Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 256-257

C-6-1

High-modulus Porous MSQ Films for Cu/Low-k Integration (keff < 2.7)

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1. Introduction

Towards 65nm technology node, porous MSQ materials have been extensively developed to realize ultra Cu/Low-k interconnects (keff<2.7) for high-end processor and low-power SoC applications (1). However, application of porous materials to Cu interconnects causes serious reliability problems such as film delamination during Cu-CMP process, void formation in Low-k films after anneal (2) and an increase in leakage current between narrow lines.

In this study, we have studied the effect of porosity on these problems through 300mm-wafer integration of Cu with MSQ films whose porosity was systematically changed using the same MSQ base materials. Based on the results, we have developed high-modulus porous MSQ films (k=2.3) for reliable Cu/Low-k integration.

2. Experimental

The porosity of MSQ films were changed by making main-MSQ base materials fixed with various porogen contents. The 250nm thick porous MSQ films were coated and cured on 300 mm Si wafer, which was followed by deposition of 50nm thick capping CVD-SiC layers. The 320nm pitch damascene patterns were formed using ArF lithography and dual hard-mask dry etching processes. Dual hard mask process was used to suppress ashing damage to porous MSQ layer. After barrier metal and Cu electroplate deposition in the trench patterns, abrasive-free polishing was carried out with low pressure of 10kPa. Film delamination and voids in low-k films were observed using optical microscope, SEM and TEM.

Electrical properties and CMP compatibility were investigated as a function of the film porosity through 300mm-wafer Cu/low-k interconnects.

3. Results and Discussion

The film properties of MSQ samples are shown in Table 1. The sample A was formed using the standard MSQ material without porogen, and the other samples were prepared by introducing pores into the sample A. The film composition was constant in all the samples.

As shown in Fig.1, the dielectric constant proportionally decreased from 3.2 to 1.8, and the modulus of MSQ films drastically decreased from 17GPa to 1.6GPa with increasing the film porosity.

The correlation between the film porosity and film delamination area during Cu-CMP is shown in Fig. 2. As shown in this figure, high-porosity (> 30%), in other words low-modulus (< 8Gpa), MSQ films easily caused film delamination during low-pressure Cu polishing process. The film delamination occurred at the interface between porous MSQ layer and capping CVD layer. This result indicates that high-modulus low-k film (>8GPa) was needed for reliable CMP process.

The leakage current of MSQ films between lines was measured using L/S=160nm/160nm damascene pattern as a function of the film porosity. The annealing temperature of Cu interconnects was fixed at 250C. The correlation between cumulative probability of leakage current and porosity of MSQ films is shown in Fig. 3. It should be noted that the leakage current between Cu interconnects strongly depended on the porosity of MSQ films. An increase in leakage current became remarkable in the films with the porosity > 30%, where the number of voids in films drastically increased. Based on the results, we propose a guideline for the porous MSQ films that the porosity should be less than 30 % to maintain low leakage current between Cu lines as well as other process compatibility.

The FTIR peak ratios of Si-O/Si-CH3 are plotted as a function of the film porosity in Fig. 4. From Figs. 1 and 4, the film modulus and the peak ratio of Si-O/Si-CH3 decreased with increasing the film porosity although the film composition (Si:O:C) was constant. Consequently, the film modulus was correlated with the peak ratio of Si-O/SiCH3 in porous MSQ films. The film modulus was increased by improving MSQ materials and processes for high ratios of Si-O chemical bonds, although the porosity was not changed according the guideline. Thus, we have developed high-modulus (9.8 GPa) and low-k (k=2.3) porous MSQ films as shown in Fig.1.

In Fig. 5, the leakage current between the Cu interconnects (L/S=160/160nm and 160/140nm) was compared between high-modulus MSQ (k=2.3, 9.8GPa) and the conventional MSQ (sample C; k=2.2, 5.3 GPa) films. The degradation in leakage current was remarkable at S=140nm in the conventional MSQ films, whereas the leakage current characteristics was much improved in the high-modulus MSQ film. Consequently, high-modulus porous MSQ films is a promising low-k candidate for reliable Cu/low-k integration (keff<2.7).

4. Conclusions

We quantitatively investigated the effects of porosity of MSQ films on k-values, Young’s modulus, CMP compatibility, void formation after annealing, and leakage currents between Cu lines. Based on the results, we propose a guideline for porous MSQ films that the film porosity is needed more than 30% in terms of electrical results and process reliability. We have developed the high-modulus and low-k porous MSQ processes in 300mm-wafer Cu/low-k integration for 65nm node and beyond.

Acknowledgement

The authors sincerely thank ArF lithography group for their technical collaborations and Dr. N. Endo for technical discussions.

References

[1] ITRS Roadmap, Semiconductor Industry Association, San Jose, CA (2001)
[2] J. C. Lin et al., in Proceeding of IITC, pp.48-50, San Francisco, CA (2002)

Table 1 The film properties of MSQ samples.

test-sample	porosity (%)	density (g/cm3)	composition (atomic%)		
			Si	O	C
A	0	1.49	31	53	16
B	26.1	1.1	31	54	15
C	33.6	0.99	30	53	17
D	45.0	0.82	30	52	18
E	54.4	0.68	30	52	18

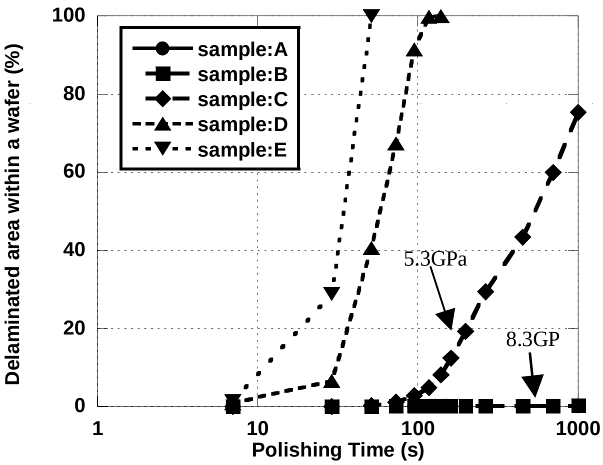

Fig. 2 The influence of film porosity on resistivity in Cu-CMP.

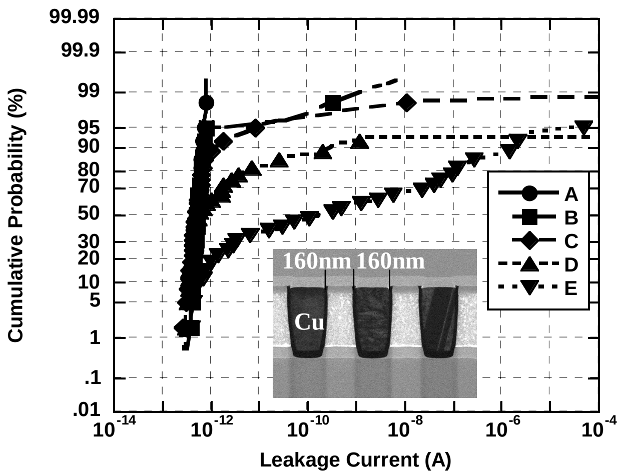

Fig. 3 The influence of film porosity for leakage current.

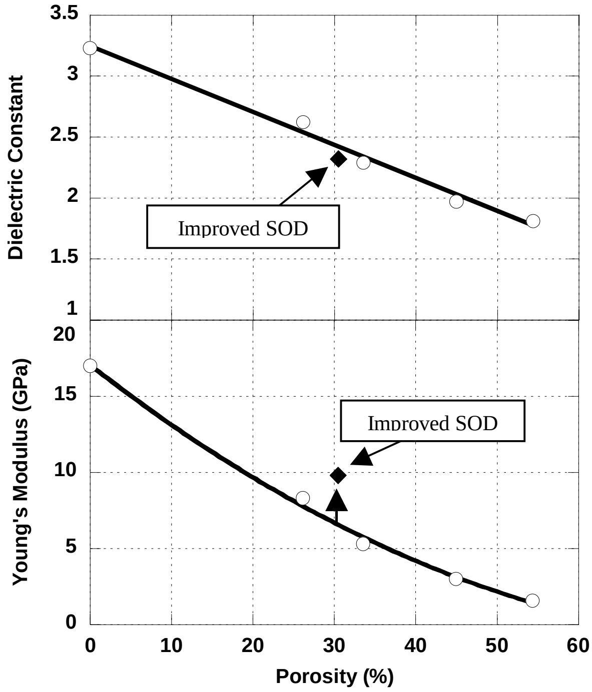

Fig. 1 The relationship between film porosity and dielectric constant or Young's Modulus.

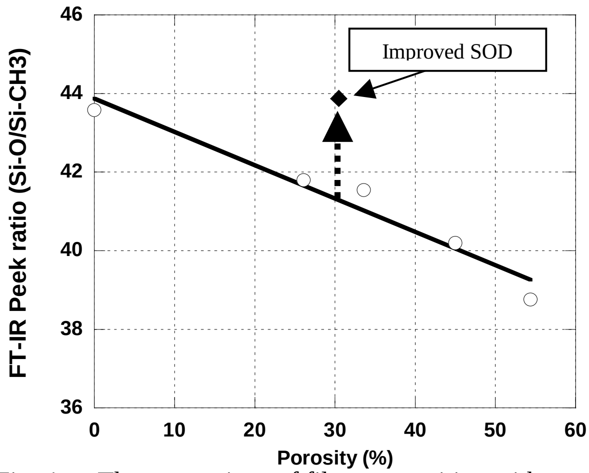

Fig. 4 The comparison of film composition with conventional porous-MSQ and improved SOD

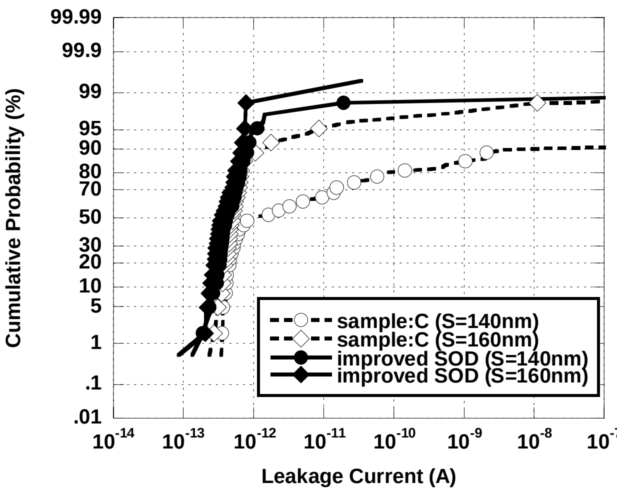

Fig. 5 The effect of improved SOD for leakage current. (Line width:160nm)