Mass Absorption Coefficient of Tungsten and Tantalum at 1450-2350 eV

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Introduction

Recently, beamline station 2-ID-B at the APS has been used to image integrated circuit interconnects in both two and three dimensions. Thickness information may be obtained in 2-D images if the x-ray attenuation is measured and the mass absorption coefficients are known. Good contrast may be obtained in images of integrated circuit interconnects near 1800 eV. However, the mass absorption coefficient of tungsten and tantalum had only been measured with line sources and never directly across its M_V, M_{IV}, and M_{III} edges. A preliminary experiment was performed on tungsten in 2001 [1]. The M_V and M_{IV} edges were observed, and it was learned that their widths were a property of solid-state physics. However, the mass absorption coefficient was larger than predicted by theory and above (but consistent with) line source measurements from the literature.

Methods and Materials

Thin films of tungsten and tantalum were grown at NIST by using sputtering with Ar ions. The sample thicknesses were approximately 50 and 150 nm. The masses of the samples were found by using a high-precision balance (weight before and after deposition). The samples were further characterized by x-ray reflectivity to confirm the mass density measurements and optical reflectivity to assess the samples' flatness. The intensity of x-rays passing through each sample was measured for photon energies between 1450 and 2350 eV. The ratio of intensities gives the transmission of the sample. By using two samples, the method is relatively immune to variations in the transmission of the beamline as well as the state of the surface of the films. The measurements were averaged over several runs, and the energy panels were overlapped to avoid end effects.

After the pure materials were considered, line scans were taken of a sample of an integrated circuit interconnect. The tungsten spectrum was identified *in situ* in the sample.

Results

We found that our previous measurement of the mass coefficient of tungsten was indeed too high, presumably because we used the wrong value for the thickness (which was taken from the specification of the vendor). The present samples, grown in house, were more carefully characterized. We also observed, presumably for the first time, the M_{III} edge of tungsten and the M_V, M_{IV}, and M_{III} edges of tantalum. In addition, we observed x-ray absorption near-edge spectroscopy (XANES) oscillations in tungsten whose energy values were in agreement with spectra we calculated within multiple-scattering theory. However, the overall shape of the spectrum was more consistent with an atomic time-dependent local-density calculation (also performed by us), leading to the conclusion that a unified description of the spectrum would require both multiple scattering and atomic screening to be implemented in the same code.

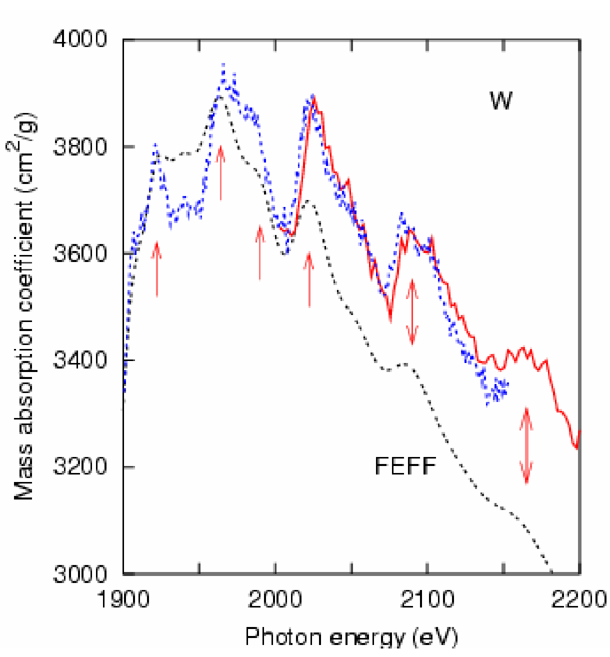

FIG. 1. Comparison of theory (FEFF) and experiment for the XANES region of the W absorption spectrum. The points of agreement are noted with red arrows. The red and blue data were taken with different energy panels.

Regarding the circuit sample, we found that the silica spectum (not measured directly) plays an important role in the observed spectra. However, it was possible to obtain the silica spectrum indirectly by assuming the spectrum associated with a tungsten line within silica was the spectrum of tungsten minus silica. In this manner, it was possible to measure the amount of silica that was displaced by the tungsten lines that were deposited by the focused ion beam (FIB) process: about half the thickness.

Discussion

The joint experimental-theoretical approach taken here helps verify the correctness of the procedure. Difficulties in the earlier experiment [1] were indicated only by a comparison with theory. In the present experiment, the tungsten spectrum would have been very difficult to interpret without the multiple-scattering code.

Since the reference spectra of tungsten and tantalum had been obtained, work in 2003 centered on the application of these spectra to 2-D images of an integrated interconnect spectrum [2]. Enhanced motion control enabled the work in 2003.

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References

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