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Plasma-enhanced polymerization thin films as a drift barrier for Cu interconnects

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1 Introduction

A divinyl siloxane benzocyclobutene (DVS-BCB) film is promising low-dielectric constant (low-k) interlayer dielectric (ILD) as characterized by an excellent barrier for Cu ions drift [1]. In fact, barrier-metal-free Cu damascene structures were fabricated with the BCB ILD [2, 3].

In the advanced metallization, further reduction of k-value is needed to reduce the interconnects delay, whereas k-value of BCB remains 2.6–2.8 [3]. Therefore, to apply the barrier property of BCB to advanced metallization, the combination of the ultra low-k porous silica and the thin BCB barrier is necessary. In this paper, we studied the barrier properties of thin BCB films as a reinforcement layer for a barrier metal against Cu ion drift.

2 Experimental

DVS-BCB monomer as shown in Fig. 1 was used for depositing low-k films by employing a plasma-enhanced-polymerization (PEP) process [3]. In the PEP processes as indicated in Fig. 2, the deposition proceeds by keeping the BCB monomer structure in the film. From the capacitance-voltage measurements, the value of the specific dielectric constant (k) of BCB was determined to be 2.6. The barrier ability of the BCB film was studied by using a metal-insulator-semiconductor (MIS) structures with Cu electrodes as shown in Fig. 3. As a reference, chemical-vapor-deposited methyl doped silica (SiOC) was studied. Thin BCB or SiOC films with thicknesses of less than 30 nm were formed on 138-nm-thick porous silica film [4] followed by evaporation of Cu electrodes.

The time-dependent dielectric breakdown (TDDB) was measured by using a probe card under the bias-temperature (BT) stress. TDDB measurements were performed in a nitrogen atmosphere to avoid the oxidation of Cu electrodes. Prior to the measurements, the samples were heated for 12 h at 200°C to remove residual moistures in the porous silica.

3 Results and Discussion

The distribution of the time-to-breakdown t_{BD} for the Cu/BCB (200 nm)/Si-MIS structure under positive electric field stress $E > 0$ agrees well with that for $E < 0$ as shown in Fig. 4. In the case of SiOC, on the other hand, t_{BD} for $E > 0$ was degraded with respect to $E < 0$ as shown in Fig. 5. It is widely known that Cu ion is generated and drift through the dielectrics by applying a positive bias stress at elevated temperatures around 100°C [5, 6]. The conductive path formation through the film under the positive bias is faster for the case of SiOC than BCB. The identical t_{BD} distribution for BCB suggests that Cu ions can hardly drift into the film. That is, the anti-diffusive characteristics of a BCB blanket film formed with the PEP process was confirmed.

For further examination of BCB barrier effects, the TDDB tests were performed by using the Cu/thin-BCB/Po-SiO/SiO_2/Si stacked MIS structures. The BCB cap thickness was determined accurately by ellipsometry using the multilayer model, where the parameters for bottom porous silica (138 nm, k = 2.1) and thermal oxide (30 nm, k = 3.9) were fixed. As listed in Table 1, the impact of BCB on the total capacitance of the MIS structure was weak. Figure 6 shows the Weibull plot of t_{BD} of the stacked MIS structures. Without BCB cap (BCB = 0 nm), *i.e.*, blanket porous silica with Cu electrodes, all tested capacitors met the breakdown within 1000 sec under 3.5 MV/cm at 200°C. The t_{BD} was dramatically improved by forming a 15 nm-thick BCB cap. No thickness dependence was found for BCB cap up to 30 nm as shown in Fig. 7. In addition, thin SiOC cap slightly improved the mean-time-to-failure (MTF) of the t_{BD} distribution. From the above facts, the barrier property of BCB is available at least down to 15 nm. Fig. 8 represents the field dependence of MTF of the MIS structures with and without BCB cap. The porous silica with $E < 0$, in which no Cu ion drift occurs, shows satisfactory MTF at 200°C, while a 30-nm-thick BCB cap significantly prevents the Cu ion drift into the porous silica. However, small amount of Cu ions seem to permeate through the BCB presumably because pin-holes and locally dissociated monomer in the thin BCB layer might form a weak spot.

Nevertheless, the combination of the barrier metal and thin BCB can be a possible solution to apply BCB for advanced Cu interconnect. As previously reported [7], a Cu plating solution permeates into the porous silica and such penetration was prevented by forming a 10-nm-thick BCB sidewall on the porous silica trench wall surface. In this case, the plating solution infiltrated through the defects in thin barrier metals directly formed on the porous silica. And Cu ions also drift into the porous silica through the defects in the thin barrier metal as shown in Fig. 9 (a). Such drifted Cu ions through the thin barrier metal can be effectively prevented by forming a thin BCB layer on the porous silica as shown in Fig. 9 (b). Namely, thin BCB could prevent both wet chemicals and drifted Cu ions. In addition, it should be noted that thin BCB scarcely increases the total interline capacitance. For example, when 15-nm-thick BCB was formed on 140-nm-thick ultra low-k film with k = 1.8, the effective k-value increase is only 3% (k becomes 1.85). Thus, thin BCB is useful as a reinforcement layer for a thin barrier metal against Cu ion drift.

4 Conclusion

The barrier property of PEP-deposited BCB was studied. The BCB MIS capacitors showed no polarity dependence of BT stresses at 200°C under 2 MV/cm. While SiOC MIS capacitor under positive bias showed a significant degradation in the lifetime. A thin BCB cap with a thickness of 15 nm formed on the porous silica improved the MTF of the stacked MIS structure more than 10 times. Thin BCB is promising dielectrics for advanced Cu interconnects as a reinforcement layer for a thin barrier metal.

Acknowledgments

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Table. 1 BCB thickness, total thickness (BCB+Po-SiO+SiO_2) and estimated k values for fabricated stacked MIS structures.

BCB thickness		total thickness	effective
target (nm)	measured (nm)	(nm)	k value
0	–	168	2.28
15	17.5	185.5	2.31
30	33.6	201.6	2.33

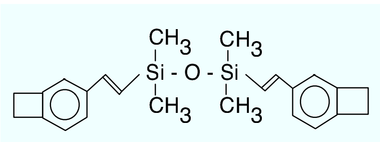

Fig. 1 Molecular structure of DVS-BCB monomer.

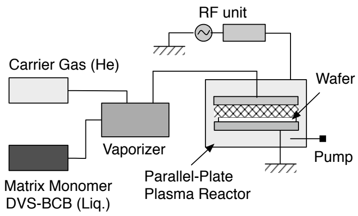

Fig. 2 Schematic diagram of a plasma-enhanced polymerization system.

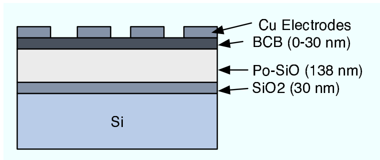

Fig. 3 Thin-BCB/porous silica (Po-SiO)/SiO_2 stacked MIS structure for electrical measurements.

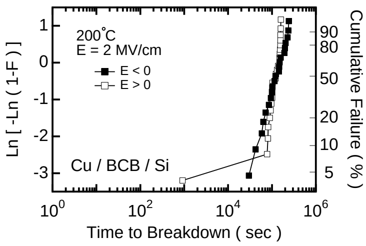

Fig. 4 Weibull plot of t_{BD} for a blanket BCB film with Cu electrodes.

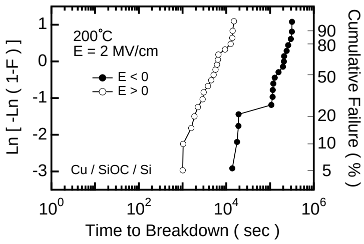

Fig. 5 t_{BD} distribution of the blanket SiOC MIS capacitors.

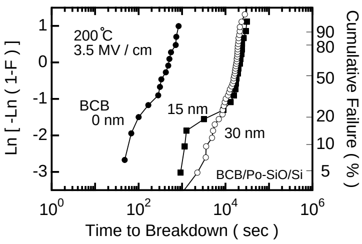

Fig. 6 t_{BD} of the Cu/BCB/Po-SiO stacked MIS structures.

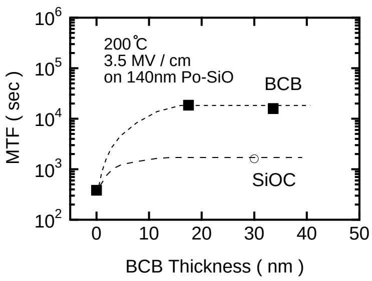

Fig. 7 MTF as a function of BCB or SiOC thickness.

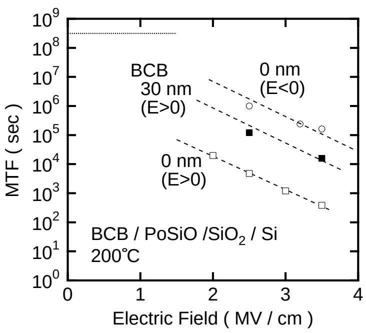

Fig. 8 Field dependent MTF for stacked MIS structures.

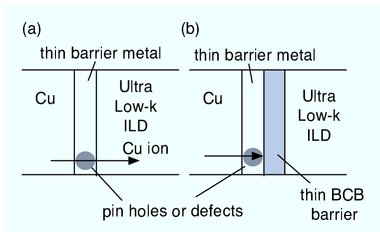

Fig. 9 Cu ion drift through a defect in thin barrier metal (a) and its suppression by forming a thin BCB barrier layer (b).