DOI: 10.1017/S1431927603444991
Microsc Microanal 9(Suppl 2), 2003

X-ray spectral imaging in the STEM for microelectronics failure analysis

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Failure analysis of microelectronics components often involves analytical electron microscopy as it combines high-resolution imaging of device structures with the ability to perform chemical analysis on almost the same length scale. Analysis strategies include energy-filtered imaging, EELS or x-ray point acquisition, or mapping of the same signals in a STEM. Point analyses tend to be subjective as one only collects spectra from features visible in the various imaging modes and then typically only from those features that are obviously out of place. Mapping, whether with energy-filtered imaging, STEM/EELS, or STEM/EDS, often relies upon choosing the elements before hand and can be fraught with artifacts. As an alternative to the above strategies, spectral imaging, where a series of complete x-ray spectra are collected from a 2D area, holds great promise for comprehensive microanalysis. The challenge of comprehensively analyzing such large data sets via multivariate statistical analysis techniques has largely been overcome [1]. In this paper we will discuss the application of our automated spectral image analysis software to x-ray spectral images acquired in the STEM in the context of a microelectronics failure analysis problem.

A failure was observed in a CMOS device that was consistent with a short circuit somewhere in the structure. A FIB cross-section was prepared from the region of a particular failed device. Faint contrast was observed at the boundary between two interlayer dielectrics (ILDs) as seen in the annular dark-field (ADF) STEM image in Figure 1. An x-ray spectral image was acquired on a Tecnai F30-ST TEM/STEM equipped with an EDAX R-TEM SUTW x-ray detector with Tecnai Imaging and Analysis (Emispec) acquisition/drift correction software. The spectral image was acquired at 64x256pixel x 1024-energy-channel resolution from a 200x800nm region corresponding to ~3nm/pixel and 10eV/channel, 100msec/pixel dwell time, and drift corrected every 64 spectra. The total acquisition time was 32 minutes (x-ray acquisition plus drift correction time). The spectral image was analyzed with our automated x-ray spectral image analysis software [1] in 20 seconds on a PC workstation equipped with dual Pentium IV Xeon 2.4GHz processors and 2Gb RAM although this level of computing power is by no means necessary for rapid analysis. The software automatically found five components to describe all of the chemical information in the 16384-spectrum raw spectral image. The five component images describe where and how much of the corresponding component spectral shape is found in the microstructure. Two components were found describing the Si-O ILD. Due the FIB specimen preparation process the specimen is not uniform in thickness-under the metal lines, the ILD is thicker and therefore the Si:O peak-intensity ratio is larger than for the ILD between the metal lines. Since our algorithms make no assumptions about expected Si:O ratio, two components are needed to model the real variation in the Si:O peak-intensity ratio. Another component found was for Pt inadvertently sputtered on the specimen surface during FIB preparation. It is extracted as a separate component since its spectral variation is different than that of the ILD-components for example. As a result, the Pt is spectrally deconvolved, on a sub-pixel basis, from the underlying material. Part of the Ti layer was in the analysis region and was found as a distinct component. Perhaps of greatest significance for the present failure analysis was the automated detection of a sub-5nm layer containing Al at the ILD boundary. The Al was likely inadvertently sputtered onto ILD-1 during a patterning step. Four of the component image/spectrum pairs, Ti, Al, Pt and one of the Si-O components, are shown in Figure 2.

References

[1] P.G. Kotula et al., *Microsc. Microanal.* **9** [1] (2003) 1-17.
[2] Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United Stated Department of Energy (DOE) under contract DE-AC04-94AL85000.

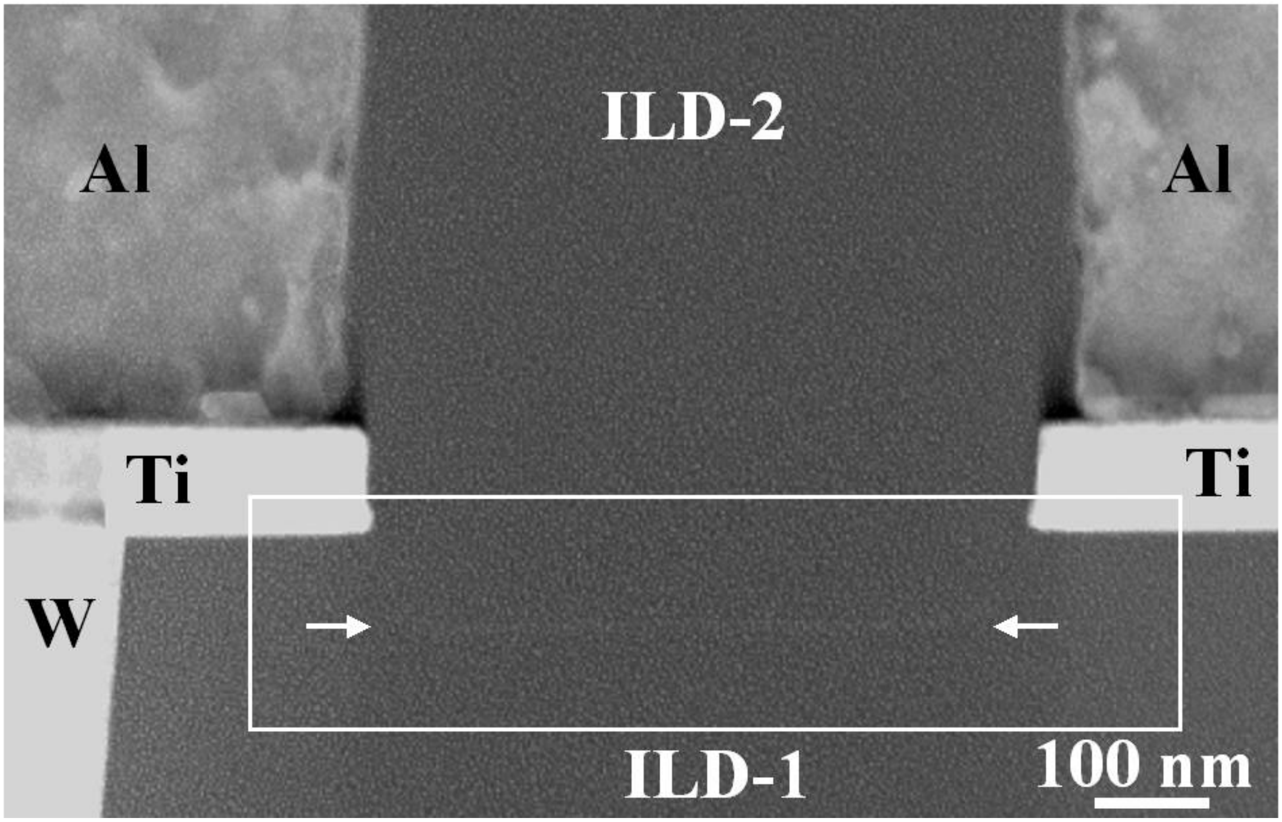

FIG. 1. ADF-STEM image of the region between two metal lines showing fain contrast at the ILD boundary. A white box outlines the region of the spectral image.

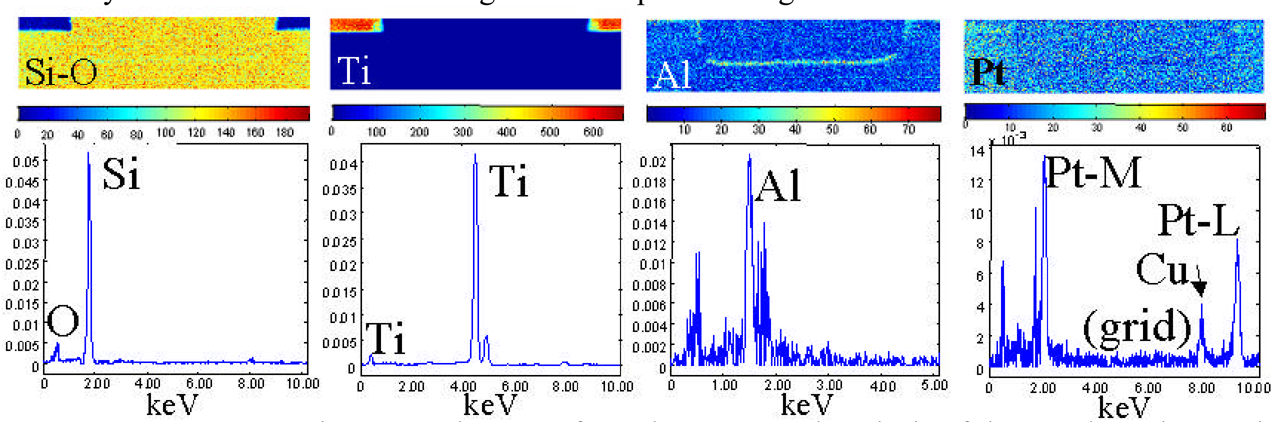

FIG. 2. Pure component images and spectra from the automated analysis of the ILD boundary-region showing a sub-5nm Al layer

https://doi.org/10.1017/S1431927603444991 Published online by Cambridge University Press