Voltage Contrast Imaging in the **ORION® PLUS** Helium Ion Microscope

**Application**
Passive voltage contrast for inspection, defect re-detection, and failure analysis in semiconductor devices.

**ORION® PLUS Capabilities**
High sensitivity to surface potentials, high resolution imaging, non-destructive imaging, variable beam energy.

**Background**
Passive Voltage Contrast (PVC) imaging is widely accepted in failure analysis laboratories because it is a fast and easy technique to localize electrical defects. Both SEM and FIB technologies are utilized to carry out this task.

**Challenge**
In some applications the SEM induced PVC is too weak or non-existent, excluding this technique from these tasks. FIB is often utilized due to the superior PVC effect induced by an ion beam. However, resolution is a severe limiter of FIB performance. The sputtering damage induced by traditional gallium LMIS FIB makes it unfeasible to look at smaller structures – which becomes more of a challenge as device dimensions shrink. Gallium is also a contaminant and a p-type dopant, meaning that it quickly begins to alter the electrical properties sought to be measured.

**ORION® PLUS Solution**
The helium ion microscope (HIM) is able to address these limitations, providing a new degree of PVC data. To test this, samples were investigated in cooperation with Dr. Rainer Reiche and co-workers at Qimonda Dresden GmbH & Co. (Germany). They prepared samples for analysis, including SEM imaging, and they also provided detailed sample descriptions and image interpretation. We show here several illustrative examples.
Figure 1 provides an example of electrical inspection on a fully processed DRAM sample that has been passivated with silicon nitride. In such cases one relies on the phenomenon of static capacitive contrast to analyze buried features. Conducting features with a good connection to ground can charge oppositely to the beam-induced potential, reducing fields and allowing those features to appear brighter in the image. The task of inspecting for leaky conducting lines was frustrated in SEM. In this case the secondary electron signal was not sensitive enough to the subsurface fields to evoke the contrast. The HIM imaging, however, provides very strong contrast for this application. We highlight the three pairs of lines near the center of the image, marked with arrows, which are easily distinguished from their neighbors. Their bright appearance reveals a good connection to ground. Even the interlayer dielectric layer beneath the lines shows strong contrast, appearing almost black.

PVC is also utilized for defect re-detection and analysis for process monitoring during manufacturing of devices. To demonstrate this application, a DRAM sample was polished down to the substrate contact level, exposing the row and column decoders. There are many contacts visible, both large and small, that differ in their electrical connection to the substrate. Some are connected to n- or p-type diffusion areas, while some are connected to gate structures. One can compare the observed PVC with what is expected for a good device in order to look for variances that would point to defects that require further investigation. Figure 2 shows an example of such imaging. Shown are two HIM images of the same two 150 nm diameter contacts. The upper left contact is connected to a p-type area, while the lower right is connected to n-type. Since HIM always creates positive charging, the p-type connection will experience a forward bias and thus appear brighter, since charge can be replenished from the substrate. In order to maximize the contrast, the operator should reduce the landing energy, the effect of which can be seen by comparing the two panels in the figure. Using the definition of feature contrast between two areas as:

\[ C = \frac{(I_2 - I_1)}{(I_1 - I_{ref})} \]

(where \( I_{ref} \) is the background) we obtain contrast of 30% at 25 keV beam energy but a much more substantial 235% at 10 keV. This will aid in spotting more subtle variations. It would be impossible to obtain this level of spatial resolution in the traditional FIB imaging used for such tasks, since the probe size would be too large. In addition, the sputtering and implantation would be highly destructive at such high magnification. No change to the structures are observed with HIM.
Figure 3 shows three transistor contacts. It is hard to achieve voltage contrast between these types of connections, but with low energy HIM it can be achieved, yielding a contrast value of 33%. There is a moderate loss of resolution seen in decreasing the beam energy for this task. Figure 4 shows two rows of these same contacts, now imaged at 25 keV HIM landing energy. There is no longer PVC seen for the contacts themselves, but now sub-surface dopant concentration contrast appears. This

Figure 2. HIM images of tungsten plugs in a de-processed device, top-down view. Beam energy used for imaging is indicated in each panel.

Figure 3. HIM image of source-drain contacts in de-processed device, top-down view. Beam energy was 10 keV.

Figure 4. HIM image of source-drain contacts in de-processed device, top-down view. Beam energy was 25 keV.
allows inspection of the overlay between the contacts and the buried diffusion layers. The spatial resolution is also restored, allowing a sharp view of the contacts. We note in Table 1 recommended imaging parameters for observing PVC in defect detection applications. We make a final note that sample tilt can be utilized to enhance the contrast as well, although we do not describe this here.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Beam energy</td>
<td>10 – 20 keV</td>
</tr>
<tr>
<td>Beam current</td>
<td>1.0 – 1.5 pA</td>
</tr>
<tr>
<td>Beam dwell time</td>
<td>5 µsec (small contacts)</td>
</tr>
<tr>
<td></td>
<td>20 – 50 µsec (larger contacts)</td>
</tr>
<tr>
<td>Spot control</td>
<td>4 – 5</td>
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<tr>
<td>Image Size</td>
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<tr>
<td>Flood gun</td>
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<tr>
<td>Sample bias</td>
<td>2 V</td>
</tr>
<tr>
<td>Sample Tilt</td>
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</tr>
</tbody>
</table>

Table 1. Imaging parameters for voltage contrast imaging in a process monitoring application.

In summary, passive voltage contrast imaging in HIM can be utilized as a sensitive probe of the electrical connectivity of conductors. It can be utilized with both surface and subsurface features for inspection purposes. Quantitative measurements on exposed contacts indicate changes in conductance to ground and is thus useful for localizing areas that vary from design expectations.

References: