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A Novel TEM/AFM/STM Microscopy for Cu Nano-Wire Electromigration

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1. Introduction

The electromigration in scaled metal interconnects is one of key issues for ultra large scale integrated circuits (ULSI) [1]. It has been reported that the electromigration is caused by electron momentum transfer to Cu atoms[1,2]. Blech [3] pointed out the stress field in the wire during electromigration, which was confirmed indirectly by measuring the dependence of the wire length on the electromigration life time. However, the compressive stress which is induced by electromigration has not been directly observed yet. In this paper, we report a new method for characterization of electromigration using a transmission electron microscope (TEM) with an atomic force microscope (AFM) and scanning tunneling microscope (STM).

2. Experinental

By implementing an AFM/STM tip to a TEM as shown in Fig. 1(a), it becomes possible to detect the stress and current in Cu nano-wire under the TEM observation as schematically shown in Fig. 1(b). In order to visualize the contact state with an atomic-scale resolution, we employed a TEM/AFM/STM combined microscopy as reported in our previous paper [4]. In the present experiment the AFM Cu tip was prepared by evaporating a 6 μm thick Cu film on the Si AFM tip surface. The Cu coated tip surface was in contact with the sharp edge of a Cu thin layer with the stress of several tens of nano-Newton, which produces a nano-scale contact. Then a careful tensile deformation was applied to the nano-contact, and as a result a free standing nano-wire is formed between the two tips. The conduction current through the contact is simultaneously measured by STM function, where the AFM tip is used as a STM tip in the present experiment.

In the AFM the stress is detected by using an optical lever deflection method [5]. By flowing the current of 100 μA through this wire, electromigration is forced to occur.

3. Results and Discussions

A series of TEM images are shown in Figs 2(a)-2(d). A motion of the swelled part of Cu wire which is indicated as 'P' in Fig. 2(a) moves to the Y direction from the left to the right. This shows that Cu atoms of the swelled part move toward the anode electrode subsequently. As shown in Fig. 2(c) the swelled part finally reaches the anode electrode, resulting in becoming a part of the anode electrode.

The measured stress during electromigration process is shown in Fig. 3. The direction of the compressive stress is found to be parallel to the wire presumably due to the electron wind from the cathode to the anode. Points a to c indicated in Fig. 3 correspond to the pictures (a) to (c) in Fig. 2, respectively.

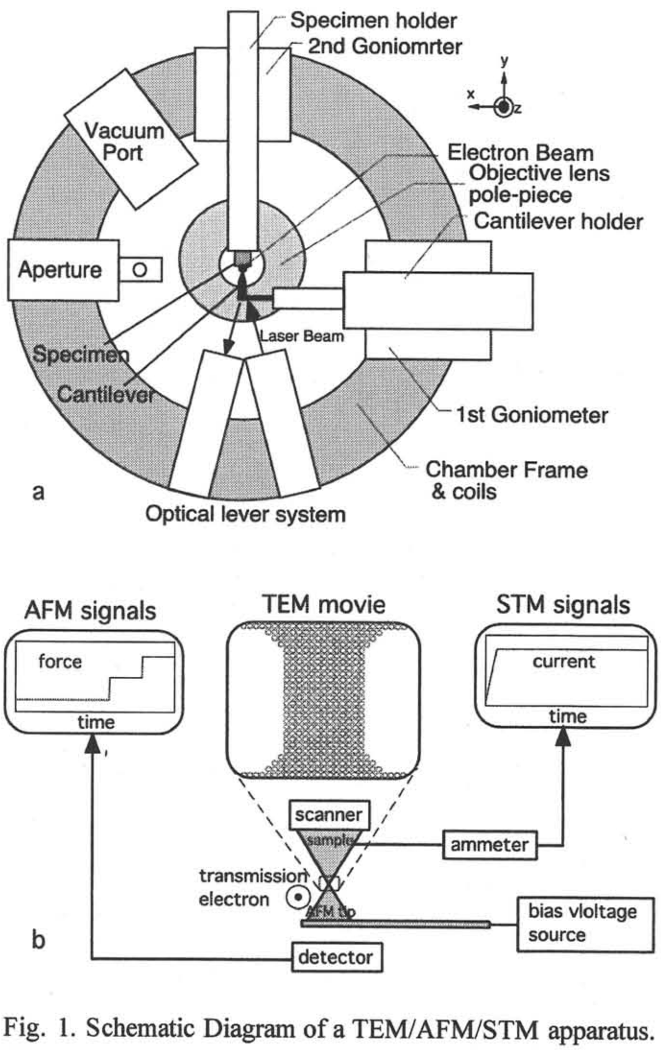

Fig. 1. Schematic Diagram of a TEM/AFM/STM apparatus. (a) TEM/AFM apparatus. (b) TEM/AFM/STM instrument.

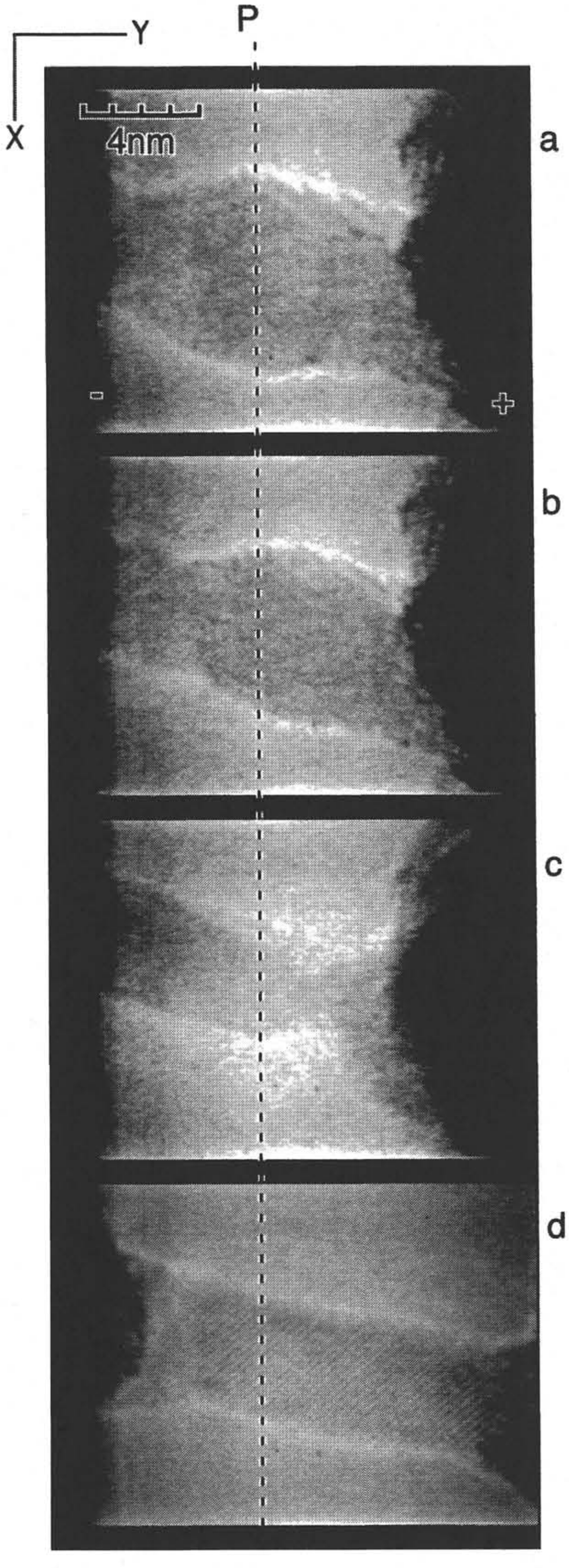

Fig. 2 A series of TEM images during electromigration. The evolution of electromigration at swelled part of wire is observed.

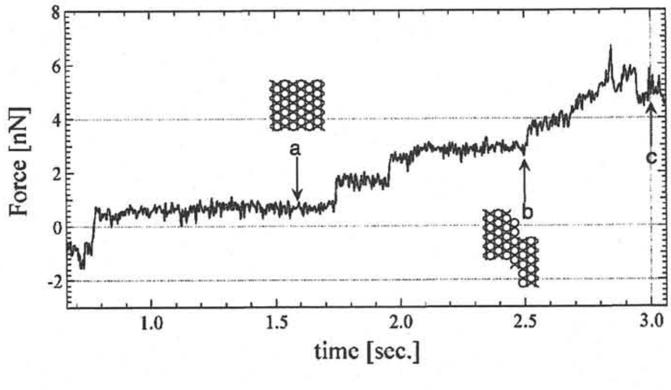

Fig. 3 The stresses measured simultaneously with TEM observation shown in Figs. 2(a)-2(c), at which the time corresponds to a-c, respectively.

The measured stress versus time curve shows a step-like behavior with an increment of approximately one nano-Newton. The electrical power through the wire was 50 mW and current density was approximately $3 \times 10^7 A/cm^2$. Furthermore, Fig. 2(d) shows the final structure of the nano-wire, which clearly shows the Cu single crystal lattice. The single crystal growth process proceeds during the electromigration so that defects in the wire are swept away to the anode electrode plane. The step-like change of the observed stress in Fig.3 could be associated with the creation of new layers of Cu single crystal plane along the wire.

4. Conclusions

A new method for the characterization of electromigration in a Cu nano-wire has been developed by use of TEM/AFM/STM combined microscopy. Direct observation of the stress change in the Cu nano-wire was achieved. This TEM/AFM/STM spectroscopy would be used for the analysis of future nanometer-size interconnects.

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