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# Comparative Studies of Pore Seal Films for Porous-Silica / Cu Interconnect

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## 1. Introduction

The leakage current in porous-silica low-k films was increased due to the damage induced by Cu plating solutions [1]. It is necessary to avoid permeation of wet chemicals such as Cu plating solutions into porous low-k films for achieving high reliability of the interconnects. A pore seal technology [2] is one of solutions to avoid permeation of wet chemicals.

In this work, the effects of pore sealing with different materials on the leakage current and dielectric constant were comparatively investigated.

## 2. Experimental

Self-assembled ultra low-k porous-silica films (k=2.09-2.12) with a thickness of 130 nm were formed on 300 mm Si wafers by spin-coating of a precursor solution of silica oligomer and nonionic surfactant [3-4]. The films were calcined to burn out the surfactant and to stabilize the chemical structure of the matrix. Subsequently, tetramethylcyclotetrasiloxane (TMCTS) vapor treatment was performed to enhance the elastic modulus and hydrophobicity of the films. The average pore size of the films was approximately 3 nm as measured by small angle X-ray scattering [4].

Plasma-polymerized BCB films, CVD SiOC films derived from dimethyldimethoxysilane (DMDMOS), or CVD SiCN films were deposited on the porous-silica films with thicknesses of 5, 10 and 15 nm.

The pore seal layer / porous-silica samples were dipped into a Cu plating solution for 70 seconds and rinsed with deionized water (DIW) for 90 seconds and then dried with pure nitrogen blow.

## 3. Results and Discussion

Figure 1 shows the dielectric constants and square of the refractive indices of porous-silica films and the pore seal films; BCB, SiOC and SiCN. Dielectric constants of the pore seal films were greater than that of porous-silica, so that a pore seal film must be as thin as possible to keep the effective dielectric constant low.

Figure 2 shows the contact angle of the pore seal films for DIW and the Cu plating solution. The contact angles of BCB and SiOC were about 85 and 105 degrees, respectively, indicating that SiOC has a higher hydrophobicity.

Figure 3 shows a cross-section TEM image of Cu damascene interconnects. The trench sidewalls of the porous-silica were covered with a 5nm thick BCB film for pore sealing.

Figure 4 shows the leakage currents in Cu / porous-silica damascene interconnects and out-of-plane porous-silica layer. The line-to-line leakage current of the Cu damascene with a metal pitch of 300nm was 10 times larger than that of the out-of-plane porous-silica, and the breakdown field defined at 1μA/cm$^2$ for the Cu damascene was lower than the out-of-plane. One of the causes of the difference in the leakage current level might be due to the difference in the extent of the permeation of a Cu plating solution into porous-silica because process induced damage is more significant in the Cu damascene structure.

Figure 5 shows the influence of line capacitance on pore seal thickness which covers trench sidewall of the damascene interconnects. Since the criterion of the incremental ratio of line capacitance with pore seal is less than 5 %, 5 nm thick SiOC film and 5 to 10 nm thick BCB film are able to be used as pore seal.

Figure 6 shows the leakage current in Cu / porous-silica damascene interconnects with line / space = 160 nm / 160 nm sealed with 5nm thick films. The leakage current for the SiOC pore seal was lower than the case of BCB and SiCN. It is found that a 5 nm pore seal layer was not enough for BCB and SiCN.

Figures 7 and 8 show the leakage current and apparent dielectric constant of porous-silica films as a function of pore seal layer thickness, after dipping the samples in the Cu plating solution and DIW. The leakage currents for BCB and SiCN pore seals thicker than 10 nm were less than $1x10^{-8}$A/cm$^2$, while the leakage current for SiOC sealing thicker than 5 nm was less than $1x10^{-9}$A/cm$^2$, which was almost equal to the leakage current level of a reference sample which was not dipped in the Cu plating solution. From the result of leakage current, it is possible to prevent permeation of Cu plating solution into porous-silica film by using 5 nm SiOC, 10 nm BCB or SiCN. The contact angle of SiOC more than 90 degrees shown in Fig. 2 implies that no penetration of the wet chemicals into porous-silica occurs through the SiOC pore seal even if small pin hole exist [5].

Considering the results of Fig. 5, 7 and 8, a 5 nm thick SiOC film and a 10 nm thick BCB film could be possible candidates as pore seal materials.

## 4. Conclusion

The performances of pore seals of BCB, SiOC and SiCN on porous-silica were compared in terms of the leakage current and apparent dielectric constant. It is found that SiOC film thicker than 5nm and BCB film thicker than 10nm are effective as pore seal.


## 5. Acknowledgements

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## References


[1] R. Yagi, et al., Symp. on VLSI Tech. (2005), to be presented.

[2] M. Tada, et al., IEEE IEDM2003 Tech. Dig. p. 845 (2003).

[3] Y. Oku, et al., IEEE IEDM2003 Tech. Dig. p. 139 (2003).

[4] N. Fujii, et al., Mat. Res. Soc. Symp. Proc. Vol. 812, F4. 10 (2004)

[5] Y. Yang, Journal of Pharmaceutical Sciences Vol. 70, No.7, p. 719 (1986).


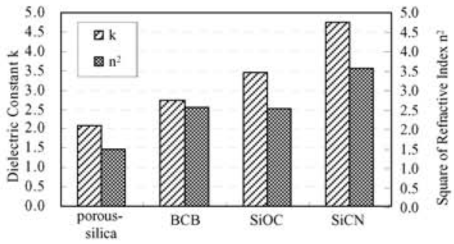


Fig. 1. Dielectric constants k and square of refractive indices $n^2$ of porous-silica, BCB, SiOC and SiCN

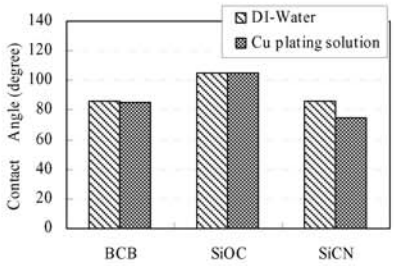


Fig. 2. Contact angle of the pore seals to DIW and Cu plating solution.

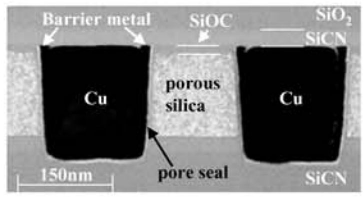


Fig. 3. A cross-section TEM image of interconnects.

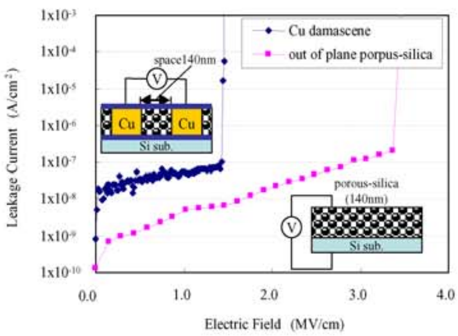


Fig. 4. Leakage current for Cu damascene and out-of-plane porous-silica layer.

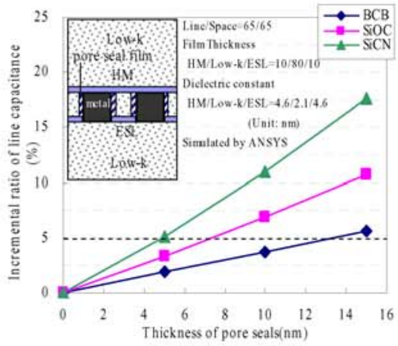


Fig. 5. A simulation result of increment of line capacitance for 45 nm node interconnects.

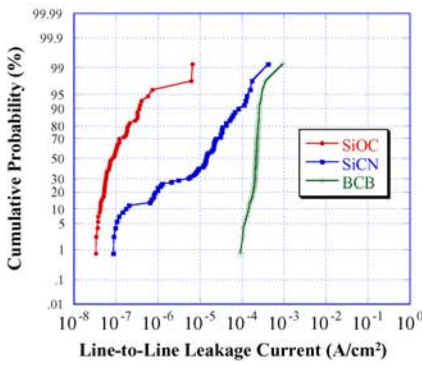


Fig. 6. Cumulative probability of line-to-line leakage current in each pore seal films of 5 nm thickness (line / space = 160 nm / 160 nm).

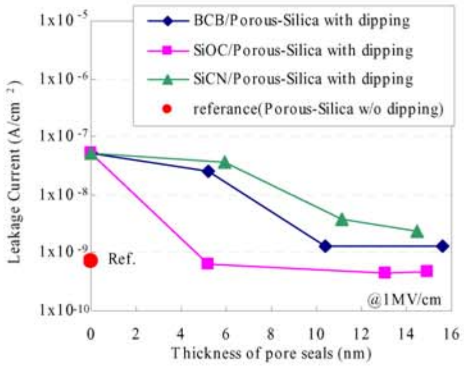


Fig. 7. Dependence of leakage current on pore seal layer thickness after dipping samples in a Cu plating solution and DIW.

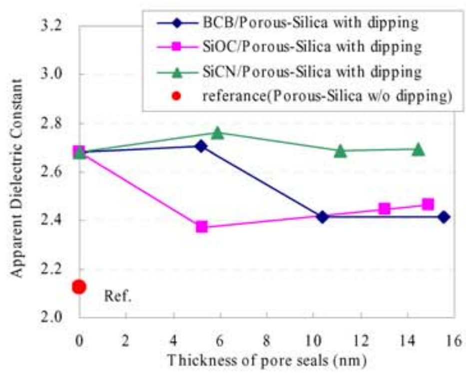


Fig. 8. Dependence of apparent dielectric constant on pore seal film thickness after dipping samples in a Cu plating solution and DIW.