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Heat and Moisture Resistance of Low-Capacitance Multilevel Interconnections Using Low-Permittivity Organic Spin-On Glass

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1. Introduction

Low-capacitance multilevel interconnections using low-permittivity (low-ε) interlevel dielectrics (ILDs) are essential to reduce interconnection delay in high-speed ULSIs. As ILDs with ε less than 3.0, organic polymers [1,2], organic spin-on glass (SOG) [3,4], and inorganic SOG (hydrogen silsesquioxane; HSQ) [5] have been proposed. The organic polymers are expected to have the lowest ε. However, their thermal stability, adhesion and mechanical strength need to be further improved to be used in the ULSI fabrication process.

The SOGs have already been widely used as gap-filling layers in conventional three-layered ILDs [6,7]. However, the reliability of the SOGs themselves has not been clarified. This is because almost all of the ILD volume in the conventional ILD structure is filled with CVD-SiO_2, and the reliability of the SOG has little effect on that of the ILD structure.

This paper focuses on the reliability of the SOGs when used as a low-ε ILD, because the SOG directly affects the reliability of ILD structure. Organic and inorganic SOGs are compared from the viewpoint of the heat and moisture resistance of their electrical properties. Reliability test results from low-capacitance interconnection test devices using an organic SOG are also shown.

2. Experimental Procedures

Sample Preparation

An organic SOG (Hitachi Chemical Co., Ltd., HSG-R7-13) and two HSQ-type inorganic SOGs (refered to as SOG-A and B) were prepared for comparison. The curing temperature of the organic and the inorganic SOGs were 450℃ and 400℃, respectively.

Using the organic SOG, interconnection test devices with low-ε and conventional ILDs were fabricated. In the case of the low-ε ILD, the SOG was formed following deposition of 20-nm-thick adhesion layer (CVD-SiO_2) on the lower metal lines, while the SOG was formed on a thick CVD-SiO_2 layer in the the conventional ILD. The SOG surface was capped with a CVD-SiO_2 layer in both ILDs.

Reliability Tests

To evaluate the heat resistance of the SOGs, samples were annealed in a N_2 ambient at temperatures from 400 to 750℃. The heat resistance of the interconnection test devices was also evaluated by an annealing test at 450℃, which is the maximum temperature used in conventional interconnection fabrication processes. To evaluate the moisture resistance, a pressure-cooker test (PCT) was carried out at 120℃ and 100%RH.

Electrical Property Evaluation

From C-V and I-V measurements, the ε and breakdown voltage were obtained. The breakdown voltage was defined as the voltage at which the leakage current rises to 1 $\mu A/cm^2$.

3. Results and Discussion

Heat Resistance of SOGs

Figure 1 compares ε of the SOGs after a 30-min heating test. In the case of SOG-A, the ε at 400℃ was 2.7. However, it increased to over 3.5 after annealing at higher temperatures or longer annealing at 400℃. In the case of the organic SOG, the ε was stable (ε=2.6 to 2.9) at temperatures up to 700℃. This temperature is sufficiently high for interconnection processing.

Moisture Resistance of SOGs

The degradation in the electrical properties during the PCT is shown in Fig. 2. The ε and the breakdown voltage of the inorganic SOG-A and SOG-B were significantly degraded after 20-hour PCT. This was due to moisture absorption accompanied by Si-H decomposition. In the case of the organic SOG, little degradation was observed, and the low-ε properties still remained even after a 100-hour PCT. This shows that there is little moisture absorption into the organic SOG even after a long PCT.

Reliability of Interconnections using Organic SOG

The thermal stability of the low-ε ILD is shown in Fig. 3. Four-level interconnection test devices were submitted to a heating test at 450℃ for 12 hours, and the line-to-line capacitance between the first-level metal lines was compared to that of two-level devices. The capacitance of both samples were the same: 71% of the capacitance of the conventional ILD. The effective ε was 3.1. This clearly

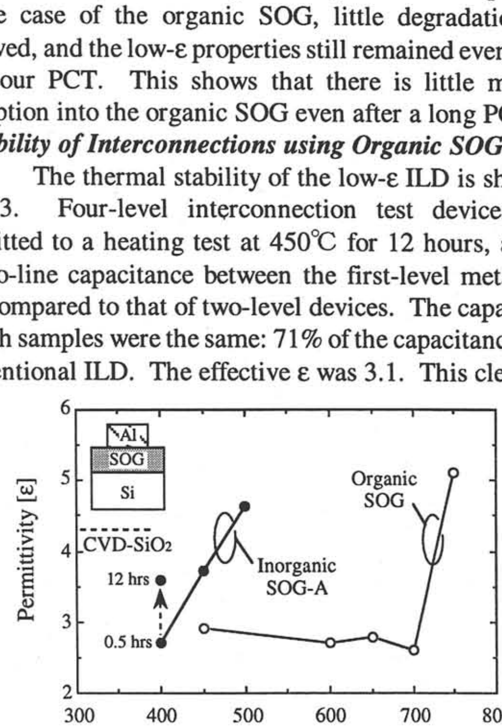

Fig. 1 Permittivity of low-ε SOG after a 30-min heating test

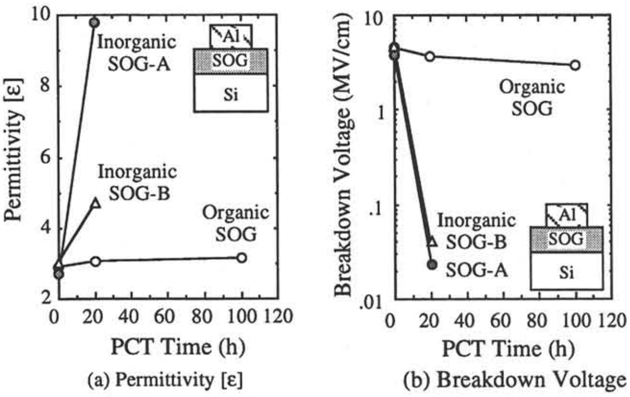

Fig. 2 Degradation in the electrical properties of low-ε SOGs during the pressure-cooker test (PCT)

shows that the heat resistance of the low-ε ILD is sufficient for interconnection processing up to 450℃. The slight increase in the effective ε compared with that of the organic SOG (ε=2.9) was probably due to the higher ε of the adhesion layer.

The interconnection test devices were also submitted to the PCT to evaluate their moisture resistance (Fig. 4). In the case of the conventional ILD, the effective ε increased by 19%, and the breakdown voltage decreased by 43% during the PCT. This degradation is likely due to moisture absorption into the CVD-SiO_2 on the sidewall of the first-level metal lines. In the case of the low-ε ILD, less degradation was observed: the increase in the effective ε was 12%, and the decrease in the breakdown voltage was 23%. The effective ε after the PCT was still about 70% of that in the conventional structure, and the breakdown voltage was about the same (3 MV/cm^2) as that of the conventional one.

From these results, we conclude that low-capacitance interconnections using the low-ε organic SOG have sufficient resistance against heating and moisture stress.

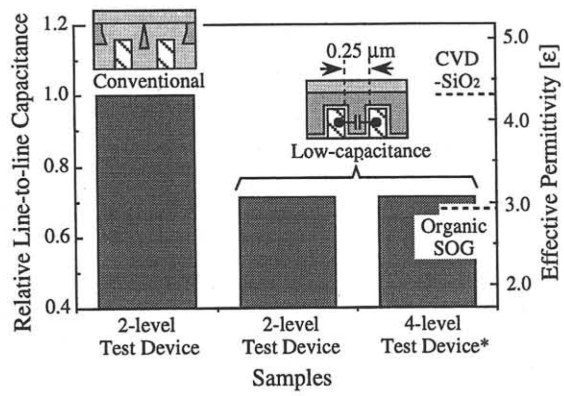

Fig. 3 Effect of the upper-layer-interconnection fabrication process and the heating test on the line-to-line capacitance between first-level interconnections

(* After heating test at 450°C for 12 hours)

4. Conclusions

The reliability of low-ε organic and inorganic SOGs was investigated from the viewpoint of the heat and moisture resistance of their electrical properties. The low-ε property of the organic SOG was found to be stable during heating tests up to 700℃ and a PCT for 100 hours, while that of the inorganic SOG (HSQ) was degraded through a heating test at 400℃ or a PCT of only 20 hours. Low-capacitance interconnection test devices were fabricated using the organic SOG, and submitted to reliability tests. The low line-to-line capacitance remained at about 70% of that of a conventional device even after the tests, showing that the low-capacitance interconnection is sufficiently resistant to heating and moisture stress

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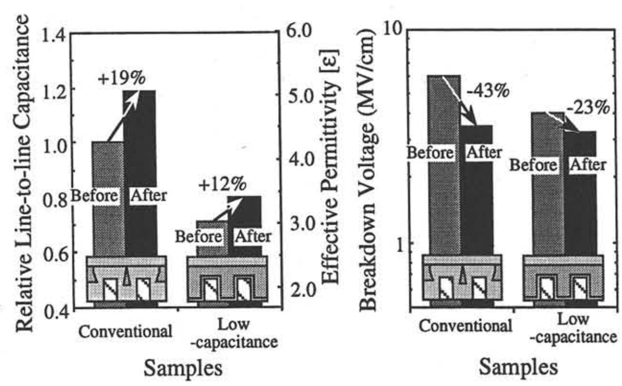

Fig. 4 Degradation in the electrical properties of interconnection test devices during the pressure-cooker test (PCT)