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Sub-80nm Resolution X-Ray Fluorescence Imaging Spectrometer for Semiconductor Applications

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Electron or x-ray excited X-ray fluorescence analysis is a widely deployed technique in various fields such as materials science, semiconductor manufacturing and defect review for thin film characterization. Layer thicknesses with sub nanometer accuracy and elemental composition to below a weight percent can be measured. With electron beam instruments such as SEMs, spatially resolved fluorescence maps are obtained by raster scanning a finely focused electron beam using energy or wavelength dispersive spectrometers (EDS/WDS) to collect elemental distribution and concentration information. The spatial resolution for these maps is fundamentally limited for thick (>1um) samples by the electron interaction volume to the order of one micrometer. This restriction can be overcome by the use of high-resolution Fresnel zone plate lenses as x-ray imaging optics. Based on this concept we have designed an x-ray fluorescence imaging spectrometer which combines the elemental identification capabilities of a spectrometer with the high spatial resolution (sub-80nm) of zone plate imaging optics. Such a spectroscopic imaging system can potentially be employed advantageously in many semiconductor applications. As a first application we demonstrate sub-surface imaging of copper interconnects and identification of manufacturing problems and failures.

The system described in this paper is operated on a scanning electron microscope and is optimized to image copper structures in ICs. It is equipped with a zone plate manufactured by Xradia Inc. to image the 930eV x-ray fluorescence line of copper (CuLα_1 line) at an imaging resolution of 50nm. The system can also be tuned to other x-ray fluorescence wavelengths to image elements different from copper. The description of the instrument and its capabilities are described already in detail elsewhere [1]. To demonstrate the spatial resolution of the imager, we imaged a copper resolution target with 70nm thickness and a copper grating structure and these are shown in fig 1. The copper test target was first imaged with a field emission SEM (shown in fig 1A) to show the structure of the target and then with the fluorescence imager (fig 1B). The narrowest separation between the lines is 50nm. Fig 1C shows the x-ray fluorescence image of a copper grating structure with a period of 140nm. From figs 1B and 1C, it was concluded that the spatial resolution of the imager is limited currently to approximately 65nm. Furthermore, the x-ray fluorescence image in fig 1B shows an inhomogeneous distribution of copper which are not apparent in the SEM image. This is a direct consequence of the different contrast mechanism. Fig 2A shows the image of a three layer copper chip [2]. All three layers are visible and in focus at the same time. The width of the thinnest metal line is about 250nm. The bright dots are vias connecting various metal layers. Fig 2B is obtained by convolution of fig 2A with a point spread function of 1um and assuming a pixel size of 0.5um; typical parameters normally encountered in EDS or WDS. Comparison between the two images illustrates the resolution power of the imaging spectrometer, for which along with very high spatial resolution, depth information is also retained. The details of the experiments and the results obtained with various copper chips will be presented.

References:

[1] M. Feser et al., Conference proceedings from the 31st International Symposium for Testing and Failure Analysis (ISTFA) (2005) 158

[2] The multi layered samples provided courtesy Silyb Wafer Services Inc, 702 33rd Ave. NW, Gig Harbor, WA 98335

[3] This material is based upon work supported by the National Science Foundation under SBIR grant No. DMI-0512910.

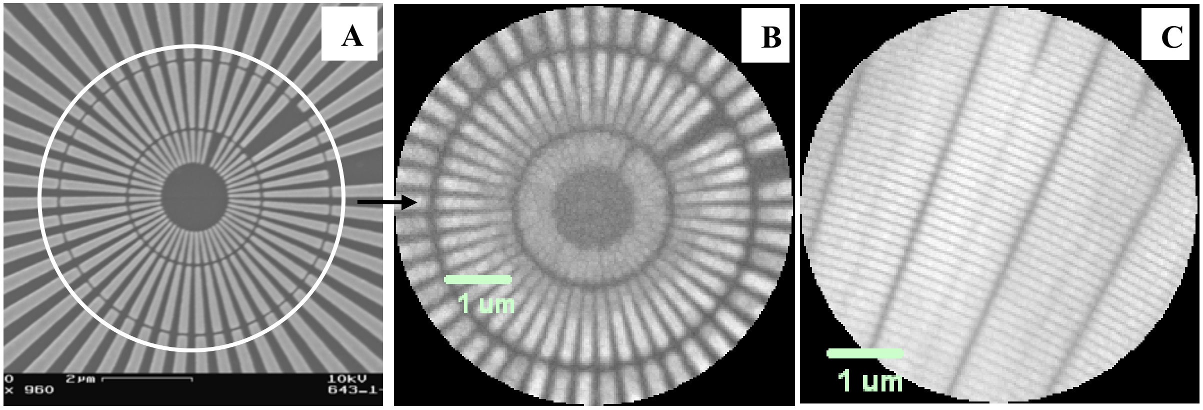

Fig. 1. Images a copper resolution target. Fig (A) is a scanning electron micrograph of the resolution target. Fig (B) is an x-ray fluorescence image recorded with the fluorescence imager. The image (B) corresponds to the area within the white circle shown in (A). (C) shows the x-ray fluorescence image of grating structure of 70nm grating width.

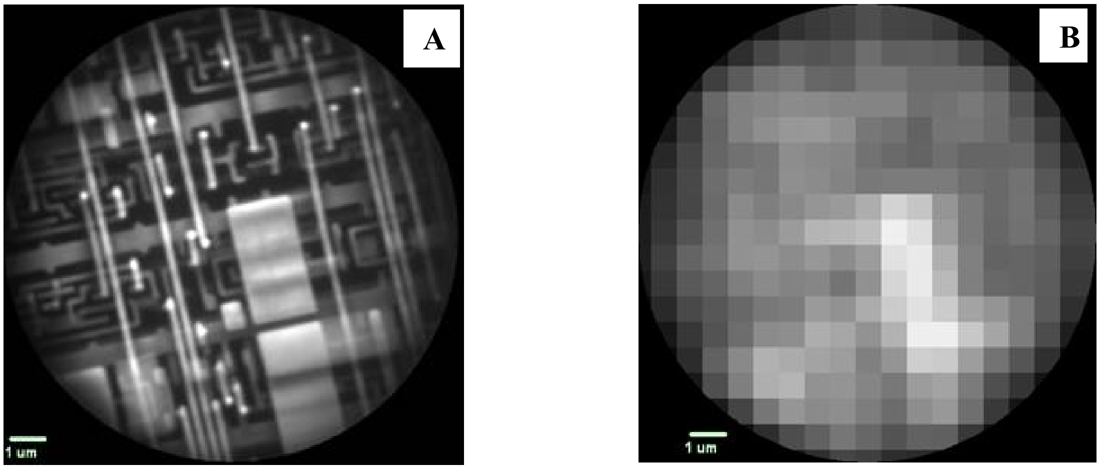

Fig. 2. Fig (A) is a Cu x-ray fluorescence image of a three layered Cu chip acquired with the fluorescence imager at 15kV electron beam voltage and 500nA electron beam current. The electron beam size was 10um and the integration time was 30min at an x-ray take off angle of 90deg. The small Cu lines are approx. 250nm wide. The brighter dots are vias connecting metal layers M1 and M3 and the dimmer dots are vias connecting M2 and M3. All three metal layers can be seen. Fig (B) shows the image (A) blurred with PSF = 1um and pixel size = 0.5um to show a comparison to EDS mapping data.