

Hard Mask through UV Light-induced Damage to Low-k Film During Plasma Process for Dual Damascene

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1. Introduction

In general, to successfully form a dual damascene structure in low-k material, hard masks such as SiO₂ or SiN are used to protect the low-k films from the unnecessary chemical reactions with radicals or ions in the plasma process [1-2]. On the other hand, as many papers report, UV light has been used as a cure technique of low-k film for polymerization and porogen burnout [3]. However, excessive irradiation accelerates the carbon depletion in low-k film. As a result, it causes the DD profile deterioration, k-value increase, moisture uptake, mechanical strength change, etc. [4]. Considering the processes such as the via-hole/trench RIE process, resist removing after the etching process and resist removing in rework, it is a concern that UV light from plasma can penetrate the hard mask and have an impact on the low-k film under the hard mask film. In this study, hard mask through UV damage to the low-k film during plasma process for dual damascene was studied in detail.

2. Experiment

Figure 1 shows the sample structures used in this experiment. The thickness variation of the TEOS hard mask is 15, 115, 315 and 515nm. First, a 15nm TEOS film was deposited on a 500nm SiOCH film ($k=2.4$), and additional TEOS film was deposited with several thicknesses. For the SiN hard mask case, a SiN film (300nm) was deposited on the 15nm TEOS film. No pretreatment of the TEOS film deposition was performed.

Inductive coupled plasmas, namely O₂, He, H₂ and Ar, were irradiated to the samples in this experiment. The samples were not heated during plasma irradiation. The plasma irradiation time was 60 and 300sec.

3. Results and discussion

Figure 2 shows carbon profiles measured by EELS of the TEOS (15nm) /SiOCH sample before and after the O₂ plasma irradiation. One can observe a moderate C-profile in the vicinity of the TEOS/SiOCH interface, even if O₂ plasma is not irradiated. This carbon depletion is due to the plasma damage of TEOS hard mask deposition process. The damage was directly caused by chemical reaction and UV damage during the TEOS film deposition process. Furthermore, the O₂ plasma irradiation accelerates the damage and makes the C profile broader.

Figure 3 shows TDS results of the samples without and with O₂ plasma irradiation. It is clearly shown in Fig.3 (a) that outgas of $M_z=18$ (H₂O) increases with the O₂ plasma irradiation. Referring to the results of Fig.2, it is considered that this outgas originates from absorbed moisture with dangling bonds in the damaged region of the SiOCH film. Figure 3 (b) shows outgas of $M_z=15$ in TDS. More outgas was detected in the samples with the O₂ plasma irradiation. It is considered that CH₃ fraction easily decomposed from the SiOCH film owing to the UV photon irradiation, and was released by thermal assist. On the other hand, Fig.4 shows TDS result of TEOS (15nm)/SiOCH sample exposed to O₂ radical for 600sec. There is no difference in CH₃ outgas depending on the irradiation. As a result, it was proven that the SiOCH film was protected from a chemical reaction by the TEOS hard mask. That is, the damage to the SiOCH film by the O₂ plasma irradiation shown in Figs 2 and 3 is damage by the UV photons from the plasma infiltrated through the TEOS hard mask. Figure 5 also demonstrates the TEOS hard mask through UV damage. Outgas of CH₃ from the plasma-irradiated sample has a dependency on plasma gas source. This result can be basically understood in terms of the difference of penetration length and photon energy of the UV light. Photon energies and wavelengths of UV lights, which are proportional to the reciprocal of the penetration length, are 10.2eV/121.5nm and 7.8eV/160nm for H₂ plasma [5], 9.5eV/130.5nm for O₂ plasma, 11.8eV/104.8nm and 11.6eV/106.6nm for Ar plasma, and 21.2eV/58.4nm for He plasma [6]. Photon energies of O₂, Ar, H₂ plasma are relatively close. Among these samples, longer wavelength of UV photon can penetrate deeper and make deeper damaged region in SiOCH. On the other hand, the He plasma has the shortest UV wavelength. By analogy, the shortest damage depth is expected in the He plasma case. However, the He plasma case showed the second largest outgas in Fig.5. This is due to the extremely high UV energy of He plasma. In this case, although the penetration depth is shallow, the energy was effectively consumed to decompose the SiOCH film near the TEOS/SiOCH interface and induces serious damage in the shallow region.

It was confirmed for the first time that the SiOCH film was protected from a chemical reaction of plasma by TEOS hard mask. However, the plasma damage still pro-

gressed owing to the UV light penetration though the TEOS film. This will become a serious problem in an actual multilevel wiring process.

Next, the film thickness dependency of the TEOS hard mask was investigated. As shown in Fig. 6, the UV irradiation impact observed in the above results was hardly seen in the case of TEOS of 115 nm or more. The UV photon whose wavelength is less than 120nm cannot penetrate the SiO₂ [6]. Conversely, the TEOS film thickness dependency is of interest. The carbon content decreased with increasing of the TEOS film thickness. This result means that TEOS film deposition process inflicts much stronger UV damage to the low-k film than this O₂ plasma irradiation experiment does. In this experiment, we used the O₂ plasma irradiation to demonstrate plasma damage. In the actual PE-CVD deposition process, there is a variety of plasma UV luminescence from several elements such as O, C, H, and He, and the SiOCH film is exposed to higher energy UV light in the TEOS deposition process. In addition, TEOS deposition temperature is around 400C although the samples were not heated in this O₂ plasma irradiation experiment.

4. Conclusion

A TEOS hard mask through UV-induced damage of

low-k film was demonstrated for the first time by a plasma irradiation experiment. The hard mask can protect the low-k material from direct chemical reaction and damage, but UV photons can penetrate the hard mask and induce damage in the low-k film. The hard mask through UV damage showed photon energy and penetration depth dependency. Furthermore, it was found that the hard mask through UV damage during the hard mask deposition process is more serious because the process includes high-energy UV photons and high process temperature. The hard mask through UV damage found by this experiment is sure to become a serious problem in the dual-damascene process with low-k material.

References

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- EELS: Electron Energy-Loss Spectroscopy
TDS: Thermal Desorption Spectroscopy
AES: Auger Electron Spectroscopy

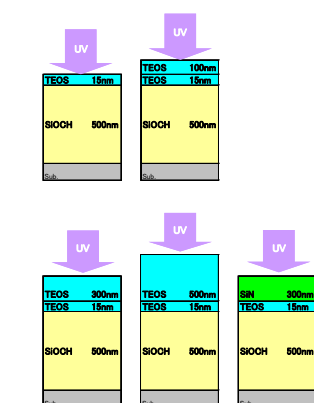


Fig.1 Experimental sample structures to evaluate the plasma UV damage to low-k film through the hard mask SiO₂ (TEOS)

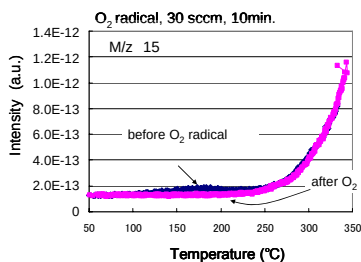


Fig. 4 TDS results of the TEOS (15nm) /SiOCH sample before and after the O₂ radical treatment for 10min.

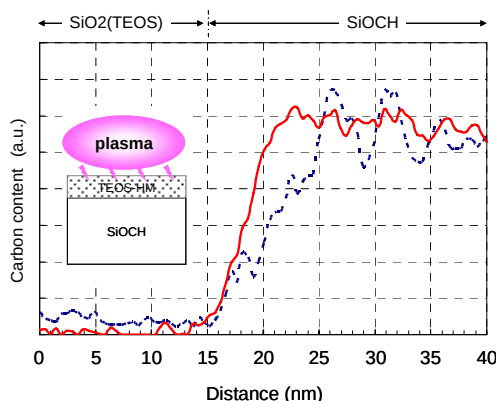


Fig. 2 Carbon profiles in the sample of the TEOS (15nm)/SiOCH before and after the O₂ plasma irradiation. (by EELS)

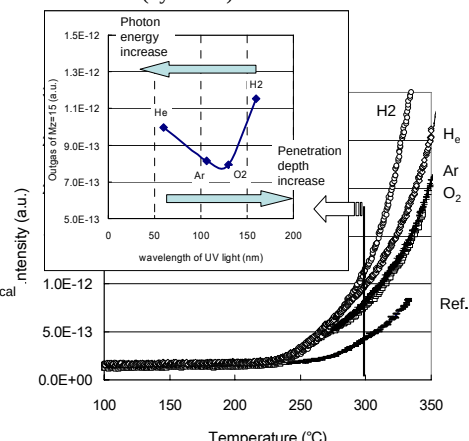


Fig. 5 Plasma gas source dependence of Mz=15 outgas in TDS. The sample structure measured is the TEOS (15nm) /SiOCH

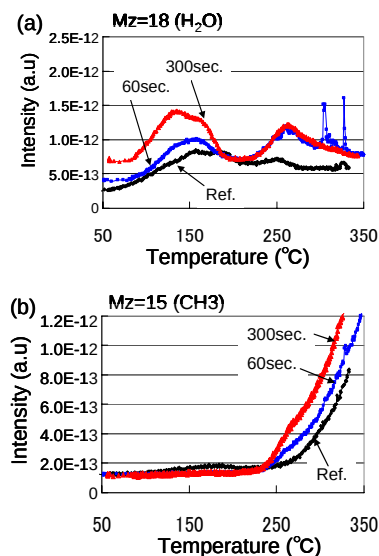


Fig. 3 TDS results of the TEOS (15nm) /SiOCH sample before and after the O₂ plasma irradiation.

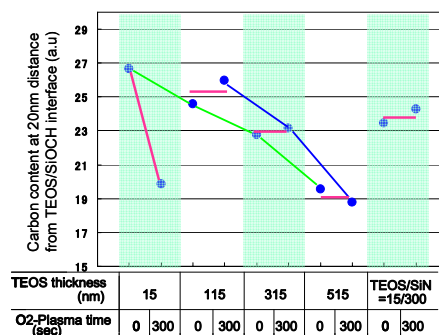


Fig. 6 Carbon content at the point of 20nm from TEOS/SiOCH interface. (by AES)