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A BKM to Measure BEOL Liner Thickness from XEDS Mapping with Accuracy Within 1%

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To precisely measure critical dimensions (CDs) and ultrathin film thickness at junctions, such as Via contact as an area of interest (AOI), and their uniformity is one of the essential daily routines for physical failure analysis (PFA) teams at semiconductor wafer foundries. Integrated chips (IC) with device built by nanometer-scale transistors are basically a complex miniature, stacked with composites of various material properties, such as semiconductors, dielectrics, and interconnects, pertinent to the needs of specific functionality that a nano-device is designed for. Constantly monitoring inline trends and dynamically improving CD uniformity, within the same wafer and across wafers during various steps of integration process are critical in wafer foundries, which helps to ensure stable baseline of high volume manufacturing (HVM), minimize inline excursions, and effectively introduce continuous improvement of process (CIP), targeting to drive for ultimate wafer yield enhancement, that can be realized technically [1~6].

With tireless efforts on continuous miniaturization of nanometer-scale transistors, this CD measurement task, seeming very simple and straightforward, turns to be quite complicated, in reality. Challenges include, (1) not only the CD itself becomes smaller and smaller; (2) but also certain intermixing of adjacent materials / elements at boundary is inevitable, and (3) the so-called "projection effect" in TEM lamellae, i.e., overlapping in TEM images due to multiple layers / features sandwiched throughout the already thin TEM foil. For example, a TEM lamellae with a thickness of 30~50nm, would have several layers of features with a dimension of few nanometers, e.g., liners, junctions, interfaces, etc. Therefore, traditional approach, to directly measure CDs based on contrast difference and judged by human vision, from images acquired by transmission electron microscopy (TEM) or scanning transmission electron microscopy (STEM), starts to be invalid or lack of desired accuracy. Instead, more often than not, one has to measure thin films from elemental mappings by x-ray energy dispersive spectroscopy (XEDS) or even electron energy loss spectroscopy (EELS).

In this paper, a best known method (BKM) to precisely measure back-end-of-line (BEOL) liner thickness from XEDS mapping, up to 1% precision, is elaborated. Ta/TaN as a liner with Cu-fill is a prevailing industry trend in modern BEOL integration for bulk CMOS or FinFET transistor node technology. Figures-1a and 1b are TEM and STEM images on a BEOL stack, and Fig.-1c is the corresponding XEDS mapping. Clearly, it is challenging to precisely measure the Ta/TaN liner thickness to within 1% accuracy, if to measure from the TEM and STEM images, and neither if directly measure from the elemental map, even if the TEM tool itself had been calibrated up to within 1% accuracy. Even by the same analyst, variations still present from time to time, which compromised the confidence level for gauge by repeatability and reproducibility (GRR). Therefore an objective measurement method has to be implemented to ensure data accuracy and an acceptable level of GRR, across the PFA team. In our experiments, Via liner CDs, measured by XEDS Linescan profiles, were compared against CDs from the same feature by TEM / STEM. Raw data acquired from an FEI Osiris Analytical TEM, and XEDS and its Qmaps being processed with a Bruker Esprint v1.9. Our BKM results demonstrated the following as useful guidelines, (1) with full-width-at-half-maximum (FWHM), e.g. from a linescan extracted from Ta mapping, in Fig.-2a, delta of FWHM displayed by mass-% vs. atomic-% was very minimum / negligible; and (2) when estimate FWHM, with Zero (0) as the minimum of peak height, and true values of both Half-Maximum and Full-Width, delta of liner CDs by FWHM from XEDS linescan are below 1% (as the TEM system being calibrated), both X-axis and Y-axis. Mostly, the TRUE end points of FWHM locate between two adjacent data points acquired in the XEDS linescan profile, depending on setting of pixel and binning. Figure-2b illustrated how to determine them in the model, from the zoom-in view of the Ta peak profile [7].

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[7] Thanks go to Albert Amann III of GLOBALFOUNDRIES Fab8 for his skillfulness in TEM sample-preparations, and Fab8 Management and Legal teams for supporting the publication clearance.

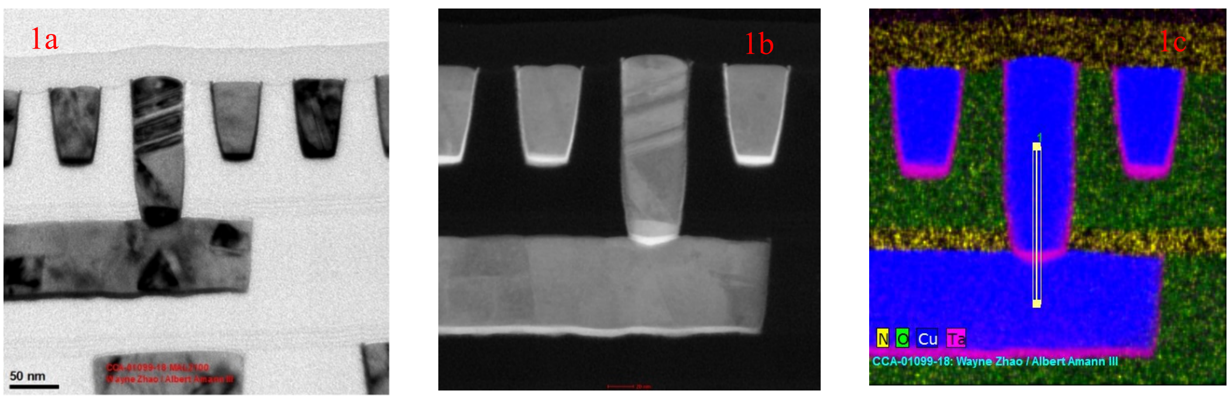

Figure 1. (a) TEM; (b) HAADF-STEM; and (c) XEDS mapping, on the BEOL Via.

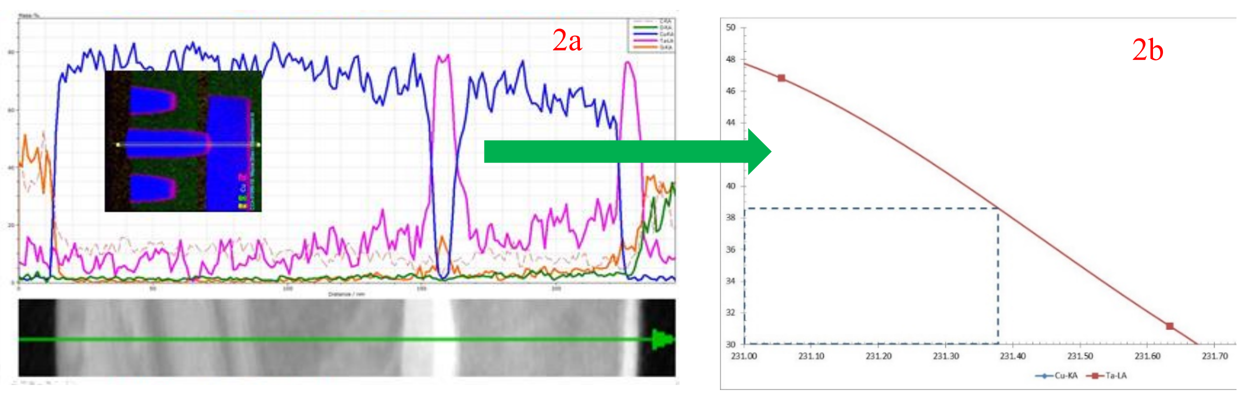

Figure 2. (a) Linescan profiles extracted from the XEDS mapping for Cu and Ta across the BEOL Via; and (b) illustration where to find the TRUE full-width and half-maximum in the model, using the right side profile of Ta peak across the Via bottom, as an example.

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