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In situ characterization of Cu CMP slurry and defect reduction using IR thermal camera

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Abstract

In order to choose appropriate property of Cu chemical–mechanical polishing (CMP) slurry, we used IR thermal camera to distinguish this slurry that belonged to Preston or non-Preston. The adoption of the IR thermal camera is to choose suitable non-Preston Cu CMP slurry in situ and find out optimal changing timing of step endpoint. Additionally supplementing robust CMP machine, appropriate Cu film quality and pre-treatment, we could obtain a total defect number is less than 10^1 order and achieve excellent Cu CMP performance. Such Cu CMP technology resulting in Cu damascene process work and make sure 0.13 μm and beyond 100 nm Cu process to be reliable and practical.

Keywords: Cu CMP; in situ slurry characterize; IR thermal camera; Defect reduction

1. Introduction

As the line width of ultra-large semiconductor integration (ULSI) decreases, the problem of RC delay becomes more serious. The replacement aluminum by the copper has been proposed when the line width is smaller than 0.13 μm because copper improves conductivity and reduces electromigration [1]. However, copper has been proven to be not easily etched by plasma. As the Cu CMP process is been developed, the copper damascene process has been made practical [2]. Unfortunately, the properties of copper are such that CMP has produced many defects, including microscratching, dishing, erosion and reduced yield [3]. Hence, this study seeks to develop a new and robust Cu CMP process that can reduce the number of defects and provide a good yield.

Choosing inappropriate slurry would yield a poor Cu CMP performance, including many defects and low yield [4,5], such that the 0.13 μm Cu process would be ineffective. This experiment utilized an IR thermal camera to select a suitable

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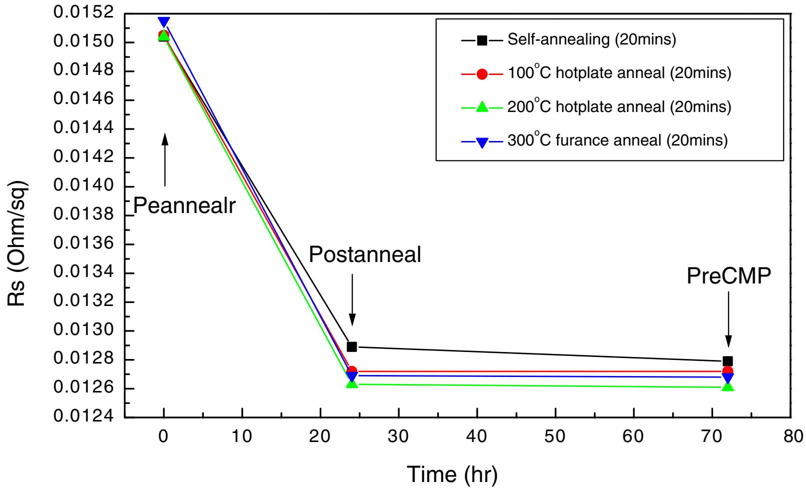

Fig. 1. Sheet resistance (R_s) testing results with different temperature treatments.

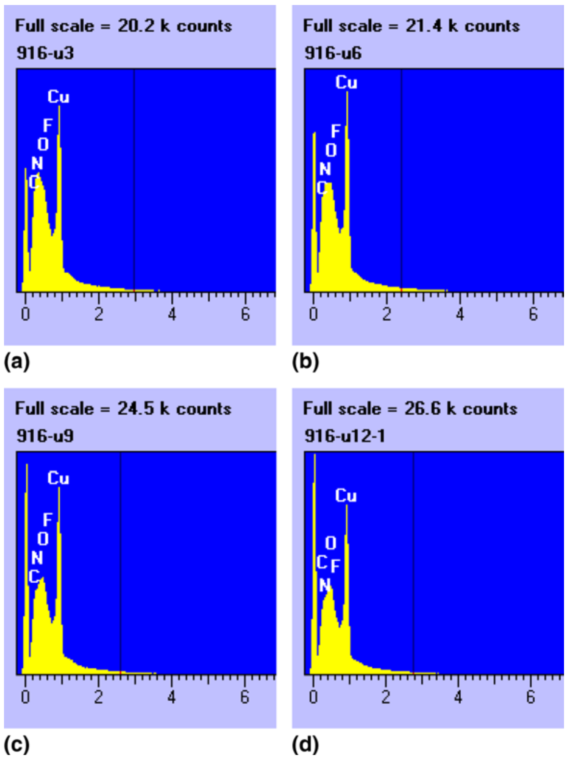

Fig. 2. EDS measured the constituent and impurity contents of pre-CMP Cu films after: (a) self-annealing; (b) 100 °C hot plate annealing; (c) 200 °C hot plate annealing; (d) 300 °C furnace annealing.

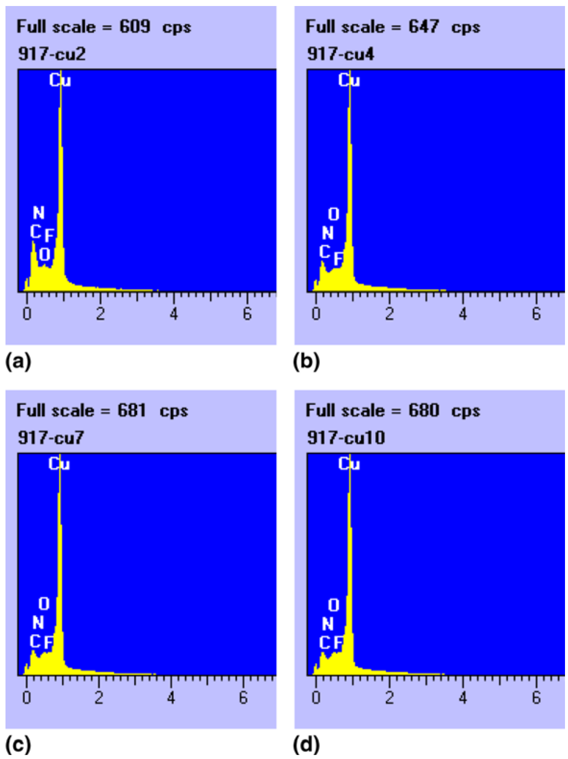

Fig. 3. EDS identified the constituent and impurity contents of post-CMP Cu films after: (a) self-annealing; (b) 100 °C hot plate annealing; (c) 200 °C hot plate annealing; (d) 300 °C furnace annealing.

non-Preston Cu CMP slurry and to diagnose the Cu CMP process in situ. Adding robust CMP machine and facility, appropriate Cu film quality and pre-treatment, yielding an almost perfect Cu CMP process without Cu residues and with a greatly reduced number of defects.

2. Experiment

This experiment was performed on a Strasbaugh 6ED™ chemical mechanical polisher. Eight-inch wafers of PE-TEOS 7800 Å/nitride 600 Å/PE-TEOS 5000 film stack were patterned using a Cu CMP test mask. A 250 Å TaN, followed by a 700 Å Cu seed layer and an 8000 μm electro-chemical plating (ECP) Cu film, was deposited by an AMAT cluster tool. A Rodel IC1400 stacked pad and a Non-Preston slurry were used for Cu polishing. During the CMP process, an IR thermal camera captured temperature profile in real time.

3. Results and discussion

The variation in resistivity, the impurity content and the grain size deeply influence the material and electrical properties of a Cu film [6]. Therefore, some proper treatments were applied to the post-electro-chemical deposition (ECD) Cu films. Then, the post-CMP results appeared to involve fewer pit defects and microscratches, low resistivity and appropriate grain size. A four-point probe measured the sheet resistances (R_s) of ECD Cu films. Fig. 1 plots the R_s testing results obtained with treatment at different temperatures. The R_s values of the pre-annealing ECD Cu film were almost the same. After 24 h of self-annealing, the Cu films were treated for 20 min under different conditions – self-annealing, hot plate annealing at 100 °C, hot plate annealing at 200 °C and furnace annealing at 300 °C. The R_s values in Fig. 1 follow the order self-annealing >100 °C hot plate annealing >300 °C furnace annealing >200 °C hot plate annealing. The R_s value associated with 200 °C hot plate annealing was lower than that associated with 300 °C

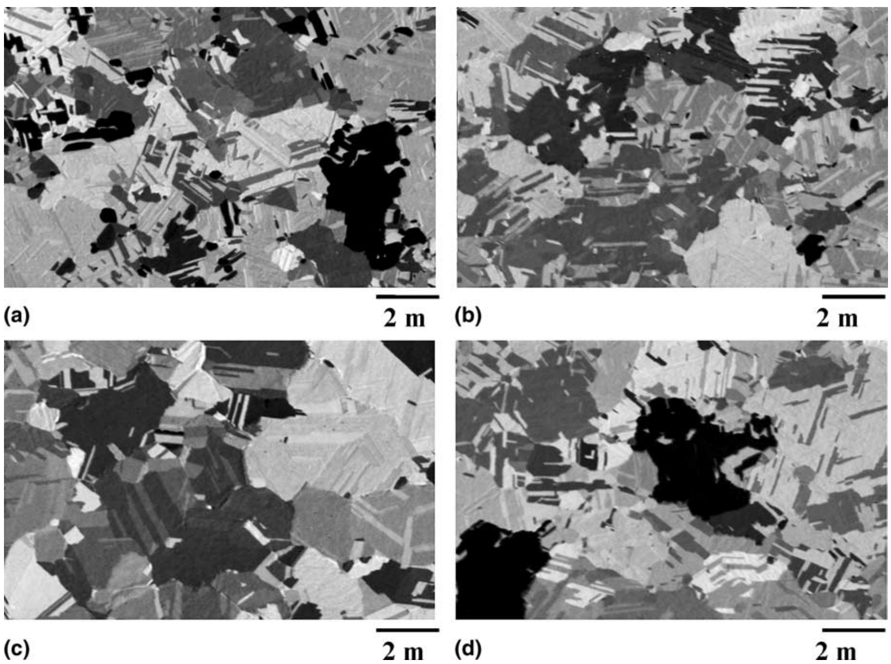

Fig. 4. Use of FIB to measure grain sizes of post-annealed Cu films after: (a) self-annealing; (b) 100 °C hot plate annealing; (c) 200 °C hot plate annealing; (d) 300 °C furnace annealing.

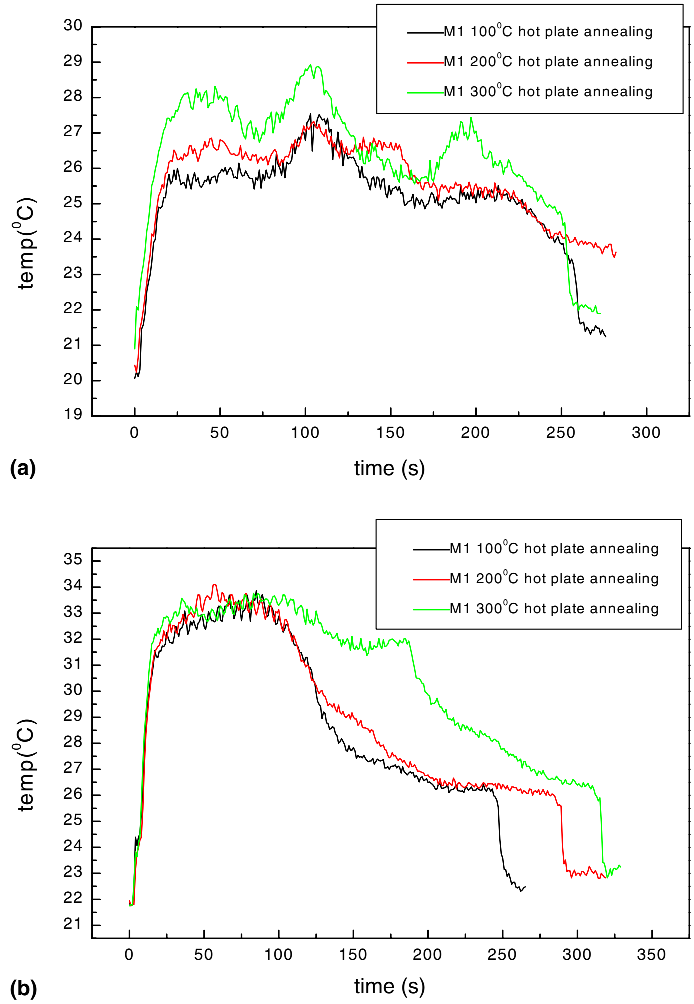

Fig. 5. Use of IR thermal camera to capture temperature profile CMP process: (a) temperature profile of Cu CMP process with slurry A mechanically dominant slurry (Preston base); (b) temperature profile of Cu CMP process with slurry B chemically dominant slurry (non-Preston base).

furnace annealing because the latter case involves a lower vacuum with more impurities, or perhaps incomplete annealing. After 48 h of self-annealing, the R_s values under all the treatment conditions were almost the same because the R_s values had become stable.

EDS was used to measure the composition and impurity contents of the pre-CMP Cu films, as shown in Fig. 2, and of the post-CMP Cu films, as shown in Fig. 3. Increasing the annealing temperature reduced the impure contents. However, for 300 °C furnace annealing, impurity contents were close to those obtained at 100 and 200 °C hot plate annealing. Fig. 2 presents these data. In the experiments, the impure contents were post-Cu CMP. Fig. 3 shows these results. A focus ion beam (FIB) was used to measure grain sizes of the Cu films; the sizes were found to increase with annealing temperature, as shown in Fig. 4.

An IR thermal camera was used to capture the temperature profile of the chips in the Cu CMP process. Fig. 5(a) plots the temperature profile associated with slurry A. Several Cu film pre-treatments, at 100, 200 and 300 °C, were employed.

Increasing the annealing temperature increased the temperature profile obtained using the IR camera. The increase of the temperature profile indicated a stronger CMP reaction and an increased removal rate (RR) [7]. While the annealing temperatures increasing, the grain sizes would be grown up (as illustrated in Fig. 4) and the RR were increased. Slurry A was mechanically dominant (Preston base). For a Cu CMP process with using slurry B, the temperature profile shown in Fig. 5(b) was obtained. The highest points of the IR temperature profiles were almost the same at all annealing temperatures. Because of, that the maximum of the Cu CMP reaction rate was the same in each case [7]. While annealing temperatures increasing, however, the polish times would increase. As the grain boundaries were reduced, the active sites would be decreased, thus resulting in the remove rate was decreased. Slurry B was also determined to be chemically dominant (non-Preston base). In a chemically dominant non-Preston slurry case, the CMP reaction active sites were Cu grain boundaries. The reason was that the Cu CMP mechanism was slurry and Cu form Cu complex compounds then abrasive particles remove the compounds. The active sites were more weak points Cu grain boundaries.

Based on the in situ IR thermal camera temperature profile, a suitable non-Preston Cu CMP slurry was identified and the Cu CMP process diagnosed. Unlike the Preston slurry that generates many defects, the non-Preston slurry contains a special surfactant that can protect the copper film by forming a complex compound [8]. Thus, the non-Preston slurry is chemically dominant. The use of a Cu film of proper quality, following proper pre-treatment, yielded a post-CMP total number of defects of less than 10^1, as measured by a KLA review SEM, as shown as Fig. 6.

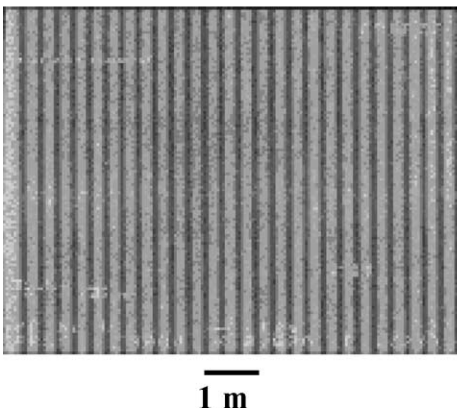

Fig. 6. Use of KLA review SEM to determine post-Cu CMP process defect results.

4. Conclusion

When the ULSI line width is smaller than 0.13 μm, the use of copper is proposed to replace the aluminum. Therefore, a robust Cu CMP technology must be developed to make the Cu damascene process reliable. However, many defects are detrimental to the yield. In this research, an IR thermal camera was used to choose a suitable non-Preston Cu CMP slurry and diagnose the Cu CMP process in real time. Additionally, using a robust CMP machine, a Cu film of appropriate quality, and a suitable pre-treatment, enables the Cu CMP process to be greatly improved, with almost no Cu residues or defects.

Acknowledgement

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References

[1] M.T. Bohr, in: Proceedings of the 1995 IEEE International Electron Device Meeting, 1995, pp. 241–42.

[2] K.H. Holland et al., Achieving CMP Manufacturability in the Current Aluminum and Future Copper Damascene Interconnection Technologies, Semiconductor Fabtech, eigth ed., 1998, p. 217.

[3] P. Stocckl, B. Saville, J. Kavanagh, T. Dellwig, Advanced Cu CMP defect excursion control for leading edge microprocessor manufacturing in: Advanced Semiconductor Manufacturing IEEE/SEMI Conference and Workshop, 2002, pp. 92–97.

[4] P. Wrschka, J. Hernandez et al., Electrochem. Soc. 147 (2000) 706.
[5] Wang Xin, Wang Hongying, Liu Yuling, Solid State Integr. Circuit Technol. (2001) 369–371.
[6] G.B. Alers, D. Dornisch, J. Siri, K. Kattige, L. Tam, E. Broadbent, G.W. Ray, Trade-off between reliability and post-CMP defects during recrystallization anneal for copper damascene interconnects. in: Reliability Physics Symposium, Proceedings of the 39th Annual 2001 IEEE International, 2001, pp. 350–354.
[7] H.W. Chiou, et al., CMP-MIC (2001) 131.
[8] Alex Shieh, S.Y. Shih, M.S. Jang, J.X. Lin, Jack Chen, Y.L. Hwang, C.T. Huang, C.C. Hsueh, Henry Chung, CMP-MIC (2001).