Factsheet 4: Scanning Electron Microscope (SEM) Imaging

Scanning electron microscopy is a powerful technique used to visualize and analyze the surface features of a sample at very high resolution. SEM produces detailed images by scanning a focused beam of electrons over the sample's surface, generating various signals that reveal information about the sample's morphology, composition, and structure. Its imaging as well as analytic capabilities are essential in the ForRES project to reach the overall objectives. This fact sheet aims to provide a concise overview of SEM Imaging, covering its working principle, key features and how it is used in forensic research of microelectronic devices.

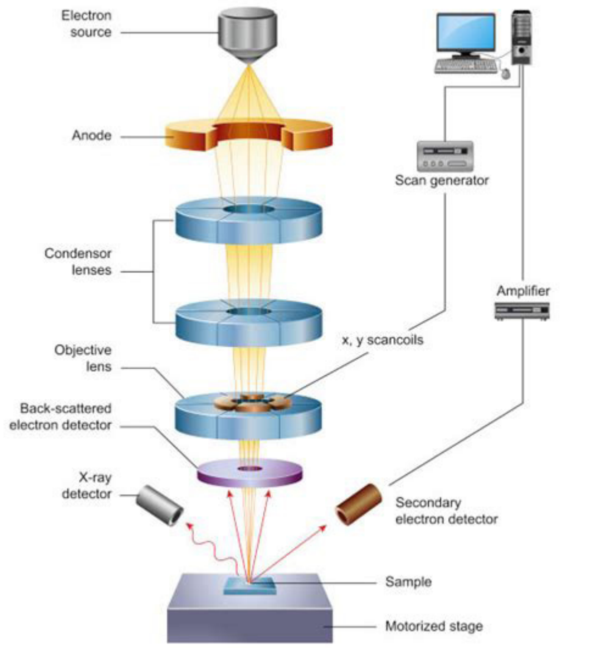

Figure 1: Schematic sketch of the main components of a SEM.
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How does a Scanning Electron Microscope work?

In a Scanning Electron Microscope (SEM) a beam of electrons is produced, which is accelerated, focused and then scanned across the sample. The electrons interact with the sample surface producing signals that are detected. These signals are translated into a high-resolution image by combining the beam position with the respective signal intensity. For enabling the electrons and generated signals to travel through the setup without losing intensity, the instrument is typically operated at vacuum. A schematic sketch of a SEM setup is shown in figure 1. The function of its main components, which are labeled in figure 1, are described below:

1. **Electron Beam Generation:** The electrons are generated in the electron source by heating a tungsten filament or using a field emission gun. They are accelerated by applying a high voltage between the anode and the electron emitter. A set of electromagnetic lenses is used to tailor the beam. First the condenser lenses adjust the beam intensity, then the objective lens is used to focus the beam onto the sample.
2. **Sample Scanning:** By using the x,y scancoils, the electron beam is deflected. Typically the beam is steered in a grid-like raster pattern, but more complex scanning patterns are also possible. Depending on the deflection range, the magnification of the resulting image is adjusted.
3. **Signal Origin and Detection:** When the electron beam strikes the sample surface, the incoming electrons, i. e. primary electrons, interact with sample atoms within a small volume at the sample surface (Fig. 2).
    a. The primary electrons can be reflected by the electric field in the vicinity of an atom core. The probability of this process is higher for materials with high atomic number. Therefore, the Back-scattered Electron (BSE) signal provides compositional contrast. These electrons have energies up to the primary beam energy and can be collected with a ring-like detector on the axis of the primary beam path.
    b. A fraction of the primary electron energy can be transferred to the sample by ejecting an electron from a weakly bound state. These Secondary Electrons (SE) have low energies <5eV and can be drawn into the SE detector by applying a small electric field. Due to their low energy, only those SE's created close to the surface can escape from the sample, thus providing information about the surface topography.
    c. If an inner-shell electron of a sample atom interacts with a primary electron, it can be exited to a higher state. By emitting x-rays with characteristic energy, the electron falls back into a lower state. By analyzing the emitted radiation through energy-dispersive X-ray spectroscopy (EDX) in the x-ray detector, the elemental composition of the sample can be studied.

4. **Image Formation:** Typically a computer is used to run the SEM. To create an image, the intensity data collected in the detector is amplified, translated into a gray value and assigned to the respective position which has been targeted by the scan generator. It usually takes a few seconds up to a few minutes until the full image area has been scanned. There are numerous parameters influencing the acquisition time and the overall appearance of the resulting image, e.g. beam intensity and energy, detector choice or scan strategy. An example of the same sample spot imaged with two different detectors (a) BSE (b) SE is presented in figure 3.

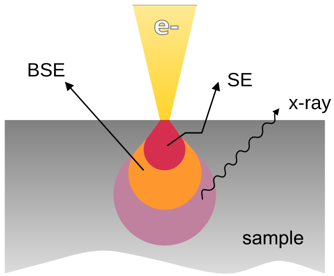

Figure 2: The primary electrons (e-) interact with the sample atoms within a small volume at the surface. Its size can be a few nanometers up to micrometers and depends mainly on the electron energy and sample material.

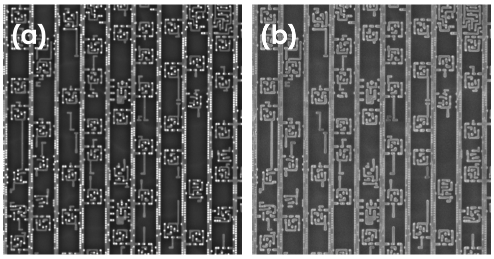

Figure 3: SEM images of the same sample spot recorded with (a) the BSE detector (b) SE detector. In image (a) the tungsten vias are well visible as bright spots, whereas in (b) the edges of the protruding Al metallization is prominent.

Key features and capabilities

- **High-Resolution Imaging:** SEM provides exceptional image resolution, revealing fine details of the sample's surface features down to the nanometer scale.
- **Multi-Signal Detection:** SEM's ability to detect and interpret various signals, including secondary electrons, backscattered electrons, and X-rays, allows comprehensive analysis of topography, composition, and crystallography.
- **High depth of field:** Due to a low beam spread, the SEM has a long focus range, aiding in the analysis of complex structures and providing insights into sample morphology.

These capabilities are essential for applications requiring detailed analysis in the nanometer range, making SEM an indispensable tool for scientists and engineers across various disciplines. Besides modern research, like material science and forensics, the technique is a cornerstone for manufacturing and process control in industrial applications, especially in the semiconductor industry.

Challenges in ForRES

- **Aquisition Time versus Image quality:** One of the main objectives of the ForRES project is the delayering of Finfet chips (see Factsheets #1 and #3) and the analysis of large areas from individual layers by SEM imaging. To achieve sufficient resolution, a set of hundreds or even thousands of image tiles is recorded. Therefore a good compromise between image acquisition time and quality has to be found.
- **Performance Stability:** In addition to the achievable quality of a single image, the tool has to be able to produce the same quality over a significant period of time. Variation of environmental conditions, e.g. temperature or humidity, can cause parameters to change. However, these conditions can be controlled relatively easily. But there are also effects caused by the tool operation itself, like charge built-up induced image distortions.

To address these challenges, the behavior of characteristic samples is studied in detail, leveraging comprehensive understanding of the SEM technology within the project's scope.

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Consortium
5 Partners
5 Countries

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