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Energy-filtered transmission electron microscopy: a tool to characterize side-wall damage in the low-k inter-metal dielectric

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Over last several decades, the characteristic trend of semiconductor industries has been the continuous miniaturization of microelectronic devices following commonly known relationship of Moore's law. As CMOS transistors were scaled, interconnects to link them are also shrunk to reduce the line pitches. The shrinkage in device dimensions to less than 0.25 µm feature size, increases propagation delay, cross-talk noise and power dissipation due to resistance-capacitance (RC) coupling between metal lines on the same level [1]. Insulators with the dielectric constant lower than that of SiO_2 known as low-k dielectrics were introduced to reduce the interconnect parasitic capacitance. Depending on the source gas and plasma conditions used to pattern the dielectric layer for metallization, plasma treatments can modify the surface chemistry (e.g., depletion of carbon), densify the underlying film, and/or roughen the surface. Plasma patterning can degrade low-k dielectrics by depleting methyl groups which increases the effective dielectric constant of a low-k material [2, 3]. In order to understand the modification at sidewalls, energy-filtered transmission electron microscopy (EFTEM) has been used to perform the elemental mapping. The resulting maps suggest damage profiles in Gaussian like shape (Fig. 2 (B)). We made a robust program to handle hundreds of energy-filtered images at a time to characterize the side-wall damage. Carbon and oxygen profiles deduced from the EFTEM mapping suggest that side-wall damage extends around 40 nm in the low-k dielectric layer. Damaged regions are depleted in carbon which increases the density of material and converted it in more SiO_2 like character. The map showing thickness over mean free path in Fig. 2 (D) also indicates a small variation across the low-k layer. Assuming uniform thickness across the low-k layer due to FIB sample preparation technique used, the variation could be explained by the change in mean free path of electrons interacting with the sample. The mean free path seems to be lower towards side-walls as compared to middle of the low-k layer. The oxygen K-edge map shown in Fig. 2 (C) suggests an increase in oxygen concentration towards side-walls as compared with that in middle of the low-k layer. The most probable explanation of increase in oxygen concentration would be the SiO_2 like character formed close to side-walls.

1. S. P. Jeng, M. C. Chang, and R. H. Havemann, "Process integration and manufacturing issues for high performance interconnect", MRS Symp. Proc. Adv. Metallization for Devices and Circuits, (1994), p. 25.
2. M. Chaudhari, J. Du, S. Bahera, S. Manandhar, S. Gaddam and J. Kelber, "Fundamental mechanisms of oxygen plasma-induced damage of ultralow-k organosilicate materials: The role of thermal ^3P atomic oxygen", App. Phy. Letter, 94, (2009), p. 2041021.
3. M. Shimada, Y. Otsuka, T. Harada, A. Tsutsumida, K. Inukai, H. Hashimota and S. Ogawa, "2-Dimensional Distribution of Dielectric Constants in Patterned Low-k Structures by a nm-probe STEM / Valence EELS (V-EELS) Technique", Proceeding of IEEE 2005: Interconnect Technology Conference, (2005), p. 88.

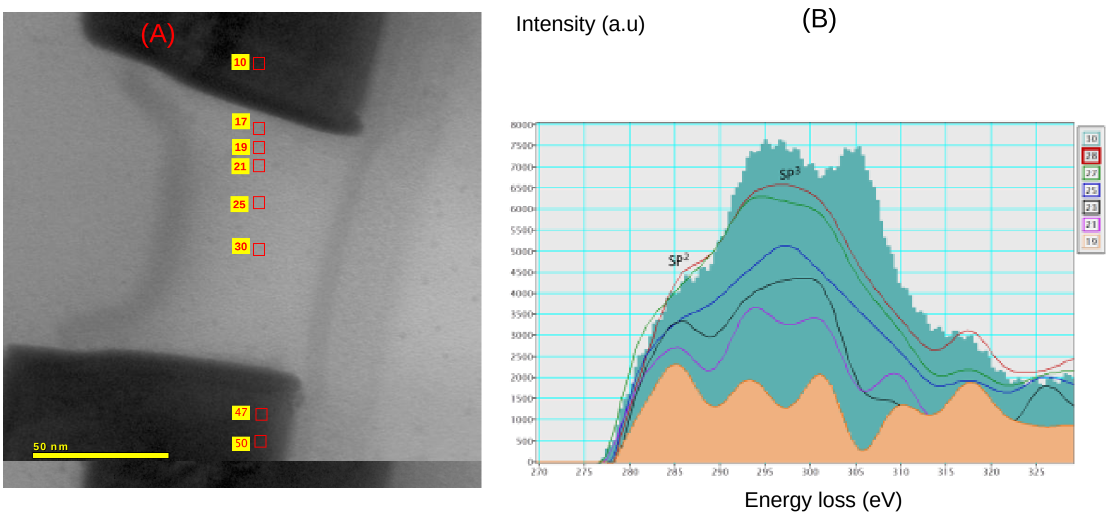

Figure 1.a.) Structure of the sample and **b.)** carbon-1s profile at various positions numbered in the image.

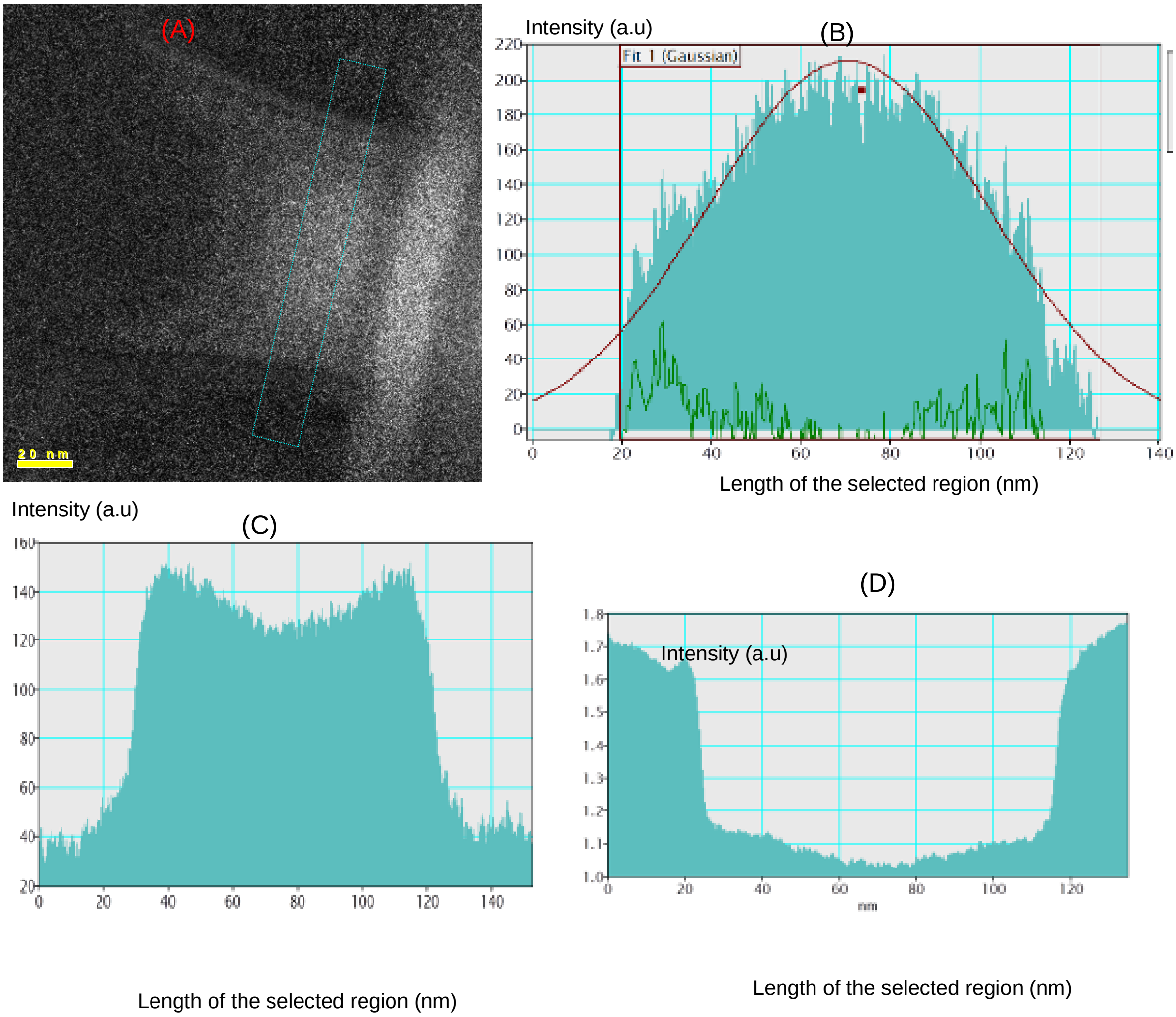

Figure 2. a.) The rectangular block in image used for the mapping **b.)** carbon mapping **c.)** oxygen mapping and **d.)** thickness over mean free path mapping inside the rectangular block.