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C-3-2

Impact of Barrier Metal Sputtering on Low-k SiOCH Films with Various Chemical Structures

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1. Introduction

Dielectric permittivity for the interconnect isolation in the advanced LSIs is decreasing to reduce the signal propagation delay. Partial replacement of Si-O component with C-based one and incorporation of pores into the matrix are practical ways to reduce the k-value. These approaches, however, are likely to cause process-induced degradation of the film. Etching and photo-resist removal processes are intensively studied in terms of the plasma damage, as shown in Fig.1. [1,2] In addition, sputtering of the barrier metals is another possible process to deteriorate the low-k film due to the plasma. This paper describes the effects of sputtering process on the low-k degradation.

2. Experimental

RF plasma with DC bias was utilized for Ta or TaN (Ta(N)) sputtering, as illustrated in Fig.2. The figure also includes schematics of the target and plasma potential, and the average potential across the chamber. Since the DC bias is considered as an offset of the self-bias V_{sb} in the sheath voltages, it enhances sheath voltage at the target side and decreases at the wafer side, resulting in higher sputtering rate for the target and lower ion bombardment to the wafer.

Samples were fabricated through low-k depositions, followed by the Ta(N) sputtering. Thermally evaporated Au through the shadow mask on the blanket Ta(N)/low-k stack acted as an etching mask to define the MIS structure, as shown in Fig.3. The k-value was derived from the capacitance and the film thickness from SEM observation. The chemical structure was investigated by FTIR analysis..

Table 1 lists three kinds of low-k materials, investigated in this work. The conventional porous SiOCHs had almost the same film composition as the rigid one, and introduction of pores decreased the density and k-value. The MPS SiOCH was obtained by plasma polymerization process using special precursor molecules of hexagonal Si-O ring structure with higher order hydrocarbon side-chains, resulting in lower density and higher C concentration. [3]

3. Evaluation of Sputtering Damage

First, the conventional porous SiOCH was investigated to see the impact of sputtering process. Fig.4 reveals that the sputtering process reduced the low-k film thickness. It is found that DC bias had a significant impact on the k-value, as plotted in Fig. 5. Low DC bias, increasing the sheath voltage at the wafer side, increased the k-value over 3.0, while higher biases keep the k-value low even after the Ta(N) deposition. Fig. 6 shows FTIR spectra for the porous SiOCH films after Ta(N) deposition under various DC biases. Si-CH_3 bond was an important chemical structure to reduce the k-value, however, the Si-CH_3 peak in the FTIR spectrum was diminishing with decreasing the DC bias, or essentially increasing the wafer-side bias. This phenomenon is consistent with the k-value increment. Since FTIR reflects the chemical structure in the film bulk, the bulk properties, not only the surface, is deteriorated through sputtering. This bias dependence indicates that the sputtering induced damage is linked with the ion bombardment.

4. Effect of Low-k Properties on Sputtering Damage

Fig.7 shows increment in k-value as a function of the DC bias for various low-k materials. Comparing the rigid SiOCH with the porous one having similar chemical composition, presence of the pore in the film enhanced the plasma-induced damage. In contrast, the MPS film exhibited the highest endurance against the damage, in spite of the lowest density. Fig. 8 shows the specific FTIR peaks for the MPS films. Application of the DC bias intensified the Si-CH_3 peak with reduction of the hydrocarbon peak.

Trends in the Si-CH_3 and hydrocarbon peaks for all low-k materials were plotted in Fig.9. In cases of the rigid and porous SiOCH, both peaks decreased with decreasing the DC bias, or essentially increasing the wafer bias. Reduction of hydrocarbon in the MPS at lower bias was observed as well as the other SiOCHs, however, Si-CH_3 component increased by lowering the DC bias in this case.

For the rigid and porous SiOCH, similar behavior in both of hydrocarbon and Si-CH_3 implies that methyl group, which is considered as a major low-k component in these films, is removed away from the silica backbone due to ion bombardment. In the case of the MPS, however, higher order hydrocarbons are partially decomposed prior to breaking the Si-CH_3 bond, as shown in Fig. 10. Partial decomposition of large hydrocarbon eventually leads to the smallest hydrocarbon group (-CH_3), attached to the silica backbone in the MPS. Remained large hydrocarbons protect the low-k component by sacrificing themselves.

5. Conclusions

Impact of barrier metal sputtering on the low-k damage was presented. Since ion bombardment causes significant degradation of low-k material, higher DC bias, which reduced sheath voltage at the wafer surface, suppresses the process-induced damage. The MPS SiOCH of hexagonal Si-O backbone with large amount of hydrocarbon groups, is another approach to suppress the damage due to protection of Si-C bond during the plasma process.

Acknowledgements

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References

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[2] M.A.Worsley, et.al., J.Appl.Phys., 101, 013305 (2007).
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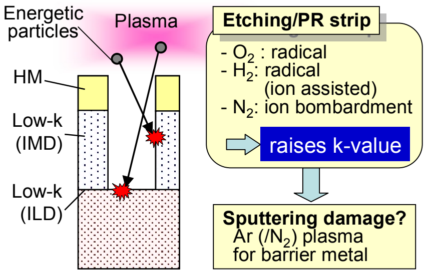

Fig.1 Impact of the plasma process on the advanced interconnect with low-k dielectric. Barrier metal sputtering is also plasma process, which might cause low-k degradation.

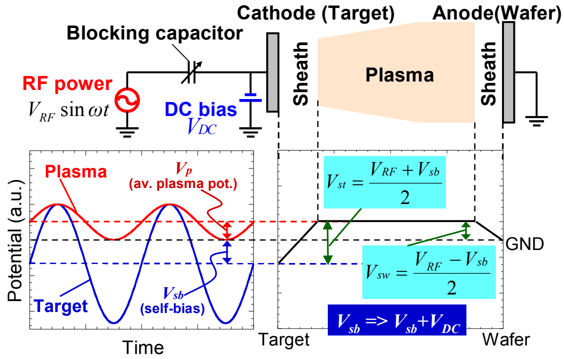

Fig.2 Concept of the RF-DC coupled sputtering system from the viewpoint of potential distribution. DC bias modifies both cathode and anode sheath voltages, resulting in higher voltage at the target and lower voltage at the wafer surface.

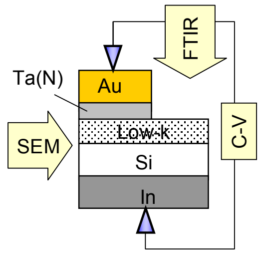

Fig.3 Schematic illustration of the evaluation structure and experimental procedure in this work.

Table 1 Properties of low-k materials, investigated in this work.

Low-k film	Rigid SiOCH	Porous SiOCH	MPS SiOCH
k-value	2.9	2.6	2.5
Pore size (nm)	-	0.65	0.36
Density (g/cm^3)	1.49	1.26	1.13
Si:O:C	1:1.6:0.8	1:1.5:0.7	1:1.1:3.2
Modulus (GPa)	12	3.9	2.8

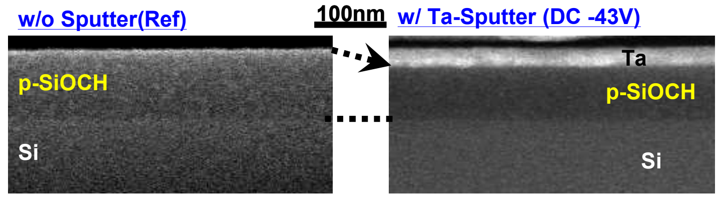

Fig.4 Cross sectional images of porous SiOCH before and after Ta deposition. Sputtering reduced the dielectric thickness.

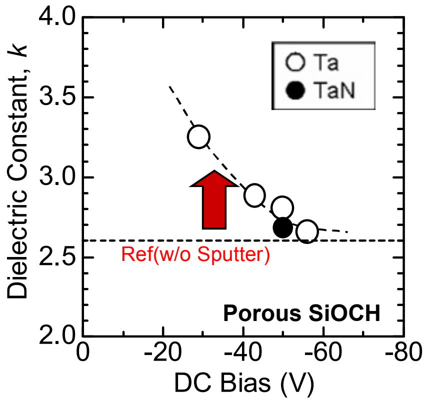

Fig.5 Dielectric constant of the porous SiOCH film after Ta(N) deposition as a function of DC bias for the sputtering. Lower bias increased k-value of the low-k.

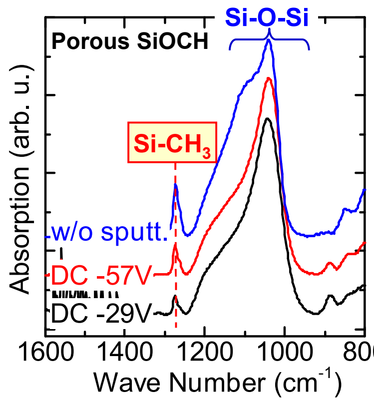

Fig.6 FTIR spectra of the porous SiOCH after Ta(N) sputtering followed by Ta(N) removal. As sputtering DC bias decreased, $Si-CH_3$ peak dropped.

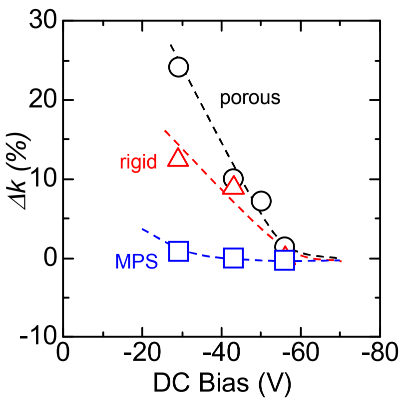

Fig.7 Increment in k-value vs. DC bias for the sputtering for various low-k materials. MPS showed minimum degradation in k-value among investigated low-k film.

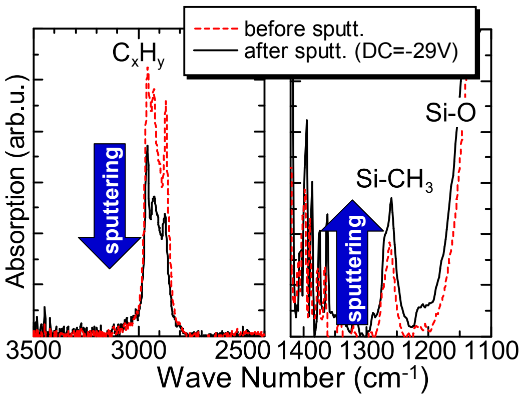

Fig.8 Magnified FTIR spectra of hydrocarbon and $Si-CH_3$ in the MPS film with and without Ta sputtering. Sputtering lowered the hydrocarbon peak height, and enhanced $Si-CH_3$ peak simultaneously.

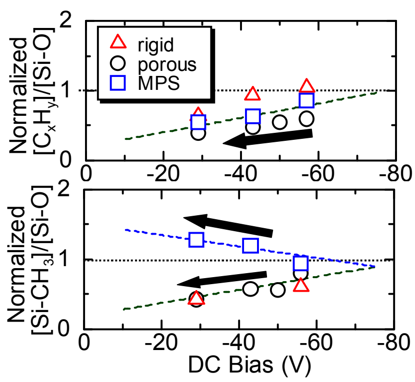

Fig.9 Trend of FTIR peaks with the DC bias. The peak ratio was normalized with that obtained from each low-k film before sputtering.

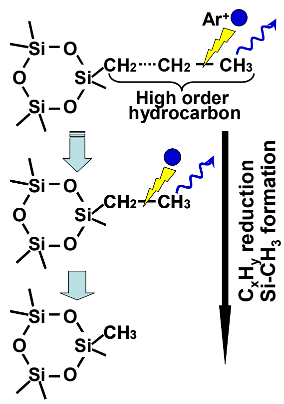

Fig.10 Schematic model of ion bombardment effect on the MPS films with higher order hydrocarbon.