A technique for void detection using electron-beam-based wafer inspection

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Introduction

Cu/low-k integration technologies have recently been developed with the scaling down of size and the increase of circuit speed of very large-scale integrated devices. Accordingly, high-speed techniques for inspecting not only smaller defects but also sub-surface defects such as voids in Cu/low-k multi-level interconnects are necessary for the rapid development and precise control of the process.

In this work, we developed a technique to inspect Cu interconnects inline at high-speed. Namely, a test pattern of a Cu via chain was inspected, and a mechanism that causes the voltage contrast (1) generated by metal voiding was investigated. This technique is aimed at use with high-speed automated wafer-inspection systems using electron beams.

Experiment

Via chains 0.25-μm width were fabricated on eight-inch p-type Si (100) substrates by the Cu dual-damascene process. Fluorosilicate glass (FSG) and Si_3N_4 was used as inter-level dielectrics and etch stop layers, respectively. Isolated p-n junctions were formed between the bottoms of the via chain and the Si substrate. Accordingly, the large-scale via chain is electronically formed when a positive voltage is applied to the chain. The via chains fabricated on the wafers were inspected by using an electron-beam wafer-inspection system (Hitachi I-5010)(2). The irradiated energy of the electron beam was varied from 0.5 to 3.0 keV and the beam current was 100 nA. To investigate the voltage contrast generation of the SEM images, I-V characteristics of the detected defects were measured by Nano-prober (3).

Results and Discussion

The defects have detected under several incident-electron-beam conditions by the new technique. Figure 1 shows examples of SEM images of the detected defects. These images were captured by single scan of the electron beam. At the irradiation energy of 2.0 keV or below, the areas where Cu has risen to the top surface are brighter than those where the cap-SiO_2 has risen. Defect 1 can be easily seen at the irradiation energy of 2.0 keV or below, however, no defects can be seen at 3.0 keV. This is because the Cu via chain was negatively charged when the electron irradiation energy was higher than 3.0 keV. The charging voltage depends on the secondary electron yield at the irradiation energy (4). When the Cu chain is negatively charged, the bottoms of the via chain are connected to the Si substrate electronically because the p-n junction at the bottom of the chain are forward biased. On the other hand, when the Cu chain is positively charged, the charging voltage at one end is different from that at the other end. As a result, voltage contrast (4) can be seen at 2.0 keV and below. However, defect 2 can be easily seen at 2.0 keV only. To understand the reason the defects were detected at different irradiation energies, the resistances of the defects were determined from I-V characteristics by Nano-prober (2).

Figure 2 shows examples of the measured resistance of the defects. The resistances strongly depend on the differential voltage between the ends of the defect (V). Moreover, the changes in the resistances are, depending on kind of the defect, considerably different. Defect 1 is an incomplete contact failure and defect 2 is a void according to the cross-sectional TEM images as shown in Fig. 3. The resistances of the void suddenly decreased at a lower differential voltage than that at the incomplete contact. It is clear that the voltage contrast at irradiation energy and the resistance at the particular voltage correspond well from the observation of several defects. For example, the differential voltage of the ends of a defect is from 4 to 6 V at the irradiation energy of 1.0 keV. To detect voids at high sensitivity, the optimum irradiation energy is 2.0 keV. Under that energy, the differential voltage between the ends of the defect is thought to range from 1 to 2 V. The defects, whose resistances are more than 10^7 Ω, could be detected under the optimum radiation energy. It is thus concluded that voids can be detected with high speed and high sensitivity by using our technique.

References

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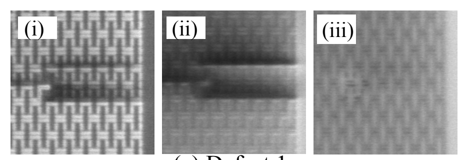
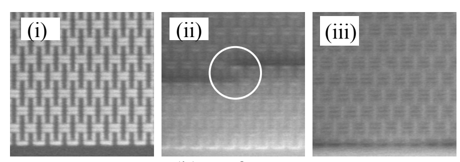


(a) Defect 1



(b) Defect 2

Figure 1. Examples of the SEM images of the defects at irradiation energies of (i)1.0, (ii)2.0, and (iii)3.0 keV.

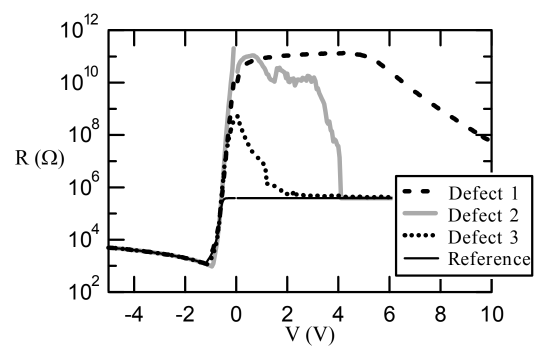
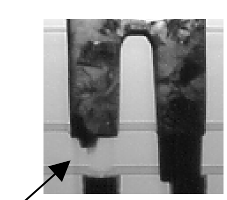
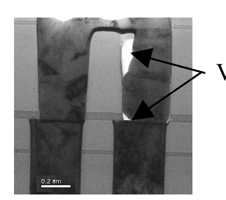


Figure 2. Resistances of the defects as measured by Nano-prober.



(a) Defect 1



(b) Defect 2

Figure 3. Cross-sectional TEM images of the detected defects after the measurement of I-V characteristics.