Characterization of Surface and Sub-Surface Defects on Devices using Complimentary Techniques

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Introduction

Being able to differentiate surface from bulk defects on devices requires the use of complimentary characterization tools. In this article, we show how light microscopy, scanning electron microscopy, energy dispersive X-ray analysis, and time of flight secondary ion mass spectrometry provides complimentary information about the surface and sub-surface composition, topography, and microstructure of a semiconductor device.

To create a gamma-ray spectroscopy detector, electrical contacts consisting of a blanket coated cathode and a pixilated anode can be deposited directly on opposite faces of a cadmium zinc telluride (CZT) crystal [1]. The contact metallization must adhere to the surfaces, and the streets between adjacent anode pads must be free of residual metal and contaminants to avoid excessive inter-pixel leakage currents. The analysis reported below was used to validate the structure and composition of the contact metal stack and to characterize the streets of the anode pad array. The particular CZT device characterized was an early prototype, and is not representative of the quality of current commercial CZT vendors. Nevertheless, it serves to illustrate the complementarities of light microscopy (LM), scanning electron microscopy (SEM), energy dispersive x-ray analysis (EDX), and time of flight secondary ion mass spectrometry (ToF-SIMS), in developing a comprehensive characterization of various types of defects that can occur in electronic devices.

Description of the Analytical Instruments

The SEM analyses were performed using a Leo 1530VP FE SEM (Carl Zeiss SMT AG) [2] using beam energies of 5 kV and 15 kV along with Oxford Instrument's Inca Microanalysis Suite for EDX analysis [3]. The anode pads are approximately 1mm x 1mm in size.

ToF-SIMS analysis were performed using an ION-TOF, model ToF-SIMS IV [4] instrument equipped with a 3 lens Bi-polyatomic primary ion source (25 kV Bi_1 was used for the analysis reported here), a low energy flood gun (for charge stabilization of insulating samples), a dual source ion gun (capable of bombarding the sample with either Cs or Ar in order to remove the outer surface layer and sample sub-surface depths of the sample during a depth profile measurement), a pulsed secondary electron detector, a reflection ion detector, two *in-situ* cameras for visualization (light microscopy [LM]) of the region being analyzed and a 5 axis motorized stage (*X, Y, Z, T, R*). The ToF-SIMS images were collected over 500 µm × 500 µm regions, using 128 × 128 pixels in the image, and summing 50 image frames; the images are displayed using a thermal scale where pixels with the highest spectral intensity appear white and pixels with no intensity appear black.

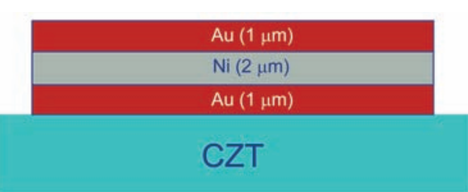

Figure 1. Cross-section of the anode pixel metal contact on CZT (anode pads are approximately 1mm × 1mm each).

Description of the Sample

The detector had a thin anode array pattern consisting of stacked layers of Au–Ni–Au, of thickness 1 µm, 2 µm and 1 µm respectively. A schematic of a cross-section of a single anode pixel is provided in Figure 1. Cropped, low magnification SEM images, which were collected at the four corners and the center of the device, are provided in Figure 2. The anode pads are approximately 1mm × 1mm in size. This device consists of an 11 × 11 anode pad array, the arrays are indicated by the dotted lines in Figure 2. The SEM images reveal contrast within the metallic pads indicative of defects. EDX spectra collected at six gold pads on the sample are provided in Figure 3. As expected, all of the spectra reveal Ni, Au, Cd and Te. The metallic stack has a total thickness of 4 microns, which is similar to the sampling depth of EDX, which would have made it difficult to determine, without prior knowledge of the structure, whether these species originate from the top-most layer of the sample or from sub-surface depths. Surface analysis of the

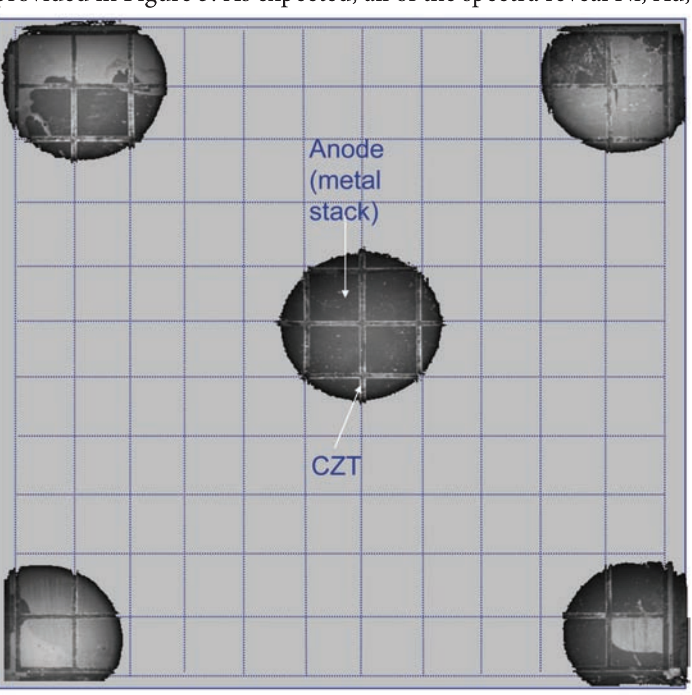

Figure 2. Low magnification SEM images collected at various regions on the device, the grey square represents the size of the actual device (11 × 11 anode pads). The anode pads are approximately 1mm x 1mm each.

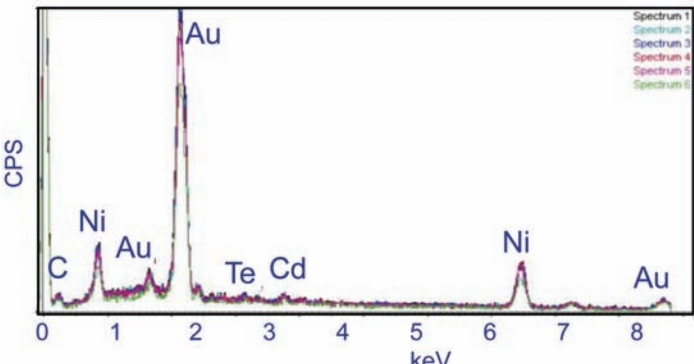

Figure 3. Overlay of EDX spectra collected at six regions on the gold pads.

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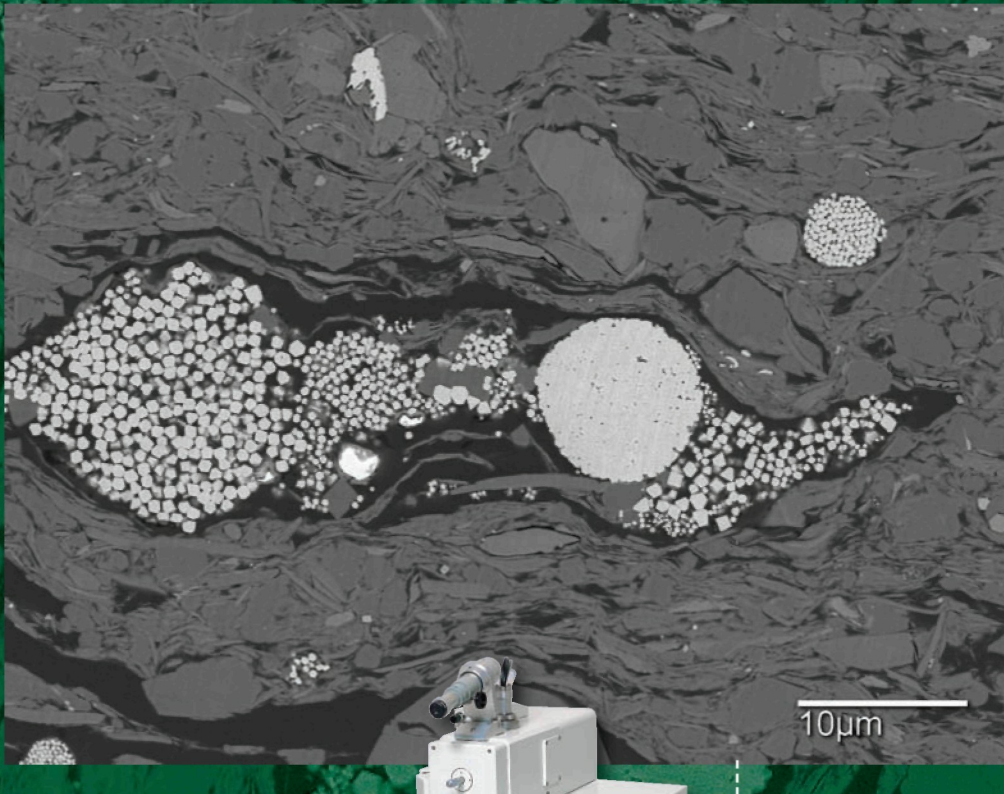

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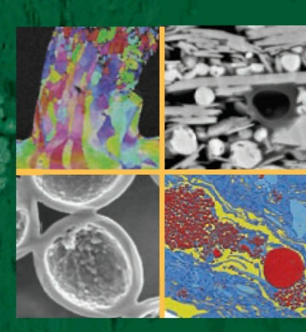

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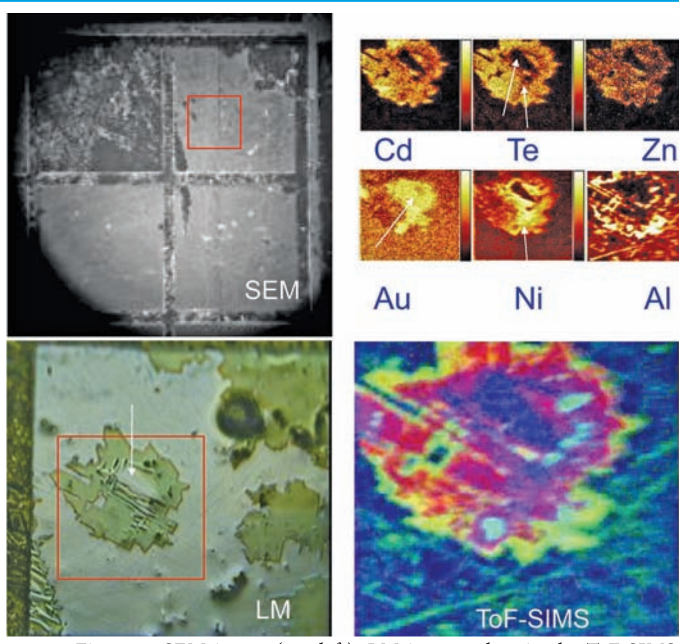

Figure 7. SEM image (top left), LM image taken in the ToF-SIMS instrument (bottom left), ToF-SIMS ion images (top right), and a color overlay of 3 of the ToF-SIMS images (bottom right; red is Cd, green is Al, and blue is Au). These data were collected in the top right region of this device, note the delaminating of the anode pad.

in Figure 6. Note that the contrast observed in the SEM image does not reveal chemical contrast in the corresponding ToF-SIMS images. Comparison with the LM image reveals that this feature is "raised;" note the shadowing on the left side of the LM image. The ToF-SIMS images reveal that the black feature shown in the LM image (indicated by the arrow) is associated with Cd, Te, and Zn, and does not have any Au. This feature corresponds to a void in the anode stack and ToF-SIMS is sampling the CZT crystal. The Ni ion image reveals a region of high intensity (a ring) around the void, indicating that the side wall of the anode stack is being sampled by ToF-SIMS.

Figure 7 corresponds to data collected in the top right corner of the device. The LM image clearly reveals delamination of this anode pad. The ToF-SIMS ion images reveal Cd, Te, and Zn in distinct locations, indicating that ToF-SIMS is sampling the CZT crystal. Note that the Au and Ni ion images have the highest image intensity in regions where Cd, Te, and Zn have low intensity (these areas are marked with an arrow); the LM image reveals that the anode metallic stack is intact within this region.

Large surface protrusions (raised regions) are evident on many of the anode pads analyzed. ToF-SIMS images collected in these regions do not reveal chemical contrast indicating that these protrusions are not associated with a change in the surface composition. We believe these protrusions are a result of Al_2O_3 particles at the CZT/Au interface. The Al_2O_3 particles originate from the polishing compound used to planarize the CZT surface prior to deposition of the anode layers, revealing that the CZT surface was not properly cleaned. New cleaning protocols were implemented and a follow-up analysis no longer shows this problem (data not shown), verifying that the new cleaning protocols worked. The defects observed on this detector are not observed on current devices.

Summary and Conclusions:

The four analytical techniques used in this study provide a complimentary set of information regarding the sample and allows the analysts the ability to differentiate surface *vs.* sub-surface (bulk) defects in a device. Both EDX and ToF-SIMS revealed the presence of Ni in each of the gold pads analyzed. ToF-SIMS also revealed the presence of Al in both the gold pad as well as CZT streets. ToF-SIMS also identified voids in the anode stack assembly (the top left pad, see Figure 6) as well as delaminated regions (the top right pad, see Figure 7) in some, but not all of the anode pads. The contrast observed by SEM in both the bottom right and bottom left pads is not associated with a change in surface composition, as determined by ToF-SIMS, rather a change in subsurface composition. Similarly, the contrast observed by SEM in the top left pad is not due to a change in surface composition; light microscopy indicates that it is associated with a change in surface topography; it is likely that Ni and/or Al are present at the CZT/Au interface. The presence of such species at the interface would account for: (1) the change in topography observed in the LM image, (2) the contrast observed in the SEM image, as well as (3) the lack of contrast in the surface composition measured by ToF-SIMS, on the top left anode pad (see Figure 6). Subsurface species would also explain the contrast observed in the SEM images shown in the lower right and lower left anode pads (Figures 4 and 5, respectively) but lack of contrast in the surface composition measured by ToF-SIMS. ■

References

[1] http://en.wikipedia.org/wiki/Cadmium_zinc_telluride

[2] Carl Zeiss SMT Inc. One Corporation Way, Peabody, MA 01960, Phone: 978 826 7909, http://www.smt.zeiss.com

[3] 300 Baker Avenue, Suite 150, Concord, MA 01742. http://www.x-raymicroanalysis.com/pages/main/inca.htm

[4] ION-TOF GmbH, Gievenbecker Weg 15, 48149 Muenster, Germany. http://www.ion-tof.com.

[5] J.C. Vickerman and D. Briggs, Eds. ToF-SIMS Surface Analysis by Mass Spectrometry, Surface Spectra/IMPublications, London, 2001.

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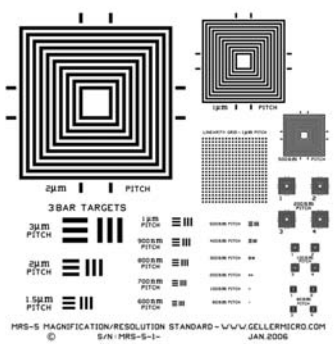

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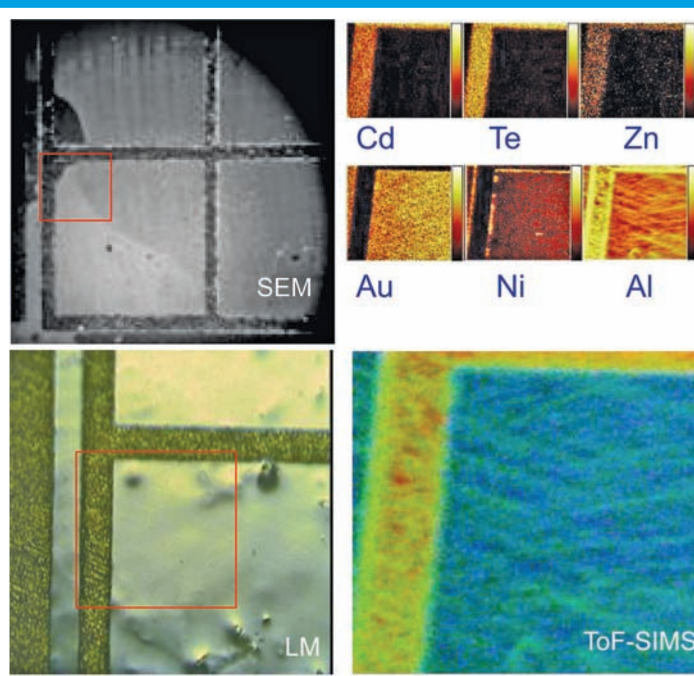

Figure 4. SEM image (top left), LM image taken in the ToF-SIMS instrument (bottom left), ToF-SIMS ion images (top right), and a color overlay of 3 of the ToF-SIMS images (bottom right; red is Cd, green is Al, and blue is Au). These data were collected in the bottom left region of this device. The red boxes in the SEM and LM images represent the regions sampled during the ToF-SIMS analysis. Each anode pad is approximately 1mm × 1mm in size.

same regions of this sample was performed using ToF-SIMS that has a sampling depth of about 1 nm and high sensitivity (ppm/ppb) for most elements [5].

Results and Discussion

The SEM image shown in the top left corner of Figure 4 reveals contrast across this metallic pad. The LM image of this same region (lower left panel of Figure 4) reveals protrusions at select locations. The ToF-SIMS images, collected within the region identified by the red box in the SEM and LM images, does not reveal chemical contrast associated with the features observed by SEM or LM. The lack of contrast in the ToF-SIMS images indicates that these features are not associated with a change in surface composition. The CZT streets are well defined and gold is uniformly distributed across this anode pad. Ni is enriched along the CZT streets, indicating that ToF-SIMS is sampling the sidewall of the anode pad assembly. Al is detected both within the CZT streets as well as on the anode pad assembly. The Al ion image reveals some contrast associated with scratches on the top surface. It is significant to note that the Au layer contains both Al and trace amounts of Ni within the sampling depth of ToF-SIMS which is about 1nm, this was not expected. The concentration of Al is estimated to be less than 0.1 atomic %. The contrast observed by SEM and LM, but not ToF-SIMS, is believed to originate from a change in sub-surface composition (presence of Al and/or Ni at the CZT/Au interface). This hypothesis could be verified by performing a ToF-SIMS depth profile analysis through the region of interest; a depth profile analysis would also reveal if the Al is present as only a surface contaminant, or if it is indeed an impurity within both the CZT streets and the anode pads.

Figure 5 shows data collected in the lower right corner of the sample. The contrast observed in the SEM image of the anode stack also does not correspond to a change in chemical contrast in the ToF-SIMS images indicating that the contrast observed by SEM is not resulting from a change in the surface composition. Inspection of the ToF-SIMS images representing the anode pad assembly shows regions that are enriched in Au, Ni, and Al (see the arrows). These features correlate with protrusions in the LM image and represents deposits/contaminants. The Al ion image reveals a high density of scratches in this anode pad, and many of these scratches are decorated with Al.

Data collected from the top left corner of the sample are shown

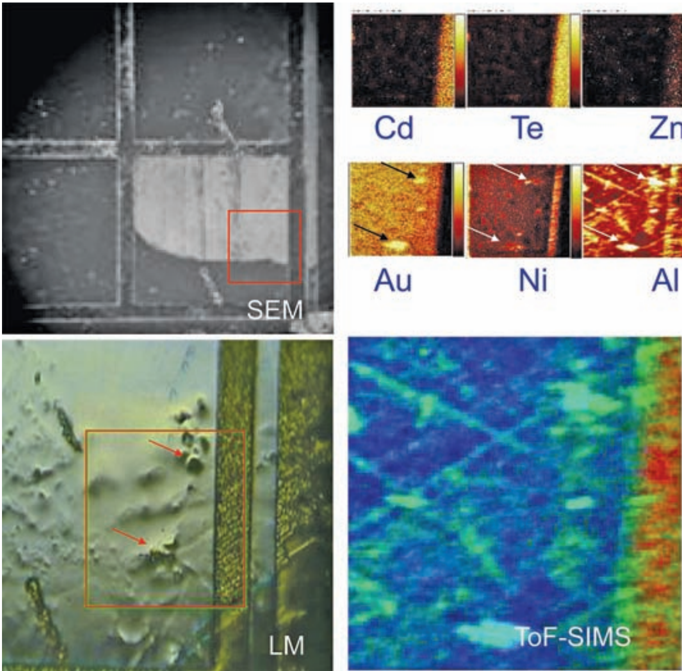

Figure 5. SEM image (top left), LM image taken in the ToF-SIMS instrument (bottom left), ToF-SIMS ion images (top right), and a color overlay of 3 of the ToF-SIMS images (bottom right; red is Cd, green is Al, and blue is Au). These data were collected in the lower right corner of this device.

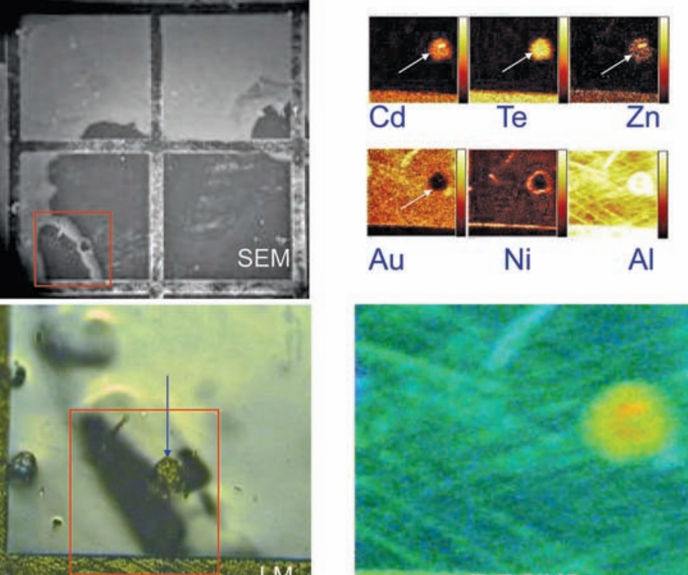

Figure 6. SEM image (top left), LM image taken in the ToF-SIMS instrument (bottom left), ToF-SIMS ion images (top right), and a color overlay of 3 of the ToF-SIMS images (bottom right; red is Cd, green is Al, and blue is Au). These data were collected in the top left region of this device, note the void in the anode pad.

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