NUTS & BOLTS

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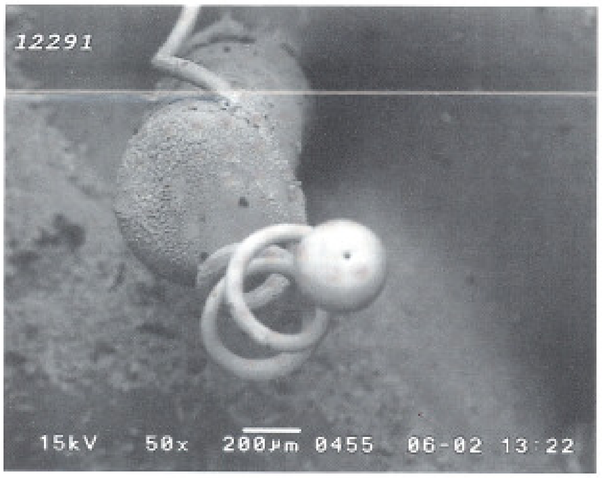
Scanning Electron Microscopes (SEM)

New Hampshire Materials Lab is pleased to announce two new in-house tools to better serve your material and failure analysis needs.



We now have a Topcon SM300 Scanning Electron Microscope and a EDAX DX prime energy dispersive analysis instrument.

Together, these instruments extend our material analysis capabilities.

The SEM is very special in several ways but most importantly, it can run both in vacuum and at atmospheric pressure and pressures in-between. This is of particular interest when one wishes to identify a contaminant on a non-conductive material.

No coating or plating is required to eliminate charging and the contaminant can be easily analyzed. An ability not shared by older SEM instruments.

Eliminating the need to coat a sample not only saves analysis time, but fine details that may be lost in the process will be visible.

Depending on the sample, the SEM can magnify from 30X to 300,000X with typical magnifications in the range of 50X to 2,000X.

The EDAX also has some special features. In addition to being able to analyze the normal full frame portions of a sample, we can also do both area and pinpoint analysis.This partial area testing provides both a spectrum of the elements and an image of the sample with the region analyzed marked. The spectrum of two samples or regions can be overlaid to check for differences.

X-ray mapping is also possible with this instrument in order to show how different elements are dispersed in the area of interest.

Equipped with a backscattered detector, the SEM allows for observation of grain boundaries on unetched samples, domain observation in ferromagnetic materials, crystal orientation of grain diameters of 2 to 10µm. Plus imaging of a second phase on unetched surfaces when the second phase has a different average atomic number. The SEM is ideally suited for defect and quality control of semiconductor devices.

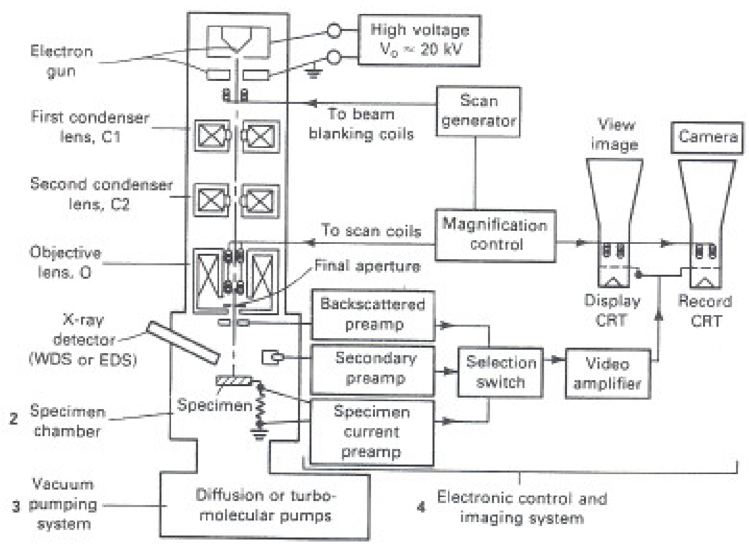


FIGURE 1: Basic components of the scanning electron microscope - WDS, wavelength-dispersive spectrometer; EDS, energy-dispersive spectrometer; CRT, cathode-ray tube

The Microscope

Figure 1 shows the basic components of the scanning electron microscope. The various components of the microscope can be categorized as (1) the electron column, (2) the specimen chamber, (3) the vacuum pumping system, and (4) the electron control and imaging system.

The Electron Gun

The electron gun produces a narrowly divergent beam of electrons directed down the centerline of the column.

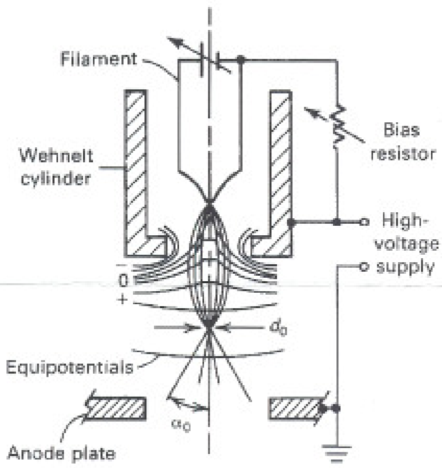


FIGURE 2: Conventional tungsten hairpin filament electron gun

Figure 2 shows a conventional tungsten gun. The electron source is a 0.25-mm (0.01-in.) diameter tungsten filament heated to 2500°C (4530°F).

The electrons boil off (thermionic emission)the sharply bent tip of the filament and are attracted to the anode. The anode is maintained at a positive voltage relative to the filament, ranging from 5 to 30 kV in scanning electron microscopes. This voltage, controlled by the operator, is generally held at 20 kV, but variation can be useful for structure and x-ray analysis.

The Wehnelt cylinder is biased negatively relative to the filament. It acts as a grid that repels the emitted electrons and focuses them into a spot of diameter d_0 and divergence half angle, α_0.

Therefore, the gun is essentially an electrostatic lens that forms an electron beam of diameter do at a point immediately above the hole in the highly polished anode plate.

The most important parameter of the electron gun is it's brightness, β, where β is a measure of the current focused on the area examined, entering and exiting this area through a solid angle. Increasing β improves the performance of the scanning electron microscope. The value of β is a function of the filament material, it's operating temperature and it's voltage.

As a tool for examining surfaces, the scanning electron microscope offers two major advantages over the optical microscope: improvements in resolution and depth of field.

Lenses

Electron microscopes have magnetic lenses that are similar to simple solenoids. A coil of copper wire, represented by the X's in Fig. 1, produces a magnetic field that is shaped by the surrounding iron fixture into an optimum geometry to produce the lensing action. As an electron moves through the magnetic field, it experiences a radial force inward, which is proportional to the Lorenz force, $v \times B$, where v is the electron velocity and B is the magnetic flux density.

The lensing action is similar to that of an optical lens, in which a ray parallel to the axis of the lens is bent to the lens axis at the focal length f, of the lens. In an optical lens, the focal length is fixed by the curvature of the lens surfaces and cannot be changed. In the electromagnetic lens, the focal length depends on two factors: the gun voltage (which determines the electron velocity v) and the amount of current through the coil (which determines the flux density, B), Therefore, the operator controls the focal lengths of the lenses by adjusting the currents supplied to them. An increase in current increases the radial force experienced by the beam and thus reduces the focal length.

Scan Coils & Raster Formation

The scanning electron microscope causes the electron beam to scan the sample surface. The two sets of scan coils (one for raster, one for deflection) are located in the bore of the objective lens cage shown in Fig.1 and perform the scanning function. These coils cause the beam to scan over a square area on the sample surface.

A double-deflection system is used, with the beam deflected by the Lorentz force produced from the magnetic fields of coil pairs. The scan generator controls the frame and line times as well as the raster size.

The double-deflection system allows the electron beam to pass through the principal plane of the objective lens very close to on-axis, which reduces lens aberration.

Detectors & Image Formation

Four detector schemes are shown in Fig. 1 that use specimen current, secondary electron, backscattered electron and x-ray signals. The secondary electron detector is generally used for image formation with the scanning electron microscope. The secondary electron detector has a screen on its outer surface that is bias at about 200 V. Electrons that pass through the screen are accelerated by a high voltage into a quartz light pipe coated with a scintillation material. The photons generated by the scintillator pass down the light pipe to a photomultiplier tube outside the vacuum system. A significant amplification is achieved, having high signal to noise characteristics. The secondary electron energies are low (approximately 5eV); consequently, the 200 V on the screen will pull many of the electrons to the screen even though that is not their initial direction.

An image corresponding to the surface under the raster is accumulated point by point on the CRTs shown in Table 1.

Advantages of SEM

As a tool for examining surfaces, the scanning electron microscope offers two major advantages over the optical microscope: improvements in resolution and depth of field.

Microscope	Minimum resolution range, nm	Maximum useful magnification
In-lens scanning electron microscope	1.5 - 3	67000 -130000x
Conventional scanning electron microscope	4 - 5	40000 - 50000x
Optical microscope	100 - 200	1000 - 2000x

TABLE 1: Resolution limits of currently available scanning electron microscopes compared with the optical microscope

In general, the depth of field of a SEM exceeds that of a optical microscope by a factor of 300. Therefore, scanning electron microscopes have found wide-spread use for examination of fracture surfaces and deeply etched samples.

ACKNOWLEDGEMENT

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