Extended Abstracts of the 1996 International Conference on Solid State Devices and Materials, Yokohama, 1996, pp. 818-820 **Sympo. II-11**

Effect of Bias Addition on the Gap-Filling Properties of Fluorinated Amorphous Carbon Thin Films Grown by Helicon Wave Plasma Enhanced Chemical Vapor Deposition

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The gap-filling properties of fluorinated amorphous carbon thin films (a-C:F) for low dielectric constant interlayer dielectrics were investigated. The a-C:F films grown by plasma enhanced chemical vapor deposition from C_2F_6 were not filled the gap between wirings without void with no bias addition. By adding 400kHz bias power to the substrate, it is revealed that the films could be fill the gaps without voids. The bias power to fill the films between gaps was 50W and the dielectric constant of the films did not changed from 2.1 by the bias addition.

1. Introduction

The device shrinkage and high performance of ULSI circuits requires low dielectric constant interlayer dielectrics. Now considerable number of works have been reported about SiOF films with a dielectric constant of around 3.5, because this films have a good process compatibility with conventional SiO_2 process. However, for the future shrinkage of the design rule of interconnections, it is required to investigate the other materials that have lower dielectric constant than SiOF films[1]. Low dielectric constant polymers are promising because the dielectric constant of polymers is lower than inorganic materials[2]. Recently, we have proposed fluorinated amorphous carbon thin films (a-C:F) which have both cross-linking structure as in polyimide and C-F bond as in PTFE (polytetrafluoroethylene) for new low dielectric constant interlayer dielectrics of ULSI interconnections[3),4)]. The a-C:F films can be deposited with high deposition rate (around 300nm/min) using helicon wave plasma enhanced chemical vapor deposition with 100% C_2F_6 and CH_4. The dielectric constant of the a-C:F films was 2.1, which was much lower than the conventional SiO_2 dielectrics (ε_r=4.0).

In order to achieve multilevel interconnection system of ULSI circuits, it is necessary to fill the a-C:F dielectric films between aluminum wirings without voids. In this study, we investigated the gap filling properties of the a-C:F films.

2. Experiment

The plasma enhanced CVD reactor used in this study was helicon wave plasma reactor (ANELVA HBiC). The source gases were C_2F_6 and CH_4. Figure 1 shows the schematic diagrams of the helicon wave plasma reactor. The 13.56 MHz 3kW rf source was coupled to the helical coil wound around the quartz tube. The 400kHz bias power was applied to the substrate. 6-inch Si wafers with TiN/AlSiCu/TiN line and space patterns (width 0.6μm, height 0.6μm, gap 0.6μm) were used as substrates.
The source power and deposition temperature was fixed at 2kW and 90°C, respectively. Bias power and pressure during deposition were changed.

When the films were deposited with C_2F_6 directly on the substrate, the films peeled off from the substrate. However, the peeling was suppressed by inserting the thin hydrogenated amorphous carbon (a-C:H) buffer layer between the substrates and the films.

The dielectric constant of the films was measured by the C-V measurement of Al/a-C:F/P^+Si diode at 1MHz. The capacitance component from the a-C:H buffer layer (ε_r=4.0) was removed by the calculation when we determined the dielectric constant of the films.

3. Result and discussion

Figure 2 shows the SEM image of gap-filling property of the a-C:F film with C_2F_6 with no bias addition. The pressure was 1.5mTorr. The a-C:F film was filled between the gaps. However, a wedged structure which leads void was formed above the aluminum wirings. This indicates that the a-C:F films at the top of the aluminum wiring form overhang structure, and no film grew under the overhang. Figure 3 shows the SEM image of a-C:F films with high deposition pressure. There is little difference in the gap-filling property, and wedges were still formed. It is known that the deposition of amorphous carbon is assisted by ion bombardment[5]. Therefore, no deposition occurred under the wedge. The wedged structure at the top of the wiring can also be explained by the high ion irradiation at the edge.

To remove the wedged structure, it is necessary to reduce the deposition rate of the films at the edge of the wiring like the biased ECR-CVD of SiO_2[6]. The gap-filling method of SiO_2 CVD based on the fact that the deposition and sputtering rate greatly depend on ion-incident angle, and the film at the slanting edge of the substrate was sputtered by Ar ions[7].

On the other hand, it is understood by the reactive etching study of fluoro-carbon plasma that the etching reaction due to CF_X ions also occurred simultaneously when the a-C:F film was deposited, and the etching reaction was enhanced by the bias voltage[5]. This suggests that the deposition rate at the top edge of wiring can be reduced and wedged structures can be removed by the bias addition without Ar ion bombardment. Then, the a-C:F films were deposited with bias addition. Figure 4 shows the dielectric constant and deposition rate of a-C:F films as a function of bias power. The deposition rate of the films decreased as the increase in bias power. The reduction of the deposition rate as the increase in bias power shows that the etching reaction of the films was enhanced by the bias power. At more than 100W, the etching reaction was stronger than the deposition and no a-C:F film was deposited. On the other hand, the dielectric constant of the films did not increase by the addition of bias power. The independence of dielectric constant to the bias power indicates that the structure of the films was not changed by the bias addition.

Figure 5 shows the SEM image of gap-filling property of the a-C:F film at 50W bias power. The gap filling property was changed by the addition of bias power, and wedges were successfully removed. With the addition of bias power, the etching reaction of deposited films occurs. This reaction reduces the deposition rate at the top edge of the wirings and attaches the deposition precursors from the bottom of the gaps. Thus, we found that the addition of bias power to the substrate was effective to fill the a-C:F films between gaps of wirings without void and dielectric constant change. For the future integration, the deposition of interlayer dielectrics will be followed by chemical mechanical polishing (CMP). This rippled surface formed by the bias addition is suitable for the future CMP process.

4. Summary

The a-C:F films grown by plasma enhanced CVD from C_2F_6 can not fill the gaps between aluminum wirings without voids. However, it is revealed that by the addition of 50W bias power, it can be filled without voids. The dielectric constant did not changed by the bias addition.

Acknowledgment

The authors would like to thank Dr. J. Sakai, Dr. Y. Tamura, and Dr. Y. Inoue of ANELVA corporation for their help with sample preparation and discussion.

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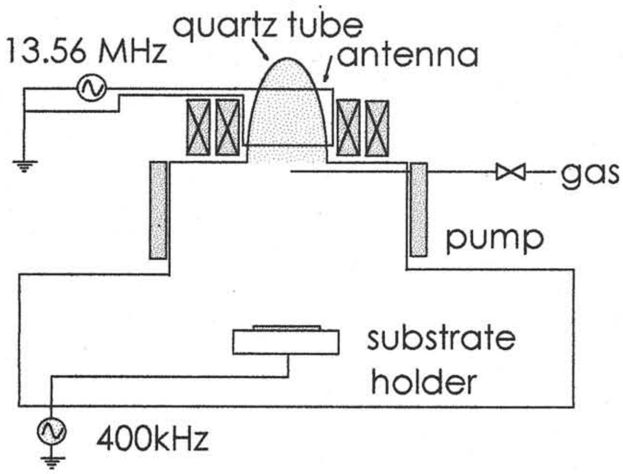

Fig. 1 Schematic diagrams of the helicon wave plasma CVD (ANELVA HBiC).

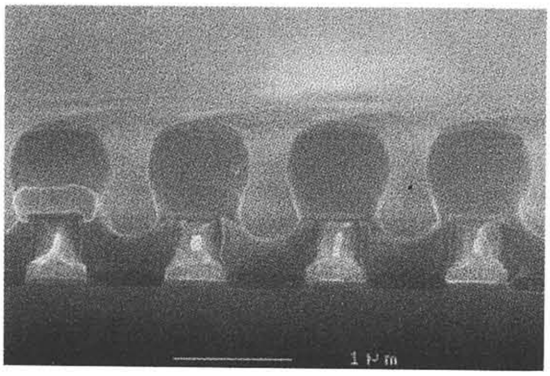

Fig.3 SEM image of gap-filling property of a-C:F film with C_2F_6. (P=12mTorr, No bias)

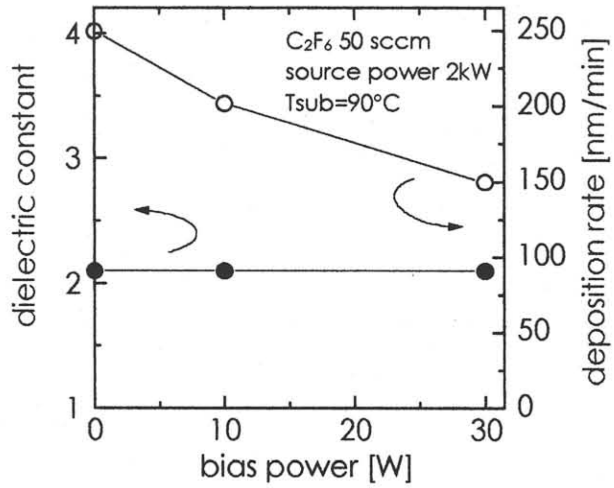

Fig. 4 Dielectric constant and deposition rate of a-C:F films as a function of bias power.

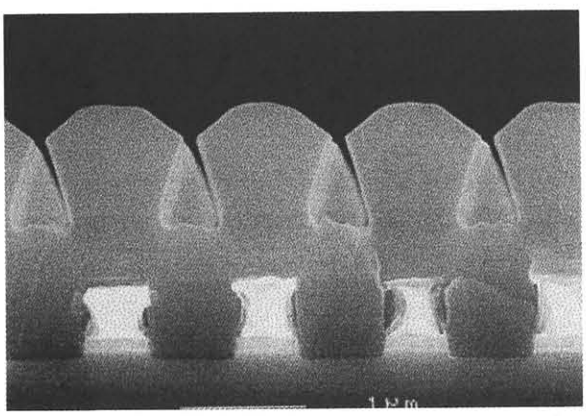

Fig.2 SEM image of gap-filling property of a-C:F film with C_2F_6. (P=1.5mTorr, No bias)

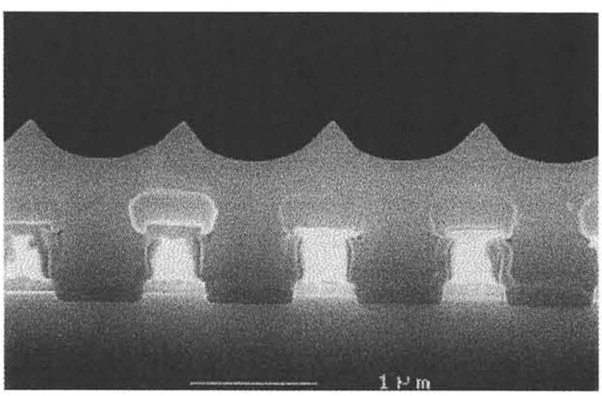

Fig.5 SEM image of gap-filling property of a-C:F film with C_2F_6. (P=1.5mTorr, bias 50W)