Extended Abstracts of the 2007 International Conference on Solid State Devices and Materials, Tsukuba, 2007, pp. 380-381

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The Evaluation of New Amorphous Hydrocarbon Film aCHx, for Copper Barrier Dielectric Film in Low-k Copper Metallization

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1. Introduction

In recent ULSI, Cu wiring and low-k dielectrics are used to reduce RC delay in interconnect. In order to increase operating speed, the reduction of capacitance for interlayer dielectric using ultra low-k materials has been required. Even though ultra low-k materials have been applied, relatively high k-value materials such as SiC or SiCN have to be used for Cu diffusion barrier. As a result, it is difficult to reduce the effective k-value (k_{eff}) of dielectrics.

For this problem, we propose the solution by developing of an amorphous hydrocarbon film (aCHx) as a new Cu barrier dielectric and present basic property of aCHx film and also show its Cu diffusion barrier capability in this paper.

2. Experimental

Figure 1 shows the microwave-excited plasma deposition equipment incorporating the showerhead structure for 200mm-diameter wafer in this study. This plasma source characterizes low electron temperature and high plasma density [1]. Additionally, using the lower showerhead to introduce the source gases into diffusion plasma region, the excessive dissociation of source gases could be prevented. Various hydrocarbon gases such as CH_4, C_2H_2 and large hydrocarbon molecules have been evaluated in this equipment.

We evaluated the fundamental properties with FT-IR, Elastic Recoil Detection Analysis: ERDA, I-V characteristics and dielectric properties. And Cu diffusion barrier characteristics are examined using MIS capacitor structure with accelerated test in an electric field [2].

3. Results and Discussions

Figure 2 shows the FT-IR spectra of the aCHx film using C_2H_2 based gases. In these spectra, CH_3, CH_2 and C-CH_3 bond are observed. However, C=C bond is not observed obviously.

Figure 3 (a) shows the x-section TEM picture and Fig.3 (b) shows an electron diffraction picture of the aCHx film. From x-section picture, the aCHx film shows macroscopic homogeneous structure. In the electron diffraction picture, obviously no pattern has shown like a graphite film which has C=C bond, and this also indicates that the film has the amorphous structure in nano-scale range.

Table 1 shows the results of aCHx films composition at various deposition conditions measured by ERDA method. In this table, C:H ratio in these films are almost 50:50 %. These results reveal that three bonds out of four in a carbon atom binds to the next carbon atoms each other without multiple bonds, then the aCHx film has a high cross-link structure. This may contribute to higher thermal stability and higher mechanical properties compare to a general hydrocarbon film, and leakage current is reduced by preventing formation of carbon multiple bonds.

These properties are achieved by using the low electron temperature plasma. Excessive ion bombardment which occurred in a parallel-plate type plasma gives damage for the deposited film that breaking C-H bonds lead to decrease concentration of hydrogen atoms in the film.

The composition of deposition gases also influences strongly to the grown films characteristics. Obviously, the ratio of hydrogen and carbon determines the thermal resistance and electrical leakage current of the grown films. In many evaluation cases, thermal resistance and leakage current are related off-trading. An optimum C:H ratio of deposition gases produces the film to show higher thermal resistance up to 350 degree C and lower leakage current less than 1E-8A/cm^2 at 1MV/cm, as shown Fig. 4 The k-value of this film was measured as 2.7.

Continually, we evaluated the Cu diffusion barrier property of the optimized film. Fig. 5 shows the SIMS profile of Cu atom into the aCHx layer on aCHx/Cu stack structure. From these profiles, no significant change can be found before and after annealed 350 degree C. Next, we examined the MIS structure with accelerated life test [2] as shown in Fig. 6. Compared to the silicon nitride film, aCHx film shows shorter life time but sufficient life time is estimated at 0.2MV/cm for the next generation device.

4. Conclusion

New amorphous hydrocarbon film (aCHx) deposited by the microwave-excited plasma with the showerhead structure has been evaluated. The low ion bombardment and the optimization of deposition gases gives the excellent film which shows the low leakage current and thermal resistance simultaneously. This film has Cu diffusion barrier ability at 350 degree C and shows more than 10 year lifetime for 0.2MV/cm, which is sufficient for next generation barrier film in the interlayer dielectric films.

References

[1] T. Ohmi et al., J. Phys. D: Appl. Phys. 39, pp.R1-R17, (2006)
[2] K. Takeda, et al., in Proc. Of IITC 2001, pp. 244-246 (2001)

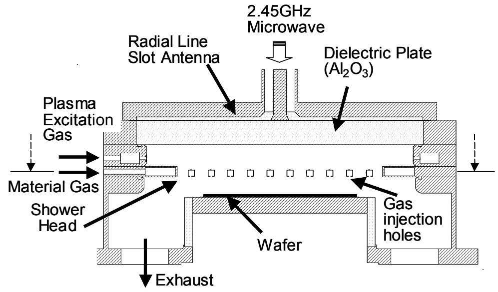


Fig. 1 Schematic diagram of a microwave excited high-density and lower electron temperature plasma equipment. This equipment is the new plasma CVD system incorporating the showerhead structure for 200mm wafer.

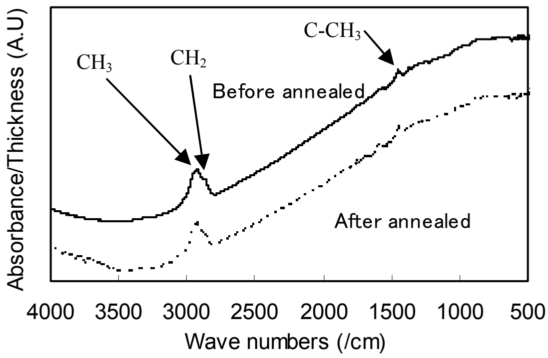
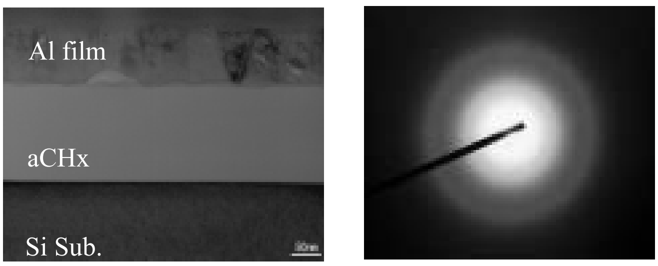


Fig. 2 Schematic view of FT-IR spectra using C_2H_2 gases before and after annealed 400 degree C.

Table 1 The result of atomic number density and C:H ratio of aCHx films deposited various conditions. The C:H ratio for all films are almost 50:50 %.

Deposition conditions	H(E17cm^{-2})	C(E17cm^{-2})	H(%)	C(%)
CH4 base 1	21.9	17.5	55	45
CH4 base 2	9.4	9.2	51	49
C2H2 base 1	8.8	10.1	47	53
C2H2 base 2	10.1	9.2	52	48
C2H2 base 3	12.2	11.2	52	48
C2H2 base 4	10.7	10.3	51	49
C2H2 base 5	10.6	10.8	50	50
C2H2 base 6	10.0	9.1	52	48
C2H2 base 7	10.1	8.9	53	47
C2H2 base 8	11.7	9.8	54	46
C2H2 base 9	7.5	6.7	53	47
C2H2 base 10	11.0	8.7	56	44



(a) (b)

Fig. 3 The x-section TEM results (a) Large scale of aCHx film show in middle layer in the picture. The aCHx film has homogeneous structure. (b) the electron diffraction picture of the aCHx film. This picture has halo and no regular pattern like a graphite film.

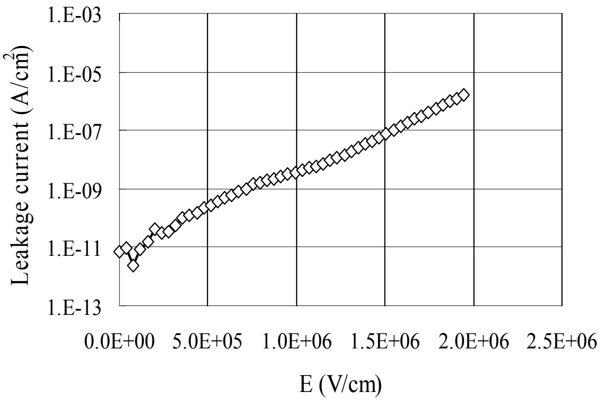
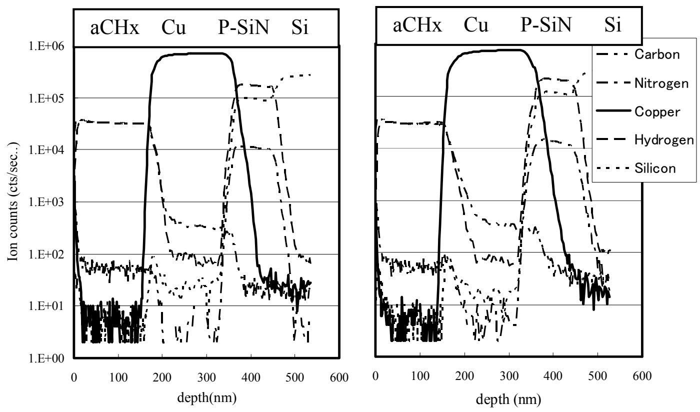


Fig. 4 The I-V characteristics of the aCHx film after optimized the deposition conditions. Low leakage current below 1E-8A/cm^2 at 1MV/cm can be realized. At the same time, the k-value of the film shows 2.7 by C-V measurement.



(a) (b)

Fig. 5 The SIMS profiles of the aCHx/Cu stack structure (a) before and (b) after annealed 350 degree C. Cu dose not diffuse to the aCHx film.

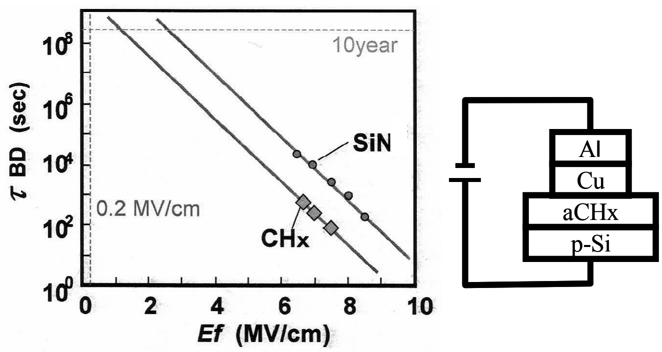


Fig. 6 The accelerated life test with MIS structure at 140 degree C. The life time of aCHx film estimated on 0.2 MV/cm is sufficient for 10 years.