90 nm Generation Cu/CVD Low-k (k<2.5) Interconnect Technology

T.I. Bao, C.C. Ko, J.Y. Song, L.P. Li, H.H. Lu, Y.C. Lu, Y.H. Chen, S.M. Jang, and M.S. Liang

Taiwan Semiconductor Manufacturing Company, Science-Based Industrial Park, Hsin-Chu, Taiwan, R.O.C

Abstract

Eight level Cu/CVD Low-k (k<2.5) + one top level Cu/USG 90 nm multilevel interconnection with 0.12/0.12 um for line width/space and 0.13 um for via has been demonstrated for the first time using 193nm lithography with OPC developed for TSMC 200mm/300mm technologies. The 8-level Cu/CVD low-k dual damascenes were constructed by nitrogen-free dielectric layers without middle trench etch stop to achieve keff=2.6. No film delamination was found by film and CMP optimization. Electrical results showed that excellent and thermally stable metal-line Rs and via-chain Rc yields from iso or dense Cu areas and 1M via chains were obtained.

Introduction

Shrinkage of devices and wiring width/space increases the need for k<2.5 low-k interlayer dielectrics and Cu wiring in 90nm and beyond ULSI technologies [1-4]. In order to keep 90 nm BEOL circuit performance the same as the one for 0.13 um Cu/Low-k interconnection with k~3.0, Cu/Low-k interconnection with k<2.5 has to be developed. To overcome the integration challenges of porous and mechanically weak Low-k dielectrics in patterning, photoresist poisoning, CMP plannarization and damaging, pattern density sensitivity, Rc thermal stability and reliabilities, major process modifications are required. In this paper, performance improvements in different critical modules are reported..

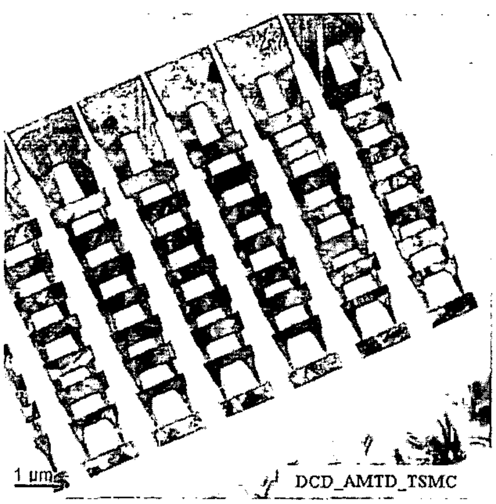

Fig. 1 Eight Cu/Low-k (k<2.5) + one top Cu/USG multilevel interconnection.

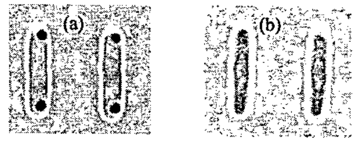

Fig. 2 SEM pictures (a) clear via (b) PR poisoned via

CVD Low-k Deposition

In this study, a high temperature plasma enhanced CVD of porous SiOC:H film with no need for post-annealing using alkyl-silane, carbon and oxygen containing precursors was investigated. The dielectric constant, k, the leakage current density at 1MV/cm and the breakdown field of this film were measured 2.5, 3.0E-9 A/cm2 and 6.5MV/cm using a mercury probe. Slightly tensile stress, 2E+8 ~7E+8 Dyne/cm2, and 0.5~0.9GPa in hardness were determined by stress Gauge and Nanoindentation. The film density was measured about 1.0~1.2 g/cm3 using a microbalance. The average pore size and porosity are ~ 6A and ~18%.

Dual Damascene Construction

In a via-first integration process, to avoid amines [4] induced PR (photoresist) poisoning, all N-free IMD film stack was used, including etch stop, Low-k, and cap materials. Fig.2 shows the PR poisoning around via holes if using nitrogen-containing dielectrics. The PR poisoning was commonly observed after trench lithography due to amine contamination in IMD film or through etch/ashing/wet processes. To further reduce total capacitance, no etch-stop layer for trench etching was used. Comparing the 0.12um/0.12um Cu width/space line to line capacitance measurements and Raphael simulations, the effective dielectric constant was calculated 2.6. The major reason to cause higher effective dielectric constant is damage in etch/ashing and moisture uptake in wet clean/CMP. Improvements in process damage will be conducted to reduce the k increase more.

A cap layer deposited on top of the Low-k was used to reduce the moisture absorption during processing, especially CMP.

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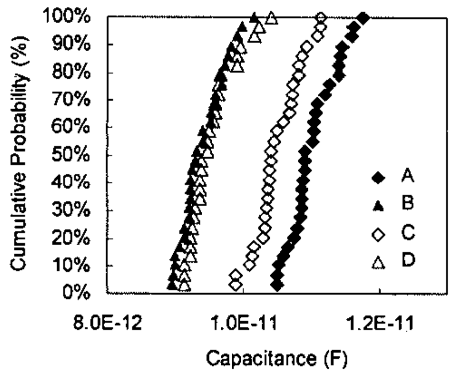

Fig. 3 0.12/0.12 um line to line capacitance (A) As CMP w/o cap layer (B) As CMP with cap layer (C) After Bake w/o cap layer (D) After Bake with cap layer

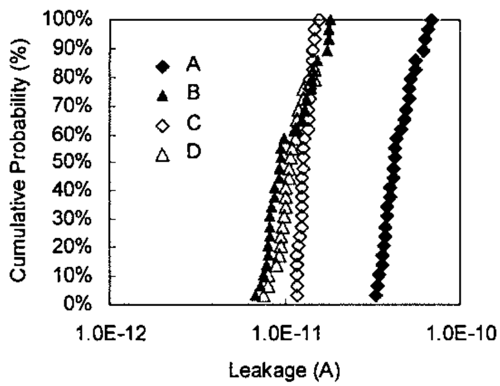

Fig. 4 0.12/0.12 um line to line leakage (A) As CMP w/o cap layer (B) As CMP with cap layer (C) After Bake w/o cap layer (D) After Bake with cap layer

Fig.3 and Fig. 4 show line to line leakage and capacitance measured from Cu/Low-k's with or without the cap layer after CMP and 400C 30 min N2 baking. Moisture uptake usually results higher line to line leakage current and capacitance due to strong polarity of Si-OH bond. Compared to the big percentage recoveries in the leakage or the capacitance of the Cu/Low-k without the cap layer after baking, almost no difference was observed for the Cu/Low-k with the cap, which demonstrates that the cap layer is effective in preventing moisture absorption.

CMP plannarization

The CMP used in this study is distinguished by the novel low friction CMP process [1]. Low friction force between wafer and polish pad results peeling free 8+1 level dual damascene structure as shown in Fig. 1. The novel CMP process benefits to resolving "Low-k recess" issue too. For a conventional CMP process Low-k recess occurred around wide Cu bond pads, as sketched in Fig. 5. By AFM (atomic force

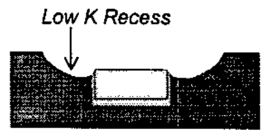

Fig. 5. Side view sketch of Low-k recess

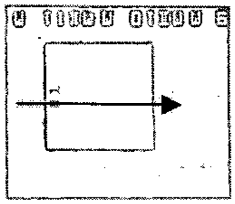

Fig. 6. Top view of scanning direction of AFM over Cu pad.

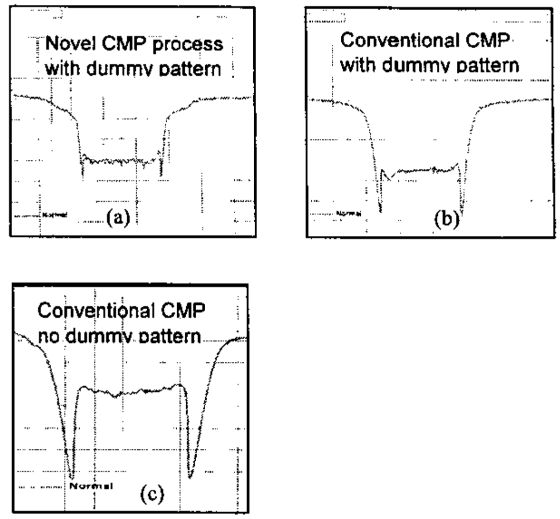

Fig. 7. AFM results of Cu pad (a) Novel CMP process with dummy patterns (b) Conventional CMP with dummy patterns (c) Conventional CMP without dummy patterns

microscope) measurement with scanning direction as shown in Fig. 6, the depth of Low-k recess could reach 1000A or above, as shown in Fig 7(c), which would result in Cu residues left in the area above the recess after upper-level CMP, hence electric short between pads and circuit will take place. Use of dummy patterns and the novel CMP process instead of conventional process effectively alleviated the Low-k recess from CMP. The Low-k recess was reduced to

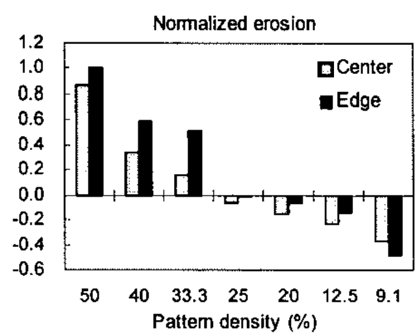

Fig. 8. Wafer center edge CMP erosion vs pattern density

less than 400A with dummy patterns only (Fig. 7(b)), or 200A with dummy patterns and the novel CMP process (Fig. 7(a)). Wafer center, edge and pattern density dependence of 0.12 um wide Cu lines on the normalized CMP erosion is summarized in Fig. 8. The normalized CMP erosion seems not sensitive to the location on wafer, but increased with the pattern density due to the high Cu/barrier/Low-k selectivity, and shows the erosion of a 25% pattern density area is nearly zero.

Electrical Results

A. Line to Line Leakage and Room Temperature Breakdown Field Ebd:

Line to line leakage and Ebd were found sensitive to the interface between Low-k and next level ES (etch stop layer). Fig. 9 to Fig. 12 show the leakage and Ebd comparison between ES or treatment splits. NH3 plasma treatment resulted in higher leakage and lower Ebd than H2 plasma pre-treatment as shown in Fig. 9 and Fig. 10. As for ES, nitrogen doped SiCN and two nitrogen free materials a-SiC and b-SiC

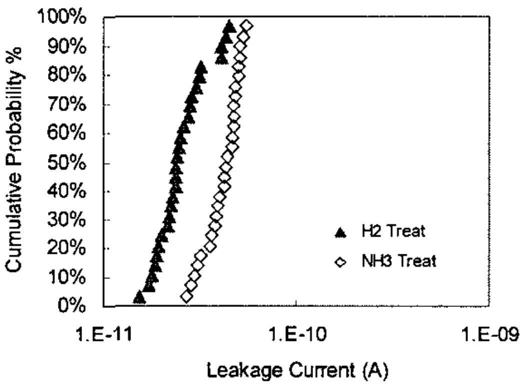

Fig. 9 0.12/0.12 um line to line leakage with pre-treat splits

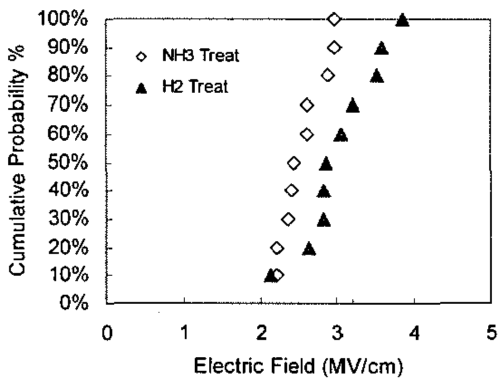

Fig. 10. 0.12/0.12 um line to line Ebd with pre-treat splits

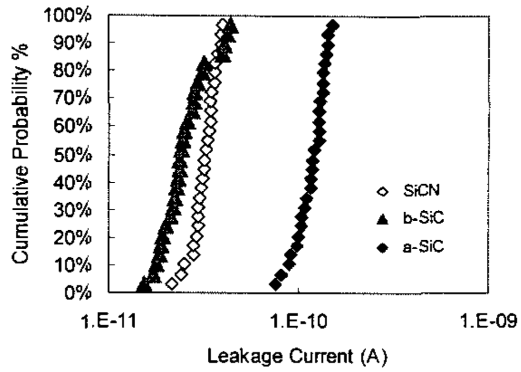

Fig. 11. 0.12/0.12 um line to line leakage with ES splits

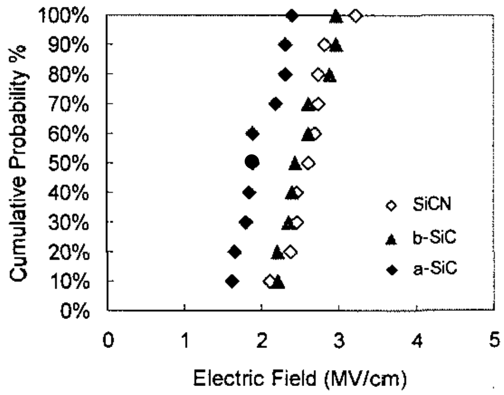

Fig. 12. 0.12/0.12um line to line Ebd with ES splits

are compared. All three ESs have the same adhesion strength to Cu and Low-k. The use of nitrogen free material is to prevent PR poisoning. However, the high electric leakage of nitrogen free SiC is an issue in circuit integrity. On the other side, SiCN has been proved to have good electrical performance but poor PR poisoning resistance as shown in

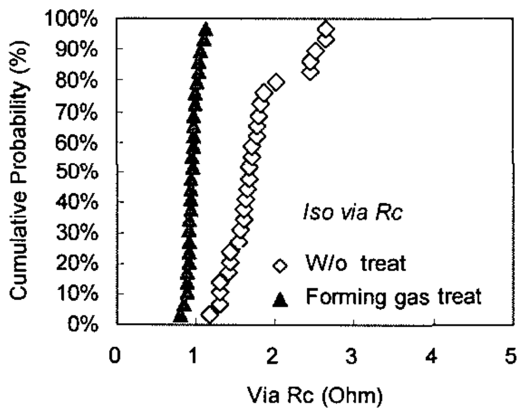

Fig. 13 0.13 um Iso single via

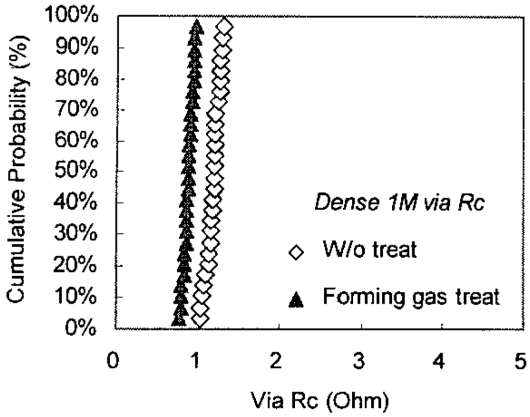

Fig. 14 0.13 um 1M via chain Rc

Fig. 2(b). To find good etch stop material to fulfill all requirements becomes a great challenge. By optimizing the deposition process, b-SiC material was found to have comparable electrical performance as SiCN as shown in Fig. 11 and Fig. 12.

B. Iso one Via and Dense 1M Via Chain Rc:

Via Rc integrity is another challenging part in the Cu/Low-k integration. Fig. 13 and Fig. 14 show the Rc performance of iso single via and 1 M via chain test patterns with and without forming gas treatment. Using forming gas treatment after ES opening to clean contaminated Cu reduced Rc value and tightened Rc distribution. The Cu vias thus built also showed better Rc thermal stability

Conclusion

90 nm generation Cu/Low-k (k<2.5) 8+1 multilevel interconnection has been successfully constructed for the first time. Nitrogen free IMD film stacks without extra dielectric amine blockers and trench etch-stops further reduced circuit capacitance. No delamination was found in 8+1 multilevel interconnection after CMP. Thermally stable iso or dense metal line Rs and via chain Rc were obtained.

References

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