Failure Analysis:
The Old and the New

David Edwards
Vern Robertson*
Natasha Erdman*
JEOL USA Inc.
Peabody, Massachusetts

Greg McMahon
Boston College

Whether it is resurrecting old technologies such as EBIC, or improving on those technologies making them easier to use, today's failure analyst has a vast and improved toolbox from which to work.

Electron Beam Induced Current is a failure analysis technique that takes advantage of the flow of the electron-hole pairs formed by the interaction of the incident beam of the scanning electron microscope, and the *p-n* junctions within a semiconductor device. By varying the beam parameters of the SEM (**Fig. 1**), the analyst can estimate the path of an electrical overstress event and possibly even the initiation point. Armed with this additional information, the root cause of the event can more easily be identified. This technique was very popular in the 1980s and 90s for analysis of integrated circuits.

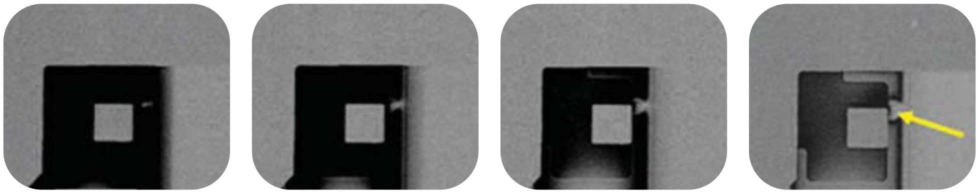

Fig. 1 – *Increasing energy of the electron beam exposes incrementally more of the EOS event.*

Back then, EBIC detected leakage between fine traces and across gates. Today, for solar cells, EBIC detects voids in the crystals, mask misalignments, and other manufacturing issues that lead to electron-hole-pair "sinks." By identifying these leakage modes, manufacturing parameters can be altered to minimize voids, correct misalignments, and otherwise improve the efficiency of the new solar cell technologies.

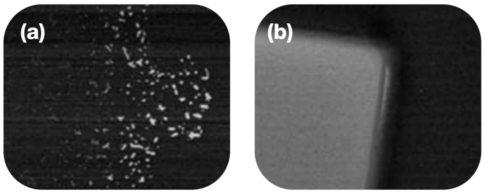

Fig. 2 — *(a) Voids decreasing efficiency (b) Misaligned layers causing leakage current.*

Hardware and Software

An EBIC image shows the underlying silicon junctions, and a secondary electron (SE) image shows the circuitry. In the past, separate photos had to be taken at different imaging conditions and viewed side-by-side to identify the location of the electrical overstress (EOS) event. With today's hardware and software, both the SE image and the EBIC image can be collected simultaneously during a single scan, and then they can be overlaid in real time. The result is a live mixed image from a single scan, with all three images saved at one time. **Figure 3a** shows the SE image of the top level circuitry; **3b** shows the EBIC image formed in the silicon; and **3c** shows the mixed or composite image. This technique works well for localizing junction breakdowns caused by manufacturing defects or electrical overstress events.

Backscattered Electron Detectors

With the old solid-state backscattered electron (BE) detectors, it was a struggle to obtain an image with a beam below 5kV and/or at low beam currents which were re-

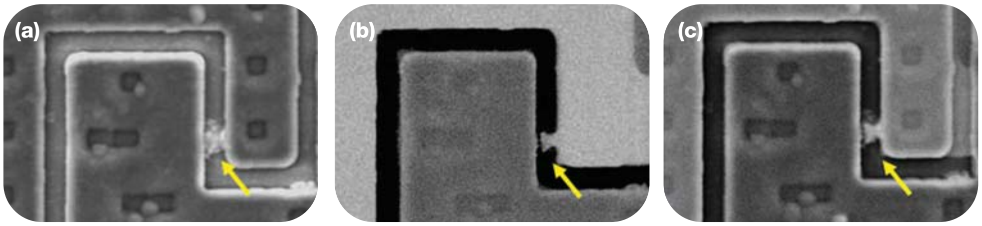

Fig. 3 — *(a) SE Image of top-level circuitry of an IC showing the disruption of the surface, (b) EBIC image of the damaged silicon junction, (c) mixed image overlaying the SE and EBIC images.*

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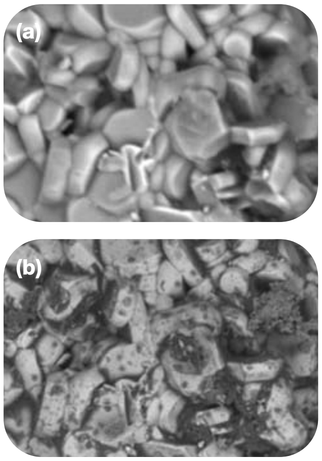

Fig. 4 — *(a) 15kV backscattered electron image of ferrite with polymer coating (b) 3kV image of the same location.*

quired at low kV to maintain the small probe diameter needed for high resolution. Even then, the image had to be focused at a slow scan speed. However, today's high-sensitivity high-bandwidth BE detectors allow imaging at less than 1 kV, and the image can be focused with the high-speed scan.

In the past, manufacturers of pretreatment coatings for automotive sheet metal would look for surface contamination at higher kVs, because of the limitations of the old BE detector. With the new BE detector, those same manufacturers are able to more easily identify contamination and produce higher quality, cleaner pretreatment coatings, enabling better and longer lasting paint adhesion. Gone are the days of the blistered paint job on your five-year-old car!

Figure 4 illustrates a similar example. The image is of a ferrite toner particle with a thin polymer coating. At 15kV the polymer is nearly invisible, as the beam almost completely penetrates the low atomic-number material. At 3kV on the exact same location, this surface now shows a thin, non-continuous coating.

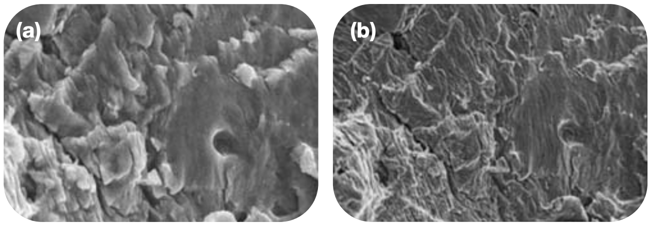

Fig. 5 – *(a) 20kV image of fatigue striations (b) the same image at 5kV.*

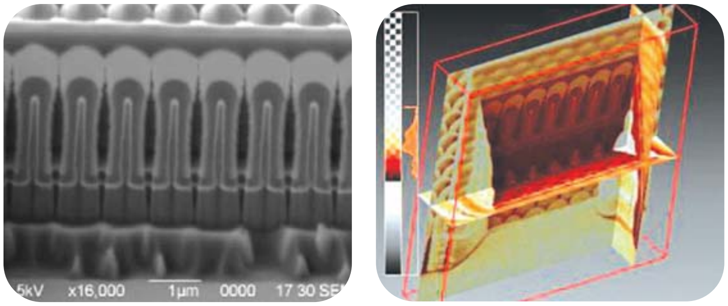

Fig 6 — *FIB cross-section of nanostructured photovoltaic architecture (left) and corresponding 3D volume reconstruction (right).*

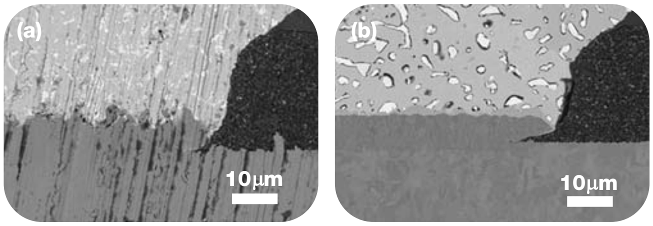

Fig. 7 — *(a) Mechanical polish of wire bond cross-section (b) CP polish of the same site.*

Today's low kV imaging is far improved over yesteryear. With higher resolution and enhanced sensitivity, surface details that in the past were lost in the noise at low kV and low beam current, or made translucent by higher kVs, can now be seen at low kV with relatively little effort. In a metal fatigue failure, the microscopic fatigue striations known as "beachmarks" are inherently more obvious when observed at low kV, especially in lower atomic-number metals such as aluminum. Compare the images of **Figures 5a and 5b**. The beachmarks in the lower left of 5b are significantly more visible than those of 5a.

Secondary Electron Detectors

Historically, ceramics and other nonconductive samples had to be coated; or, if the sample had to be preserved, a low-vacuum mode was required. As it turns out, low kV can eliminate charging during observation without the need for depositing a conductive coating or switching to low vacuum. With today's improvements, the analyst can reliably inspect ceramics and many other nonconductive samples by using a low-kV beam. In fact, imaging at 800 to 1200 volts is often all that is needed to prevent charging of the sample, while at the same time obtaining good surface information. Although conductive coating and low vacuum offer a solution, low kV uncoated imaging not only reduces charging, but also yields the most surface topography information with no concerns about artifacts that may have been introduced from coating.

Sample Preparation

Mechanical polishing is an art unto itself. A great deal of time and practice are required to reliably produce high-quality hand-polished sections with no mechanical deformations or smearing. Even then, only a few true artisans can repeatably cross-section through the center of a 0.5 μm IC contact. If the sample happens to be a gold wire bond, it is likely that the gold will smear, hiding both the grain structure and any microvoids at the bond interface.

The Focused Ion Beam (FIB) generates a gallium ion beam to produce cross-sectional cuts. When precise positioning is essential for a cross section, often the case with today's ICs, then a FIB is the tool of choice. The FIB is capable of routinely making highly accurate, precise cuts that are typically less than 20 μm wide (Fig. 6).

The Cross Section Polisher (CP) utilizes a defocused argon ion beam to produce a relatively broad cut in comparison to the FIB. A CP cut is typically 1-2 mm across, yielding a "bulk" cross-section as compared to a FIB cut of 10-20 μm. The CP can also produce high quality cross-sections of composites of both hard and soft materials with a minimum of strain and distortion of the polished surface. Both mechanical polishing and FIB cuts are known for the artifact trails they produce when a hard item such as a tungsten contact plug, lies above a soft item such as silicon. **Figure 7a** shows the micro scratches caused by the polishing media and smearing of the gold grains in the wire bond left by a mechanical polish. **Figure 7b** shows that the smearing and scratches have been removed by the CP. In this method of sample preparation, no mechanical contact

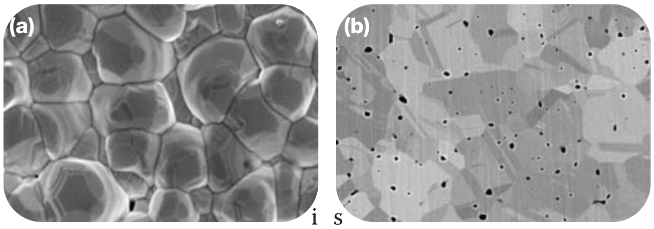

Fig. 8 — *CP confirms solar cell voiding identified by EBIC (a) Top surface of a solar thin film (b) After CP polishing*

made with the surface being imaged; therefore, no ambiguity is introduced about voids, cracks, or inclusions.

Additionally, the CP can polish the top surface of a thin film in a grazing incidence configuration. This enables both the crystal orientation and the porosity of the crystal formation to be analyzed. Notice the increased visibility of voiding in **Figure 8b**, compared with **Fig. 8a.** ❍

For more information: *Dave Edwards, JEOL USA Inc., 11 Dearborn Rd., Peabody, MA 01960; 978/535-5900; dedwards@jeol.com; salesinfo@jeol.com; www.jeolusa.com.*

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