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A new and simple probe-based method for preventing charging in focused-ion-beam micro-sampling

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Abstract

A charging free (FIB) micro-sampling technique was developed for high resolution sampling with insulator. This technique used a mechanical probe brought into contact with or close to a substrate while it is being irradiated by FIB (5 pA to 10 nA). The probe then emits electrons that neutralize charging of the surface of the substrate. The shunt current continuously flows through the probe if the distance between the probe tip and FIB irradiation site stays at a critical distance. When the probe tip is high above the substrate, it still emits electrons through the vacuum to the surface. It is concluded that this simple method of sampling insulators can attain sampling resolution similar to that of sampling conductive substrates.

Keywords: FIB; Charging; Probe; Neutralization; Sampling; TEM

1. Introduction

With the intensification of semiconductor diversification, the strategy for defect control and reduction taken in development and optimization of new processes affects the yield and throughput of manufactured ULSI products. It is crucial to carry out early detection of physical, electrical, and macro-defects by high-resolution observation, i.e., transmission electron microscopy (TEM). Focused-ion-beam (FIB) and micro-manipulation subsystems have been developed to ease the taking of "micro-samples" for analysis by TEM [1,2]. One serious problem with such sampling is charging control.

Excess charge accumulates on the surfaces of substrates made of insulators when a primary FIB is being scanned across them. This so-called

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charging is usually positive, since it results from the deposition of positive charge in ionic gallium delivered to the sample by FIB and the subsequent generation of secondary electrons that leave the sample. In the worst case, the image completely disappears (since the secondary electron cannot escape from the sample), and the milling and deposition process become unmanageable.

With the current method, the charging of insulators has to be prevented by electron-irradiation, UV irradiation, conductive-film evaporation, a conductive-membrane cover, or a conductive-paste coating for charge neutralization.

Contamination from the electron source, the conductive-film, the conductive-membrane cover, or the conductive-paste coat is all causes of concern. Furthermore, it is usually best to avoid coating conductive-films on the whole surface of a wafer sample. Moreover, the secondary electrons which are produced by electron irradiation or UV irradiation deteriorate the S/N ratio of secondary-electron images [3]. Furthermore, the setup for charging neutralization by electron irradiation or UV irradiation is complicated and generally needs skillful or optimized operation.

These conventional methods carried out for micro-sampling complicate sample fabrication and restrict the variety of practicable samples. For example, standard charging prevention in micro-sampling from a wafer does not use pretreatment of the conductive film or condition optimization. Any methods carried out for micro-sampling cause problems in defect control and reduction of LSI manufacture. Accordingly, the authors propose charging prevention of the mechanical probe near the FIB irradiation site as a method to satisfy the standard method. In the current study, the validity of this probe-based method is demonstrated.

2. Experimental

Our redesigned probe was for use with an FIB-based micro-sampling system (Hitachi FB-2000A), which included a built-in micro-manipulator. The probe-tip diameter was about 0.5 μm; the probe tip pressed on the sample with a force less than 10^{-5} N, and probe potential was fixed at 0 V.

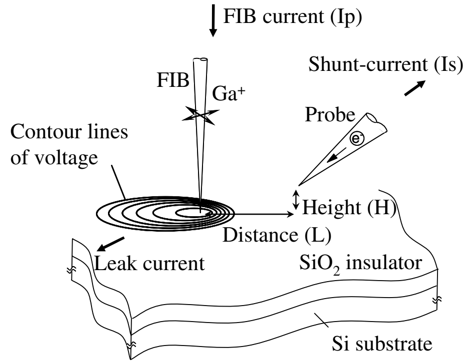

Fig. 1. Typical probe-based method for preventing charging.

Fig. 1 shows a typical probe-based method for preventing charging. An electric potential distribution was confined in the comparatively narrow site. To test the effectiveness of this method, we used diamond, SiO_2, and silicon substrates, on which a 2 μm layer of SiO_2 had been formed, as insulator samples. The volume resistance of SiO_2 is 10^{14}–10^{16} Ω cm and the resistance of a diamond is 10^{14} Ω cm. The surface resistances of the samples are sufficiently large, i.e., 10^{10} Ω.

3. Experimental results and discussion

3.1. FIB current dependence of shunt current through the probe

When scanning ion microscopy images (SIM images) of these insulators are taken by FIB scanning, charging-induced displacement of FIB irradiation site is continued. This displacement is due to repetition of electric discharge and charging on the substrate. That is caused by the proportionality of charging potential to the current that flows through the leak pass on the surface of the insulator (i.e., leak current). The pitch and the amplitude of the displacement of the SIM image increase with FIB current. And the amplitude increases with increasing charging potential. Therefore, increasing FIB current increases charging-induced displacement of the site being sampled by FIB.

Fig. 2 shows FIB current (I_p) dependence of the shunt current (I_s) on the glass substrate. The