Having Your Cake and Eating It Too: A Procedure for Obtaining Plan View and Cross Section TEM Images from the Same Site

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Sample preparation for Transmission Electron Microscopy (TEM) is usually performed such that the final sample orientation is either a cross section or a plan view of the bulk material, as shown schematically in Figure 1. The object of any sample preparation technique, for either of these two orientations, is to thin a selected volume of the sample from its initial bulk state to electron transparency, ~100nm thick. In doing so, the final sample must be mechanically stable, vacuum compatible, and, most of all, unchanged from the initial bulk material. Many techniques have been used to achieve this goal: cleaving, sawing, mechanical polishing, chemical etching, ion milling, focused ion beam (FIB) milling, and many others. These techniques can be used either alone or in combination to produce high quality TEM samples. In either orientation, once the choice of orientation is made, it has not been possible to transform a finished sample from one orientation to the other. Although electron tomography [1] can generate a three dimensional view of a site of interest, it does not give all the information that could be obtained if both a plan view and cross section TEM sample of the same site were available. In the past, if both cross section and plan view images were needed, separate samples on "equivalent" sites were required.

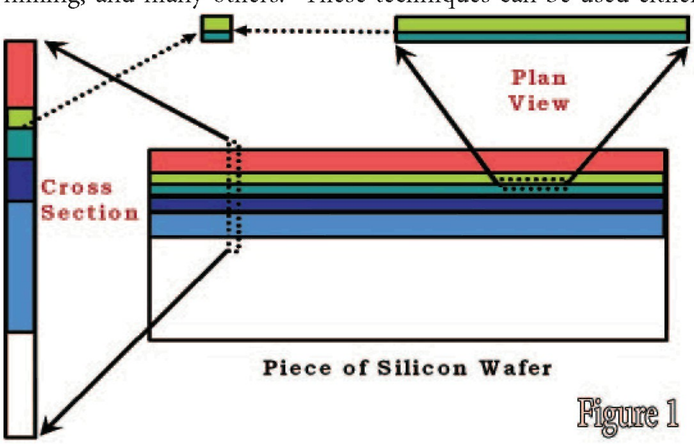


Figure 1

However, "equivalent" sites are not identical sites, just as no two snowflakes are identical. Also, the differentiation can go way beyond normal subtle process variations for several reasons. One site may have had extensive electrical characterization which would be prohibitive to repeat on another site. The defect may be one-of-a-kind, such as an early failure in an extended lifetime test, where more samples may not be available for many days or weeks.

In addition to a unique site, the defect may not be sufficiently localized for normal cross section sample preparation. A defect that can not be seen optically is commonly localized by electrical techniques, such as liquid crystal or emission microscopy. These techniques have a resolution of more than a micron under the best circumstances. Current design practices of dummy metal and dense structures are far from ideal. Even a thick TEM cross section would have much less than an even chance of hitting a specific defect, unless the defect was big enough to be seen during sample preparation. As technology progresses, the size of electrical killer defects is shrinking faster than the imaging capability of the FIB. On the other hand, electrical failure analysis techniques can usually locate the defect to well under a micron in the vertical direction. Thus, a defect can be found easier in plan view than in cross section, but the cross section is more useful in determining the point in the process the defect occurred.

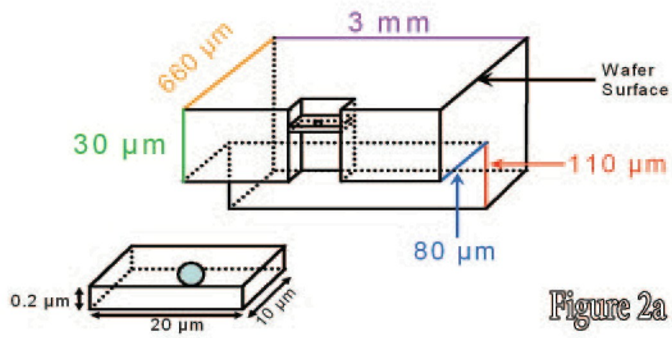


Figure 2a

By carefully using a dicing saw and a FIB tool, a procedure for transforming a plan view TEM sample into a cross section TEM sample has been developed to overcome the aforementioned challenges. This conversion is described below; the reverse transformation is similar. (A similar procedure, not described here, could also be used on an *in-situ* FIB lift-out sample.)

Normally, this conversion would be almost impossible. The traditional sample preparation techniques of polishing, dimpling, chemical etching, or tripod polishing can provide large thin areas for analysis. The large size of the thin area also means that there is no nearby mechanical support for that same thin area so it can withstand the stress of further sample preparation. Also, these techniques can leave the area of interest too thin. For example, if the plan view sample is 50nm thick, the corresponding cross section will only be 50nm tall, which would remove much of its value.

The preparation of a self-supporting (no grid) plan view sample, as described elsewhere [2], is summarized here. A dicing saw is used to cut a 660µm x 140µm x 3mm section of the bulk material, as shown in Figure 2a. A second saw cut thins the sample thickness around the region of interest to approximately 30µm and creates a ledge approximately 80µm deep. The depth of this ledge is important for the second half of the process. The area of inter-

Fig. 2b

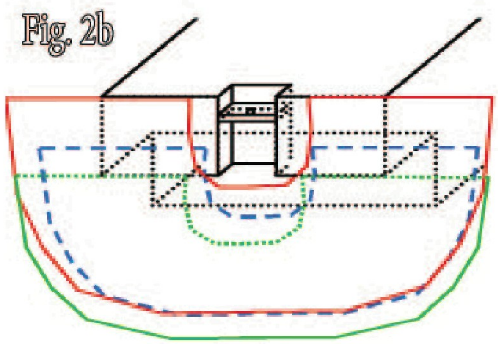
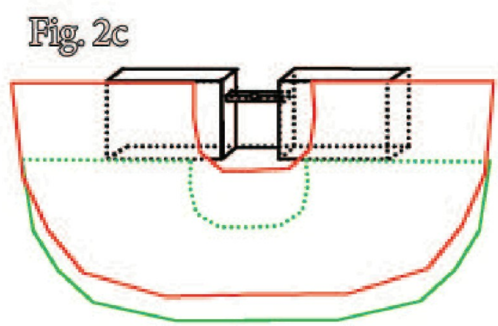
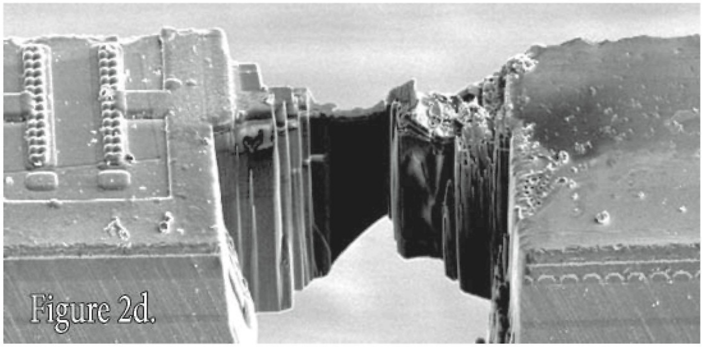


Fig. 2c





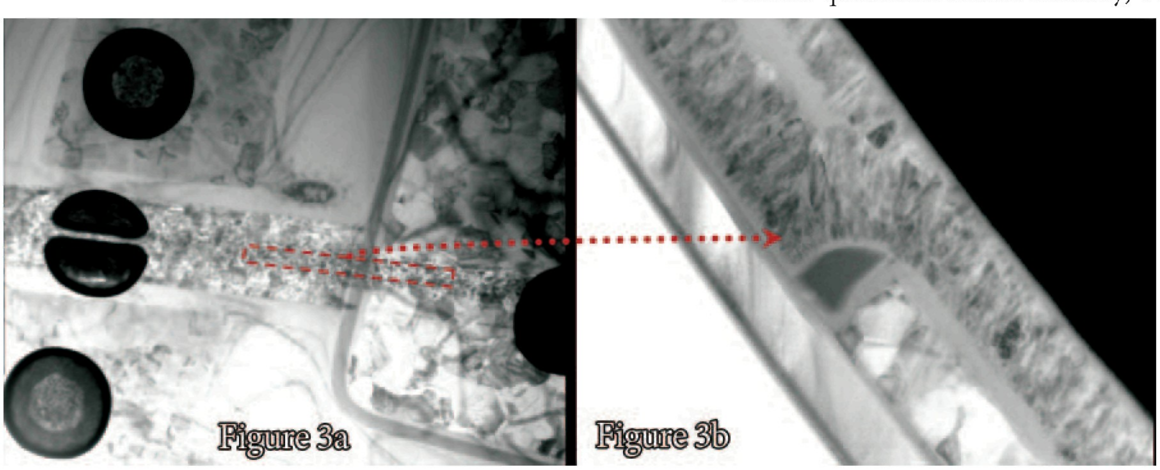
est is thinned to electron transparency using the FIB. During final FIB thinning, the region of interest can be left somewhat thicker than a normal plan view sample, however, it is still thin enough for routine TEM analysis. As part of the plan view analysis protocol, the desired plane of the cross section is determined. If necessary, this plane can be marked by laser or FIB for easier location later in the sample preparation process.

Since the starting sample for the second half of the sample preparation procedure is already only a fraction of a micron thick and most of its support will be removed as sample preparation continues, additional mechanical support of the thin area and the surrounding material is critical. First, the plan view sample is protected with a coating, such as a deposited TEOS oxide layer or by applying an M-bond epoxy film(or both). Although this coating is thin, two or three times the thickness of the sample itself, the coating increases the overall strength of the region of interest by more than an order of magnitude (approximately the square of the total sample thickness). At this point, a half-TEM grid is able to give sufficient support to the entire sample. However, the front face of the plan view sample, being only 30µm wide, is too narrow to support a half TEM grid by itself, so two additional half-TEM grids are used to provide the necessary base for the main grid, as shown in Figure 2b. The first half-grid (blue in Figure 2b), which is sacrificial and will be polished away later, is bonded to the face of the shallow cut using either M-bond or a two-part epoxy. The second half-grid (green in 2b) is bonded on top of the sacrificial grid and its face is roughly coplanar with the front face of the plan view sample. The sample is then heated on a hot plate, or in a low temperature oven, to cure the epoxy for the two half-grids. The surface of the second half-grid, along with the front face of the plan view sample, acts as a platform for the third half-grid (red in 2b), which is the primary support grid. The 80µm depth of the second saw cut is important because that depth corresponds to the thickness of the two grids and their adhesive layers. The adhesive layer under the third grid can accommodate any slight misalignment of the face of the second half-grid with respect to the front face of the plan view sample. After the third half-grid is mounted, the sample is heated a second time to cure that adhesive layer.

At this point, the sample is in the same configuration as the start of the second-side sample preparation in the traditional "H" bar FIB TEM method. Sawing, cleaving, and/or polishing will remove the bulk of the plan view sample along with the sacrificial support grid. This leaves a slice of material 10 to 30µm thick and about a micron thick at the area of interest. The sample outside the region of interest is also 10 to 30µm thick, but is still 30µm tall. The sample is thinned to the desired thickness at the region of interest using normal FIB techniques. This FIB work is very quick and clean since the cuts are about a micron in depth and the lack of surrounding material minimizes re-deposition artifacts. This is shown schematically and in a FIB-SEM image in Figure 2c and 2d, respectively.

Figure 3a shows a plan view TEM image of a poly silicon defect between two contacts and Figure 3b shows a TEM image of the final cross section. The dotted box in the plan view image, Figure 3a, shows the approximate position of the cross section image. The actual cross section spans the entire plan view image, but a higher magnification image is shown in Figure 3b to highlight the details of the defect. Although this defect is fairly large and would have been an easy cross section, the plan view shows information about this curving defect that would have taken many cross sections to obtain. The cross section shows features that are not obtainable in the plan view (and *vice-versa*). In the plan view image, the defect appears to be a single poly line which splits metal contacts and narrows on going over (or under) the gate structure. However, in cross section, the defect is identified as a silicon nitride stringer coated with two different thicknesses of poly, which goes over the gate poly and sidewall spacer. The information gained from the plan view and the cross section TEM images gives indication of the process steps responsible for the defect and leads to process changes to eliminate the defect.

Until recently, the conversion of a plan view sample to a cross section would have been unthinkable. By combining the strengths of several sample preparation tools, the conversion is not only possible, but is also relatively straightforward. As customers keep pushing, long held ideas of what is possible must be re-examined in order to meet their needs. A quote from George Bernard Shaw (or a similar quote from Robert Kennedy) best summarizes this situation: "Some people see things as they are and ask 'why?' I dream of things that never were, and ask 'why not?'" What can the TEM community do if we ask ourselves 'why not?'? ■



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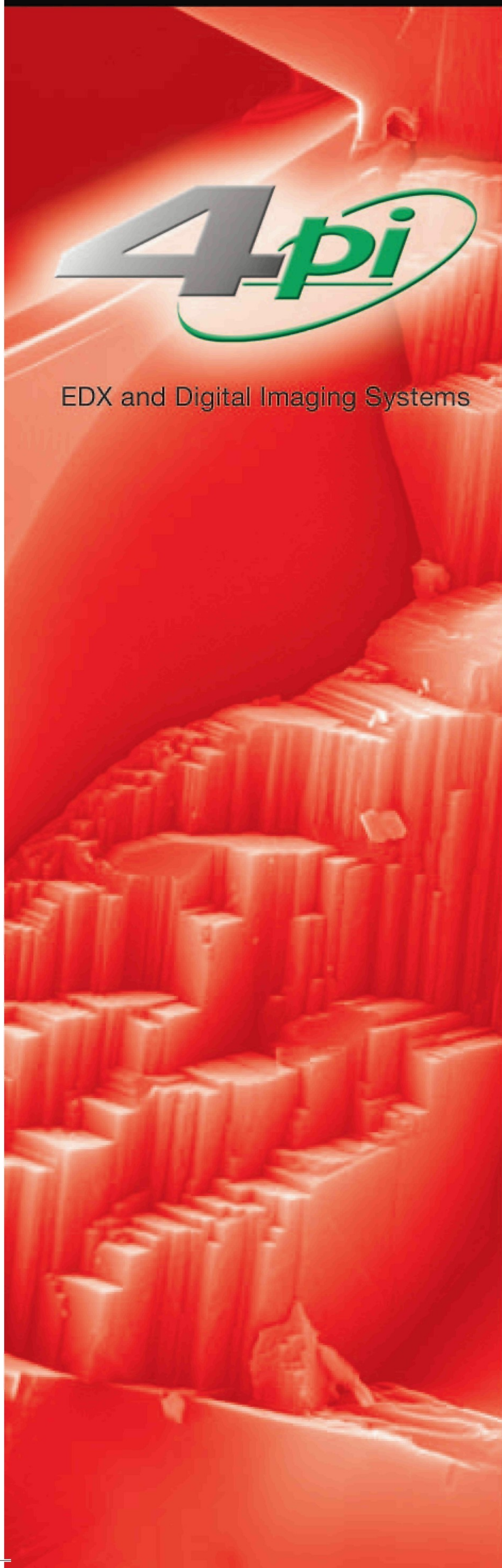
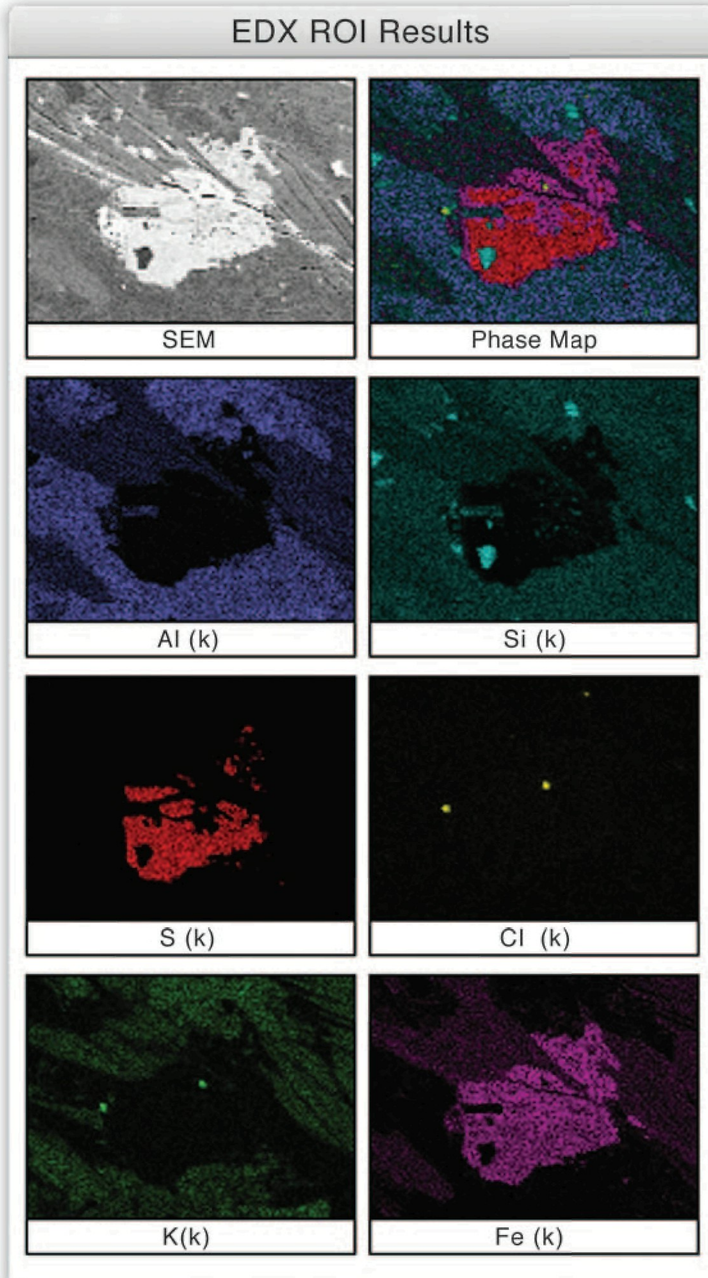
[2] Lancy Tsung et al., *Microsc. Microanal.* 6 (Suppl. 2: Proceedings) (2000) 500.





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