Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 250-251

C-5-2

Mechanical property control of Low-k Dielectrics for Diminishing CMP-related Defects in Cu-damascene Interconnects

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1. Introduction

Introducing pores in the inter metal dielectric (IMD) materials is a general method to decrease the dielectric constant in 65nm-node ULSI interconnects. When the porosity increases in the IMD film, however, the mechanical stiffness and the adhesion strength decrease, resulting in defects during Cu-CMP process. At present, it is not well understood what is a critical mechanical-parameter of the porous low-k film to make the CMP-related defects, which is one of origins for the line-to-line leakage current paths.

In this paper, as shown in Fig. 1, we investigate the dielectric constant dependency of the mechanical strength and the adhesion energies of low-k films used in Cu damascene interconnects. It is found that the adhesion energy between low-k film and hard mask is a critical parameter for diminishing the CMP-related defects.

2. Experimental

As shown in Table 1, five kinds of low-k materials were used; SOD porous MSQs, SOD porous MSZ [1], a non-porous plasma-polymerized organosilicate film such as p-BCB [2], and a rigid CVD-SiOCH. In case of MSZ, the dielectric constant were changed from 2.3 to 2.8 (non-porous) by adjusting the porogen content. The low-k films were deposited on etch-stop (ES) layer of SiCN, and hard mask (HM) of SiO_2 film was deposited on the low-k films. Then, as shown in Fig. 2, Cu single damascene interconnects (Cu-SDIs) were fabricated by ArF photo-lithography, RIE, Cu-filling and Cu-CMP. The dielectric constant (k), the elastic modulus (E), the hardness (H), and the adhesion energies of HM/low-k (G_{C1}) and low-k/ES (G_{C2}) interfaces were measured by Hg-plobe, nano-indenter, and 4pt-bending [3], respectively. After conventional Cu-CMP, number of defects in 8” wafer was measured by KLA defect tester.

3. Results and Discussion

3-1. Mechanical Strength and Adhesion Energy

Fig. 3 shows the relation between the mechanical strength and the dielectric constant (k). The rigid CVD-SiOCH with k=2.9 had the highest modulus. The non-porous p-BCB had much lower modulus than the SiOCH, probably due to their difference in chemical backbones between the silicates and the organics. The porous MSQ-A had the lowest k-value of 2.2 and the lowest modulus. The porous MSQ-B had relatively high mechanical strength among the SOD-derived films regardless of the low k-value. The modulus of non-porous MSZ with k=2.8 was much smaller than that of the MSQ-B with k=2.4, and was decreased further with decreasing the k-value, or essentially increasing the porosity in the film. The k-value dependency of the hardness was identical to that of the modulus.

Fig. 4 (a) shows the relation between the k-value and G_{C1} obtained by the 4pt-bending. The substrate-breaking occurred in k>2.6 of the CVD-SiOCH and the MSZ film due to the extremely large adhesion energy. The p-BCB with k=2.8 also kept large adhesion energy. When the k-value decreased below 2.5, G_{C1} was decreased drastically irrespective of the low-k materials.

The G_{C2}, on the other hand, had weak dependability on the k-values except for the p-BCB as shown in Fig. 4 (b). The p-BCB had extremely high G_{C2} in spite of the low modulus. These facts suggest that the G_{C2} is affected not by the k-value but the material affinity, or the chemical composition, between the low-k films and SiCN.

Consequently, the MSZ is categorized as a low-k film having low modulus but large adhesion energy to the HM.

3-2. CMP-related Defects in SDIs

Using these low-k films, the defect density in the Cu-SDIs were plotted as functions of E, H, G_{C1} and G_{C2}, respectively. Fig. 5 shows the CMP-related defect density as a function of G_{C1}. The correlation coefficient (R)of 0.94 was the highest among the other plots, indicating that the CMP-related defect density was determined primarily by the G_{C1} irrespective of the modulus, hardness and G_{C2} of low-k films.

For example, the porous-MSZ film with k=2.64 had smaller E and H than those of MSQ-B, but the G_{C1} was much larger than that of latter. In fact, the CMP-related defect density of the MSZ was 40% smaller than that of MSQ-B. Fig. 6 shows the leakage current of the Cu-SDI with the porous MSZ (k=2.64). The leakage current within L/S=0.14μm/0.14μm was the same level as that of a rigid CVD-SiOCH film with k=2.9, indicative of no critical CMP-related defects in the porous MSZ film. By introducing the porous MSZ film of k=2.64 as shown in Fig. 7, the CR product of Cu-SDI was accomplished to decrease 5.9% refer to that of the rigid CVD-SiOCH (k=2.9).

4. Conclusion

It is found that, to diminish the CMP-related defects in Cu-SDIs, the adhesion strength of low-k film to HM is a critical factor more than the mechanical strength of low-k film itself. Due to the tight adhesion nature of the porous MSZ (K=2.64) to HM, the fine-pitched Cu-SDI was successfully obtained, improving the interconnect CR-delay of 5.9% to that of a rigid CVD-SiOCH film.

Acknowledgement

The authors would like to thank, Mr. T. Nagahara and Mr. H. Ishikawa, Clariant Japan, for the supplement of the MSZ monomer., and Ms. N. Hirata, TEL, for supplement of HAC (Hot Aging Chamber) in ACT8-SOD coater.

References

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[2] Y. Harada et al., Proc. of SSDM 2002, 180 (2002)
[3]G. Kloster et al., Proc. of IITC 2002, 242 (2002)

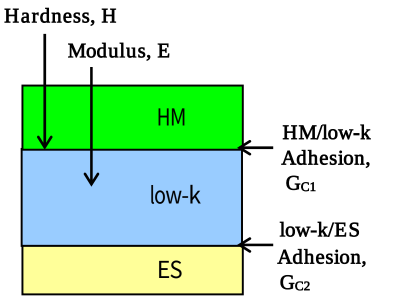

Fig. 1 Mechanical parameters of low-k films.

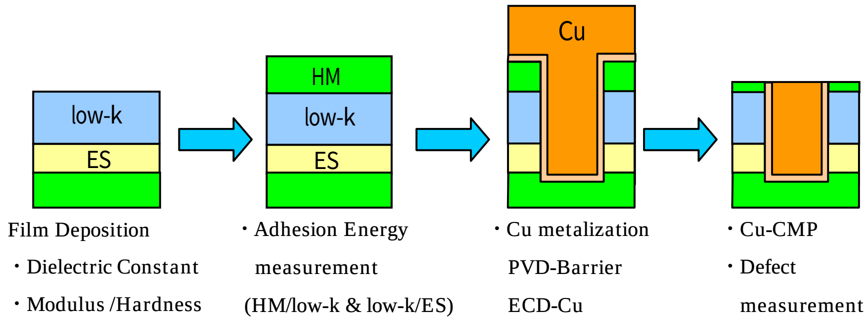

Fig. 2 Schematic diagram of process flow for Cu-SDI fabrication.

Table 1 Film properties of low-k materials

Low-k	Method	k	Mechanical Properties: Modulus E, (GPa)	Hard-ness H, (GPa)	Adhesion between HM and Low-k G_{C1} (J/m^2)	Adhesion between Low-k and ES G_{C2} (J/m^2)	Relative Defect density after Cu-CMP
Porous MSQ-A	SOD	2.2	2.4	0.40	3.3	1.15	10.0
Porous MSQ-B	SOD	2.4	6.6	0.94	5.8	2.52	2.6
Porous MSZ	SOD	2.64	3.6	0.44	> 8	3.22	1.6
p-BCB	Plasma-Polymerization	2.8	4.7	0.50	7.0	> 8	1.5
SiOCH	CVD	2.9	10.0	1.50	> 8	3.49	1.0

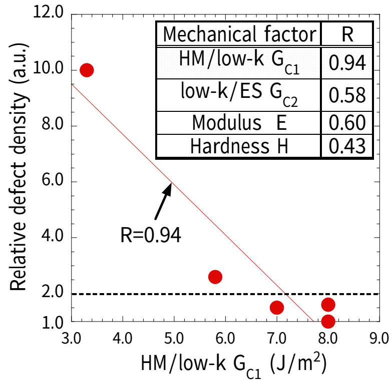

Fig. 5 Relation between the adhesion energy of HM/low-k interface (G_{C1}) and the relative defect density. The correlation coefficients of the defect density and G_{C1} as well as E, H and G_{C2} are listed.

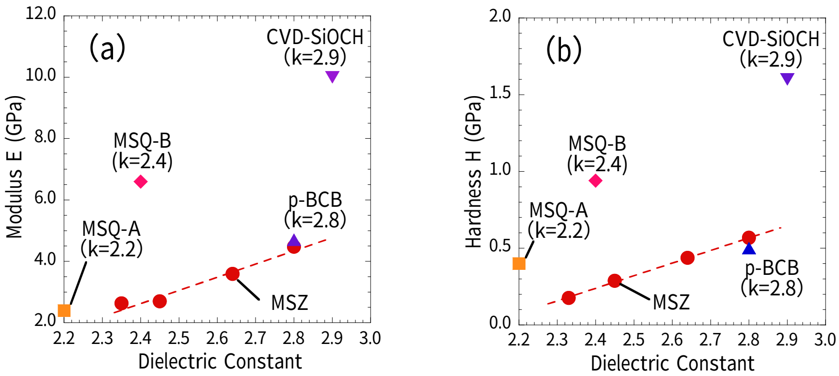

Fig. 3 Dielectric constant dependency of (a) modulus “E”, and (b) hardness “H” measured by a nano-indentation method.

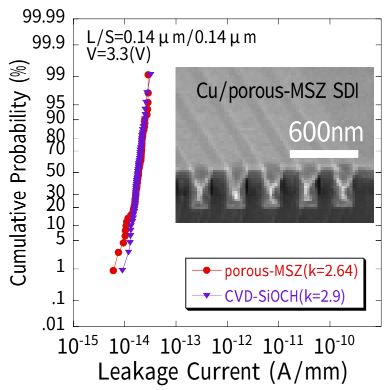

Fig. 6 Leakage currents of Cu-SDIs in the porous MSZ film of k=2.64 and the rigid CVD-SiOCH film of k=2.9.

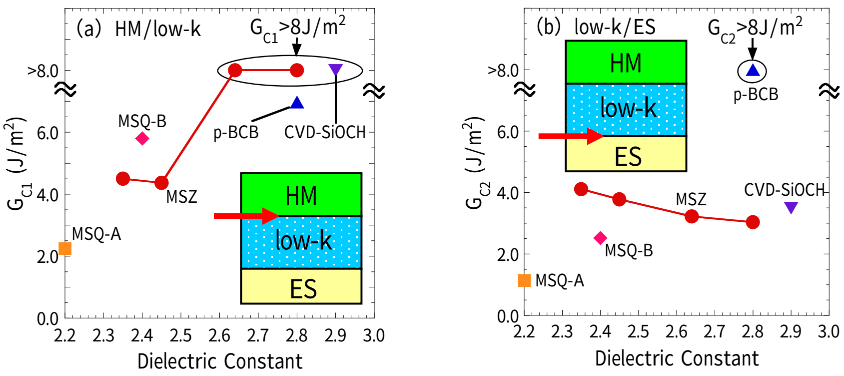

Fig. 4 Adhesion energies of (a) the HM/low-k interface, “G_{C1}” and (b) the low-k/ES interfaces, “G_{C2}” measured by the 4pt-bending method.

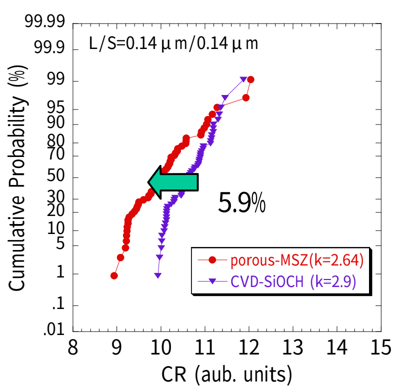

Fig. 7 CR product of Cu-SDIs in the porous MSZ film of k=2.64 and the rigid CVD-SiOCH film of k=2.9.