry formulation.

As discussed earlier, the planarization efficiency by the commercial slurry C1A1 on the hard pad is considered the benchmark for improvement of slurry for polishing on the medium pad. Figure 6 shows that the planarization efficiency by slurry C1A1 on the medium pad was clearly not satisfactory. However, the improved slurry C2′A2 produced a planarization efficiency on the medium pad that exceeded the benchmark.

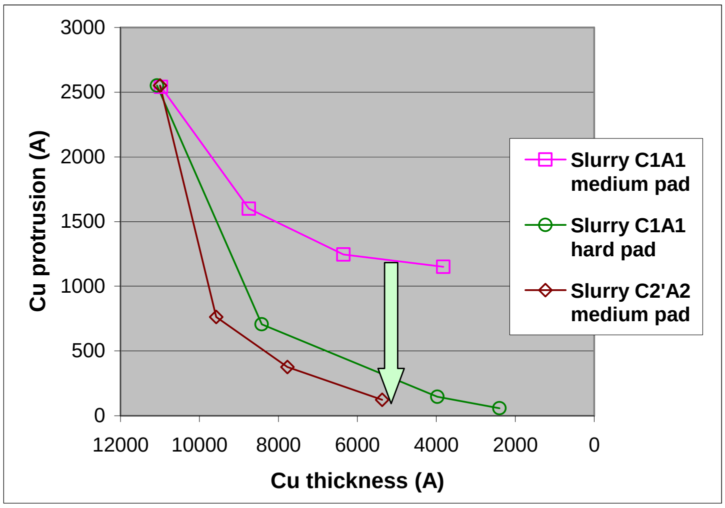

Figure 6. Improvement of planarization efficiency by slurry formulation on medium pad.

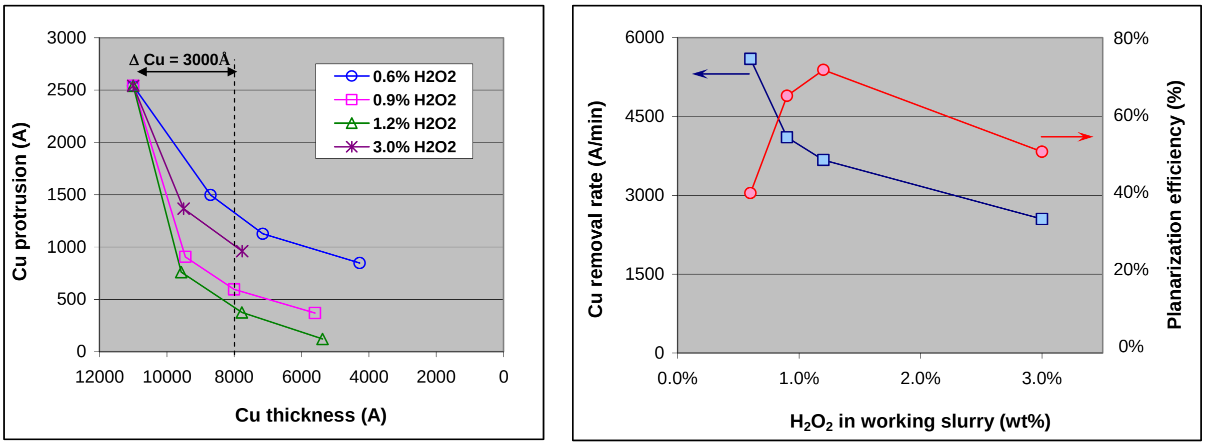

Figure 7. Effect of H_2O_2 concentration on Cu removal rate and planarization efficiency (for polishing of Cu from 11000 to 8000Å Cu) by slurry C2′A2 on medium pad.

Figure 7 shows the effect of H_2O_2 concentration on planarization efficiency on the medium pad. Planarization efficiency was calculated for the polishing of Cu from 11000 to 8000Å: [(Cu protrusion at 11000Å) – (Cu protrusion at 8000Å)] / (3000Å of Cu removed) %. The Cu removal rate decreased with increasing H_2O_2 concentration, but the planarization efficiency showed a maximum in the intermediate range of H_2O_2 concentration. The removal trend can be explained by a competition between Cu oxidation by H_2O_2 and Cu complexation with inhibitor during the formation of a protective film on Cu surface during the CMP process [14].

The planarization efficiency is determined by the difference in Cu removal rate between the Cu protrusion and surrounding field. The larger the difference in the removal rate, the higher the planarization efficiency. The maximum in planarization efficiency at intermediate H_2O_2 concentration can be explained by different characteristics of the protective film that forms at different H_2O_2 concentration and slightly different pressures that the medium pad exerts on the protruding area and surrounding field.

- At low H_2O_2 concentration, the rate of Cu oxidation by H_2O_2 is low and the protective film on the Cu surface is likely dominated by Cu-inhibitor complex which is easy to polish. This protective film on the protrusion and field can be polished at high removal rate regardless the small difference in the pressure. Thus, the planarization efficiency is low.

- At intermediate H_2O_2 concentration, neither Cu-inhibitor complex nor Cu-oxide dominates in the surface protective film. The removal rate of this film may be sensitive to pressure; the slightly higher pressure on the protrusion can produce higher removal rate compared to the surrounding field. Therefore, higher planarization efficiency is produced.
- At high H_2O_2 concentration, the rate of Cu oxidation is high and Cu-oxide dominates in the film that is more difficult to polish. The removal rate may become insensitive to the small difference in the pressure. Therefore, the planarization efficiency becomes low.

4. Conclusions

The results of this study show that pad hardness has a dominant effect on the planarization efficiency of Cu protrusion on fine line arrays. Polishing on a hard pad can quickly planarize Cu protrusion to near zero. Polishing on a soft pad cannot effectively planarize Cu protrusion and little improvement of planarization efficiency can be achieved by changing the slurry formulations. However, the planarization efficiency on a medium pad can be improved to a satisfactory level by changing chemistry and abrasive in the slurry. H_2O_2 concentration affects planarization efficiency because characteristics of the protective layer formed on Cu surface during the CMP process changes with H_2O_2 concentration.

5. Acknowledgement

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6. References

[1] S. G. Pyo, D. W. Lee, S. Kim, *Metals and Materials International*, **14**, 773 (2008).
[2] P. A. Burke, *Proc. VMIC Conf.*, pp. 379-384 (1991).
[3] E. Tseng, C. Yi, H.C. Chen, CMP-MIC, pp. 258-265 (1997).
[4] J. Grillaert, M. Meuris, N. Heylen, K. Devriendt, E. Vrancken, M. Heyns, *CMP-MIC*, pp. 79-86 (1998).
[5] J. Grillaert, M. Meuris, E. Vrancken, N. Heylen, K. Devriendt, W. Fyen, M. Heyns, *Mat. Res. Soc. Symp. Proc.* Vol. **566**, 45 (2000).
[6] D. Boning, B. Lee, C. Oji, D. Ouma, T. Park, T. Smith, T. Tugbawa, , *Mat. Res. Soc. Symp. Proc.* Vol. **556**, 197 (1999).
[7] T. Konno, *CAMP* 2005
[8] G. P. Muldowney, C. Elmufdi, A. S. Lawing, *NCCAVS CMP Users Group* 2007.
[9] S. Hymes, K. Smekalin, T. Brown, H. Yeung, M. Joffe, M. Banet, T. Park, T. Tugbawa, D. Boning, J. Nguyen, T. West, W. Sands, *Mat. Res. Soc. Symp. Proc.* Vol. **566**, 211 (2000).
[10] P. Lefevre, A. Gonzales, T. Brown, G. Martin, T. Tugbawa, T. Park, D. Boning, M. Gostein, J. Nguyen, *Mat. Res. Soc. Symp. Proc.* Vol. **671**, M4.4.1 (2001).
[11] J.-Y. Lai, N. Saka, J.-H. Chun, *J. Electrochem. Soc.* **149**, G31 (2002).
[12] H. Kim, D.-W. Park, C.-K. Hong, W.-S. Han, J.-T. Moon, *Mat. Res. Soc. Symp. Proc.* Vol. **767**, F2.4.1 (2003).
[13] V. H. Nguyen, R. Daamen, R. Hoofman, *Microelectron. Eng.* **76**, 95 (2004).
[14] J. Lin, T. Du, *ECS Transactions*, **18**, 485 (2009).