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Further Applications of Energy Filtered TEM in Semiconductor Devices

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Energy filtered TEM (EFTEM) imaging has been used extensively for material characterization[1]. One of its major uses is to enhance image contrast from an area with difficult contrast phenomena due either to little density difference or large thickness variation. The projection nature of a TEM also generates difficult contrast if the structure is curved in the direction vertical to sample. In these cases, EFTEM provides a unique method to expand the spectrum of image contrast by carefully selecting an energy that provides excellent contrast in the area of interest. We will use the term "Energy Contrast" to describe this type of contrast, which has been used extensively. The other major advantage of EFTEM is the ability to provide high spatial resolution elemental maps very rapidly. These maps are obtained by acquiring three images at different energies (e.g. the three-window-mapping technique), followed by a calculation of elemental contribution vs thickness profile by characterizing the background.

The main objective of this paper is to reveal some of the energy contrast EFTEM applications in the semiconductor industry. The samples are silicon devices prepared by cleaving followed by dicing saw cutting and finished using a FIB to make an electron transparent sample of 50 - 100 nm in thickness[2]. The microscope used is a 200KV field emission TEM equipped with a post column Gatan$^{@}$ Imaging Filter (GIF). The system allows for embedded EFTEM imaging so that recognizable areas of interest can be imaged directly on the GIF at a reduced magnification. Due to confidentiality, the scale bars on the images are removed.

The improved contrast (energy contrast) can be compared with putting in an objective aperture to enhance amplitude contrast, or by going to a microscope with lower Cs to enhance phase contrast. For energy contrast, an energy filter is needed. The first example of EFTEM energy contrast imaging is a single-shot image at the Si (L) edge for better defining the exact profile of a poly-silicon gate. For sub-0.1um geometry technology, the allowable deviation of the gate critical dimension (CD) from the target is in the order of 2-3 nm. The measurement accuracy is therefore extremely important. However, due to the inherent poor contrast difference between Si and SiO2 and also mostly due to curvature variation in the gate sidewall, it is non-trivial to define the profile and accurately measure the CD from TEM images with are a projection over some thickness. In this case, an energy contrast image at 94eV (Si –L edge) with a slit width of 20eV is used to improve the image contrast as shown in Fig 1b. Comparing to the zero-loss filtered image (fig 1a), it is clear that there is much more useful information about the profile that can be obtained from the Si (L) energy contrast image. Another example of this technique is where the optimum energy for imaging the thickness and coherence of the barrier layer used in copper interconnects is selected. An elastic image (i.e. zero-loss filtered) is shown in fig 2a, and the energy contrast image at an energy loss of 240eV with a slit width of 12eV is shown in fig 2b. Again the energy contrast image provides much more information and better characterization than the zero-loss filtered image.

EFTEM elemental maps have proven useful in many investigations of silicon devices either as process characterization or defect analysis. One example presented in this paper is a map of copper using the Cu(M) edge to identify the copper contamination in the gate oxide of a flash memory device. Fig 3a is a plan view TEM image showing presence of particles in the gate oxide. EDX analysis shows copper enrichment in these particles. A three-window map at the Cu (M) edge was taken to acquire copper map shown in Fig 3b. Use of edges from low loss region allows shorter acquiring time, which is important for taking images at high magnification to avoid drift or beam damage The second example is a nitrogen map from a rapid thermally annealed nitrogen treated gate oxide sample. At high magnification, the TEM image shows a dark layer of around 1.5 nm at the top of oxide layer (fig 4a). The Nitrogen map (fig 4b) confirms the dark layer to contain more Nitrogen. 1.5 nm is approaching the typical EFTEM elemental mapping sensitivity (~ 1 nm for most elements). More analyses are undergoing to obtain a nitrogen map from an even thinner gate oxide.

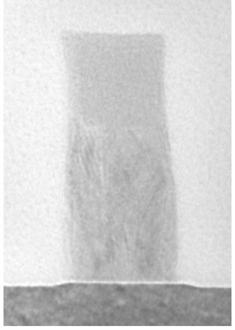

Fig. 1a-zero loss filtered

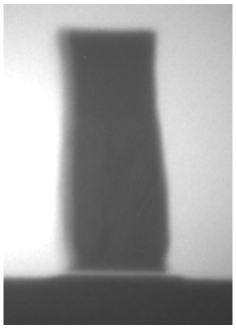

Fig. 1b-Si (L) filtered

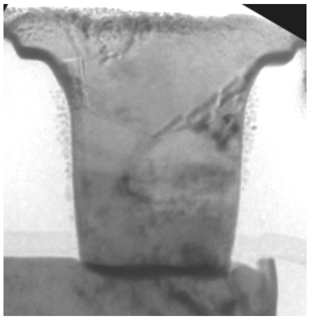

Fig. 2a-zero-loss filtered

Fig. 2b-pre-carbon edge

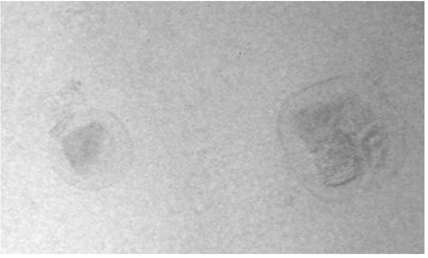

Fig. 3a – Plan view TEM

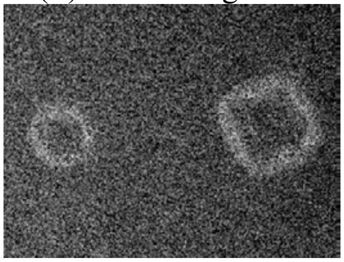

Fig. 3b – Copper (M) map

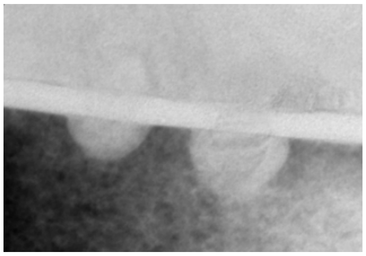

Fig. 3c – X-section TEM

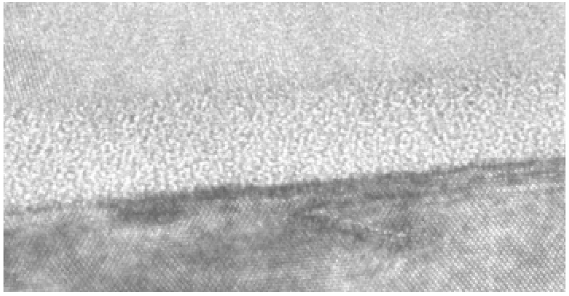

Fig. 4a – Zero-loss filtered TEM image

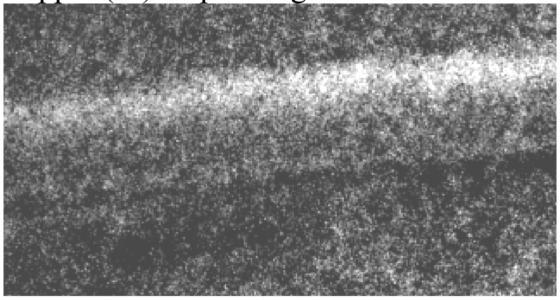

Fig. 4b- Nitrogen map of Fig. 4a

References

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[2] L. Tsung et al., M.A. O'Keefe, Proc. *Microsc. Microanal.* (2000) 500.