Quantitative Metrology Study of Cu/SiO_2 Interconnect Structures Using Fluorescence X-ray Microscopy

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Introduction

With the increasing demand for higher speed and better performance of integrated circuits (ICs), the size of features in IC interconnects has been scaled down continuously, which requires higher conductivity wiring and lower dielectric constant insulators. In 1998, Cu on-chip interconnections were used in commercial IC for the first time[1] by IBM, instead of the Al metallization system.[2] As a result of higher operating frequencies and smaller scales of the IC chips, current densities in interconnection lines increase rapidly.[3] Therefore, the reliability of these metal lines on IC chips is becoming increasingly more demanding.[4,5,6,7]

Methods and Materials

By using nanoscale scanning x-ray fluorescence microscopy (SXFM), it will be possible to measure the physical structures of these devices nondestructively, including measuring *in situ* how they change with time, current density, temperature, etc. In this report, we describe our work using SXFM to measure the elements present and their dimensions, line defects, etc., in a electromigrated test structure with multiple layers of metals (Cu, W) on top of a silicon wafer. The sample is a BEOL (back end of the line) L3 test structure provided by IBM research.[8,9] Figure 1 shows a schematic of the test structure. An important feature, which is not shown in this figure, is that there is Ta liner of roughly 20 nm thickness on the bottom and two sides of the Cu lines, acting as an adhesive/diffusion barrier.

All of our experiments on this test structure described in this report were performed on the SRI-CAT 2-ID-D beamline at the Advanced Photon Source . In order to study the submicron structures on our test sample, a Fresnel zone plate was used for microfocusing.[10] With an incident photon energy of 9.88 keV, our measured full width at half maximum (FWHM) of the central beam spot was ~200 to 250 nm, compared to the theoretical limit of ~150 nm. On the back side, a Ge detector with an energy resolution of ~250 eV was used to collect the element-specific fluorescence signals.

Results and Discussion

Scans both along and perpendicular to the Cu lines were performed, while both the Cu Kα and W $L\beta_1$ fluorescence signals were collected at the same time. We were able to measure submicron line widths, length, and thicknesses of both Cu and W structures to the absolute accuracy of 0.03 μm, and a relative accuracy of ~4% in lateral dimensions and ~10% in heights. The results are discussed in detail in Reference 9.

To show the excellent capacity of element selectivity using SXFM, we also measured the 20-nm-thick Ta liner around the Cu lines. Because the Ta $L\beta_1$ fluorescence emission energy (9.34 KeV) is very close to the energy of W $L\beta_1$ fluorescence emission,

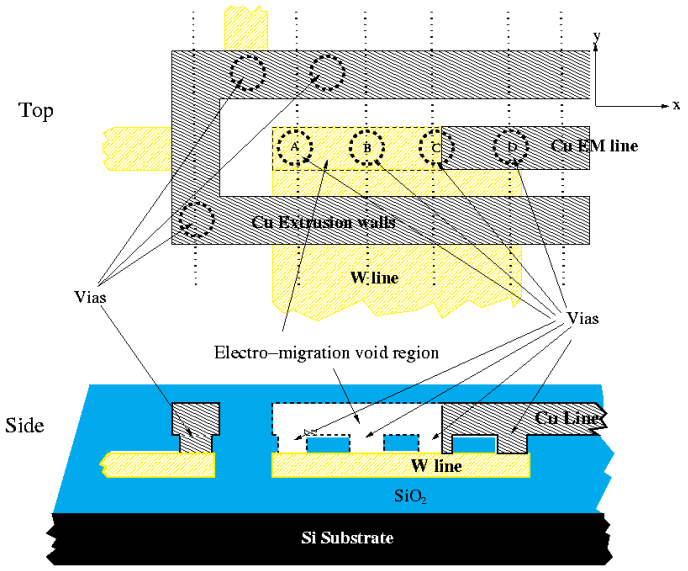

FIG. 1. Schematic of the BEOL L3-line structure.

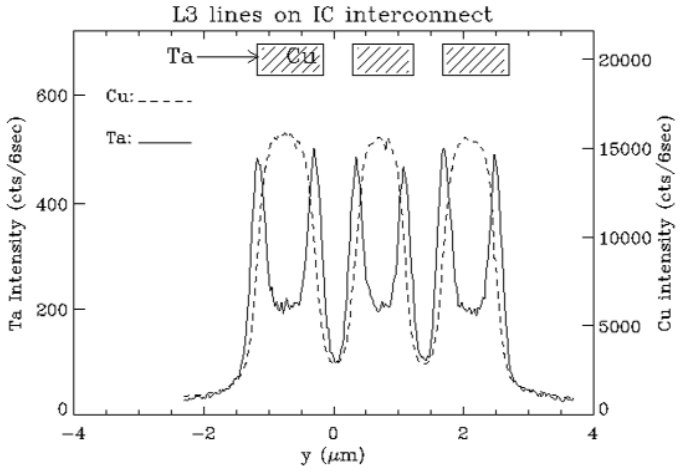

FIG. 2. Fluorescence data collected for a scan along the direction perpendicular to the L3-lines, located far away from the W-line structures. The dashed line shows the Cu fluorescence signal, the solid line shows the Ta fluorescence signal.

we moved to a location on the L3 structure where there is no W underlying layer and performed a scan perpendicular to the Cu lines, collecting both the Cu and Ta fluorescence signals at the same time. The dashed line in Fig. 2 indicates the Cu fluorescence signal and the solid line is the Ta fluorescence signal, scaled to be plotted together. The FWHM of the sharp peaks, produced by the Ta films on the left and right sides of the Cu lines, is around 0.25 μm. This is mostly due to the resolution (~0.22 μm) broadening,

yet there is also a small contribution coming from the tail extending from the fluorescence signal of the Ta films on the bottom of the Cu lines. This latter effect will also move two peaks closer to each other, by an amount of 0.34 nm, derived by using a computer simulation with a model assuming the design specification thickness of the Ta films is 20 nm. Taking this number into consideration, the width of the three Cu lines can be calculated by using the positions of the Ta peaks to be: 0.83 μm, 0.77 μm, and 0.89 μm, respectively, from left to right. These values agree with our direct measurements on the Cu lines within 4%.

Our measurements proved SXFM to be a very powerful tool for element-specific and non-destructive measurements for a variety of multielement materials systems with micro- to nanoscale structures.

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References

1 C.-K. Hu, R. Rosenberg, and K.Y. Lee, Appl. Phys. Lett. **74**, 2945 (1999).

2 D.C. Edelstein, G.A. Sai-Haiasz, and Y.-J. Mii, IBM J. Res. Develop. **39**, 383 (1995).

3 C.-K. Hu, Mat. Res. Soc. Symp. Proc. Vol. **511**, 305 (1998).

4 C.-K. Hu and J.M.E. Harper, Mat. Chem. Phys. **52**, 5 (1998).

5 B.D. Knowlton, J.J. Clement, and C.V. Thompson, J. Appl. Phys. **81**, 6073 (1997).

6 Y.-C. Joo and C.V. Thompson, J. Appl. Phys. **81**, 6062 (1997).

7 Z.H. Levine and B. Ravel, J. Appl. Phys. **85**, 558 (1999).

8 C.-K. Hu, D.C. Edelstein, C. Uzoh, and T. Sullivan, AIP Conf. Proc., Vol. **373** (American Institute of Physics, Woodbury, NY, 1996) p.153.

9 G. Xu, X. Su, C.B. Stagarescu, D.E. Eastman, B. Lai, Z. Cai, I. C. Noyan, and C.-K. Hu, Appl. Phys. Lett. **78**, 820 (2001).

10 W. Yun, B. Lai, Z. Cai, J. Masor, D. Legnini, E. Gluskin, Z. Chen, A. A. Krasnoperova, Y. Vladimirsky, F. Cerrina, E. Di Fabrizio, and M. Gentili, Rev. Sci. Instrum. **70**, 2238 (1999).