Effect of moisture on Electrical and Reliability Properties for Dense and Porous Low-k Dielectrics
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Introduction—As feature sizes of integrated circuits (ICs) continue to decrease, sub-micron, integrated circuit manufacturing (RC) delay begins to dominate overall device speed in copper/low-k metallization. To decrease RC delay time, interconnection resistance has been reduced by decreasing copper (Cu) thickness and interlayer capacitance has been lowered by replacing conventional silicon dioxide ($\text{SiO}_2$) (k=4.0) with low-k materials (k < 4.0) [1-3]. During interconnect integration, wet processes, such as polymer removal, electrochemical plating (ECP), and chemical mechanical polish (CMP), are indispensable steps. In such conditions, low-k materials have to deal with the moisture. Therefore, it is of importance to study the influence of moisture on the low-k dielectrics [4-6]. This work investigates the impact of the moisture on the physical, electrical properties, and reliability of the low-k films.

Results and discussions—Figure 1 (a) presents the FT-IR absorption spectra for the porous low-k films before and after moisture test. As shown, absorption bands resulting from H-O-H bonds at 2000-3000 cm$^{-1}$ are observed after moisture treatment, and the intensity of H-O-H bonds seems to increase with increasing the moisture immersion time. Figure 1 (b) shows the current-voltage (I-V) characteristics of the porous low-k films. As shown, the leakage current, however, the used test structures were line-to-line serpentine functions of the moisture immersion time. As also shown in Fig. 6, for 168 hr moisture-immersion samples with performing a thermal annealing at 400°C for 3h, the lifetime is increased as compared to that without a thermal annealing. However, the TDDB performance only partly be restored, which is still worse than that of the fresh sample. This also demonstrates that a annealing in N$_2$ gas can desorb partial absorbed moisture, and some chemically absorbed moisture cannot be removed, which negatively influences the TDDB performance. Page 17

Conclusions—The influence of moisture on the properties of the dense and porous low-k films is investigated in this study. We found that moisture has a negative impact on low-k film’s properties, including electrical characteristics and reliability performance. Moreover, these degradations are becoming more serious on the porous low-k dielectrics. A higher temperature during moisture immersion can deteriorate the dielectric film, but water, which is benefit to restore reliability performance. On the other hand, the chemically adsorbed moisture seems to be difficult to be removed by thermal annealing, causing a degradation of the dielectric film. Consequently, propose a new method to remove the chemically-adsorbed moisture in the low-k dielectrics is essential for promising better Cu low-k integrity.

References

Table 1: Film properties of the dense and porous low-k materials

Figure 1: Water contact angle (WCA) before and after moisture test. As shown, the WCA value is significantly reduced by using copper (Cu) instead of aluminum, while interlayer dielectrics ($\text{SiCOH}$) can be reduced by a thermal annealing; however, the value can not recover to the original value even after moisture immersion time for both low-k films. As also shown on the figures, the WCA value can not recover to the original value which is severely affected by the moisture immersion time. As also shown in Fig. 6, for 168 hr moisture-immersion samples with performing a thermal annealing at 400°C for 3h, the lifetime is increased as compared to that without a thermal annealing. However, the TDDB performance only partly be restored, which is still worse than that of the fresh sample. This also demonstrates that a annealing in N$_2$ gas can desorb partial absorbed moisture, and some chemically absorbed moisture cannot be removed, which negatively influences the TDDB performance.

Figure 7 presents the cumulative failure distribution of electromigration (EM) lifetime for typical Cu interconnect lines. The moisture treatment was performed before Cu interconnect deposition. The cumulative failure distribution is plotted by measurement of 30 sample’s lifetime using lognormal distribution [10]. For both low-k materials, the Cu interconnect line was subjected to 240°C reflow for 10s. The degradation is significant for the porous low-k films. This degraded EM lifetime is presumably caused by the degradation of the low-k film, which is a unique feature of porous low-k film. The Cu interconnect line demonstrated by scanning electron microscopy (SEM) analysis (not shown). This Cu interface was oxidized by the diffused moisture from the neighboring low-k dielectrics as apply the electrical field to the dielectrics (EM stress). Similar to TDDB results, the thermal annealing can restore the EM performance of both low-k materials. However, the used test structures were line-to-line serpentine functions of the moisture immersion time. As also shown in Fig. 6, for 168 hr moisture-immersion samples with performing a thermal annealing at 400°C for 3h, the lifetime is increased as compared to that without a thermal annealing. However, the TDDB performance only partly be restored, which is still worse than that of the fresh sample. This also demonstrates that a annealing in N$_2$ gas can desorb partial absorbed moisture, and some chemically absorbed moisture cannot be removed, which negatively influences the TDDB performance.

Figure 9 shows the cumulative probability of TDDB results for the porous low-k films with various moisture immersion times. As shown, the lifetime degrades about ten times and slightly decreases with increasing the moisture immersion time. As also shown in Fig. 6, for 168 hr moisture-immersion samples with performing a thermal annealing at 400°C for 3h, the lifetime is increased as compared to that without a thermal annealing. However, the TDDB performance only partly be restored, which is still worse than that of the fresh sample. This also demonstrates that a annealing in N$_2$ gas can desorb partial absorbed moisture, and some chemically absorbed moisture cannot be removed, which negatively influences the TDDB performance.

Figure 10 presents the cumulative failure distribution of electromigration (EM) lifetime for typical Cu interconnect lines. The moisture treatment was performed before Cu interconnect deposition. The cumulative failure distribution is plotted by measurement of 30 sample’s lifetime using lognormal distribution [10]. For both low-k materials, the Cu interconnect line was subjected to 240°C reflow for 10s. The degradation is significant for the porous low-k films. This degraded EM lifetime is presumably caused by the degradation of the low-k film, which is a unique feature of porous low-k film. The Cu interconnect line demonstrated by scanning electron microscopy (SEM) analysis (not shown). This Cu interface was oxidized by the diffused moisture from the neighboring low-k dielectrics as apply the electrical field to the dielectrics (EM stress). Similar to TDDB results, the thermal annealing can restore the EM performance of both low-k materials. However, the used test structures were line-to-line serpentine functions of the moisture immersion time. As also shown in Fig. 6, for 168 hr moisture-immersion samples with performing a thermal annealing at 400°C for 3h, the lifetime is increased as compared to that without a thermal annealing. However, the TDDB performance only partly be restored, which is still worse than that of the fresh sample. This also demonstrates that a annealing in N$_2$ gas can desorb partial absorbed moisture, and some chemically absorbed moisture cannot be removed, which negatively influences the TDDB performance.

Figure 11 shows the cumulative probability of TDDB results for the porous low-k films with various moisture immersion times. As shown, the lifetime degrades about ten times and slightly decreases with increasing the moisture immersion time. As also shown in Fig. 6, for 168 hr moisture-immersion samples with performing a thermal annealing at 400°C for 3h, the lifetime is increased as compared to that without a thermal annealing. However, the TDDB performance only partly be restored, which is still worse than that of the fresh sample. This also demonstrates that a annealing in N$_2$ gas can desorb partial absorbed moisture, and some chemically absorbed moisture cannot be removed, which negatively influences the TDDB performance.