Application Note: AN30059_E

FEG1000
High Resolution Field Emission Electron Gun

Key Words

- Surface Analysis
- High Resolution SEM and SAM
- Pulse Counting AES

Introduction

The FEG1000, Figure 1, is a high-resolution, scanned electron source intended for use on multi-technique surface analysis systems. Its applications include SEM imaging, Auger spectroscopy, multi-point Auger analysis, Auger mapping and Auger depth profiling.

Figure 1: FEG1000 field emission electron gun (shown without the ion pump for differential pumping).

Its key features are:

- Field emission source for maximum current density
- 95 nm spot size at 5 nA
- Auger analysis at very high spatial resolution
- SEM and SAM imaging
- Controlled using a PC-based data system.

Construction

The Schottky Emitter

The Schottky thermal field emitter is a high brightness, low work function electron source using a zirconium oxide coated tungsten (ZrO_2/W) emitter operating in a thermally assisted Schottky emission mode.

The Tip

The tip, Figure 2, is constructed from a tungsten wire which is brought to a point of <1 µm radius at the end. The extractor electrode, consisting of a disc with a small hole at its centre, is placed a short distance in front of the tip. When a high voltage is applied to the extractor with respect to the tip a very large electric field exists at the surface of the tip.

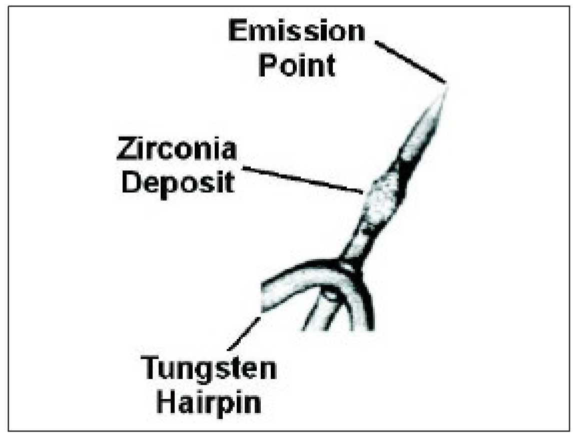

Figure 2: Schottky field emission tip.

This field is not high enough to pull electrons from the tip (cold field emission) so the tip is heated to 1800 K by a hairpin filament through which a current is passed. However, this is still not enough to allow electrons to overcome the energy barrier (or work function) of the tungsten and leave the surface of the tip. By coating the tip with zirconia (zirconium oxide), the work function is reduced to the point where the escape of electrons is more likely. At the end of the tip is a small, flat crystal plane which has a slightly lower work function than the rest of the metal.

With the work function lowered and the electrons' thermal energy raised, electrons can be pulled from this facet by the field created by the extractor voltage.

The tip is mounted in a source assembly, Figure 3, which includes the first two electron optical electrodes of the system, the suppressor and the extractor. The tip is aligned such that the end of the tip and the apertures in the extractor and suppressor are concentric.

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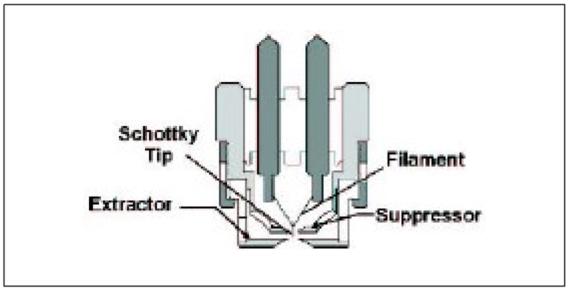

Figure 3 Source assembly.

To avoid contamination and maintain stable emission characteristics, the source is differentially pumped. This is achieved using a small ion pump.

The Suppressor

The primary function of the suppressor electrode is to suppress electron emission from the shaft of the tip such that only the end of the tip can emit. This helps to reduce the effective size of the source and thereby improves the spatial resolution. The suppressor also reduces the total emission, and therefore reduces the outgassing load. To achieve this the suppressor is held at a negative potential relative to the tip. The more negative the suppressor the less emission is drawn from the tip.

The Extractor

The primary function of the extractor is to draw electrons out of the tip. In simple terms the greater the extractor potential, the greater number of electrons that will be drawn out of the tip, although the true effect of varying the extractor potential is more complex than this. Approximately 99% of the electrons emitted from the tip are collected on the extractor aperture plate. The remaining current passes through the aperture in the extractor plate and continues down the column.

The extractor also creates an electrostatic field which, when the tip is heated, influences the migration of molecules on the surface of the tip and thereby influences the tip micro-geometry. The correct tip micro-geometry is essential for producing stable emission characteristics. When the tip is heated, a temperature dependent equilibrium is set up between the electrostatic force from the extractor and the surface tension force between the molecules. This equilibrium determines the micro-geometry for any particular combination of tip temperature and extractor voltage.

The FEG1000 Column

The FEG1000 is a two-lens electron gun, providing a variable spot size and beam current, see Figure 4. Current and spot-size are linked because they are both affected by adjusting the potential applied to the condenser lens. Trade-off exists between them i.e. small spot size, and hence high resolution, is associated with low beam current.

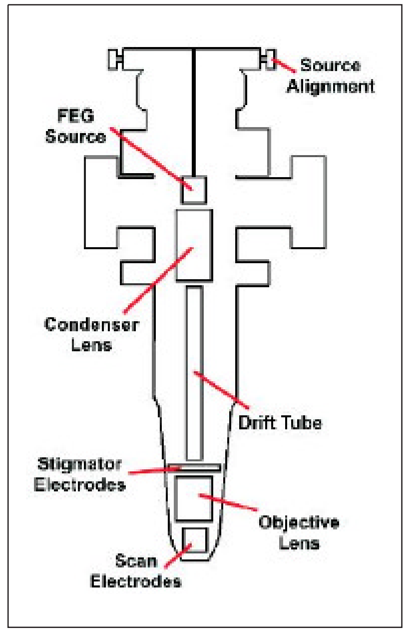

Figure 4: Schematic diagram of the FEG1000 column.

Following the condenser lens are the stigmator electrodes. These consist of 8 rods arranged radially in the flight tube. Aberrations in the lenses distort the shape of the beam resulting in an elliptical spot on the sample. The stigmators compensate for this ensuring that the spot is circular and optimising the image resolution.

After the beam has passed through the objective lens, its direction can be changed by an electric field generated by applying voltages to the scan electrodes. By varying the voltages in a systematic way, the direction of the field changes and the beam is scanned across the sample and can be used to form an image. Small scan voltages result in a small scanned area and therefore a high magnification.

Where appropriate, mu-metal shielding is fitted to the column to prevent stray magnetic fields from affecting the beam quality or direction.

Spot Size

At 5 nA beam current, the FEG1000 electron gun produces a spot size of 95 nm at 10 keV beam energy, see Figure 5, and 250 nm at 3 keV when fitted to an ESCALAB 250. 5 nA is a beam current that is suitable for Auger analysis with most modern analysers, such as the Alpha110.

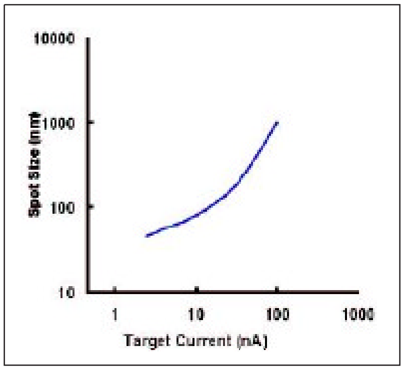

Figure 5: Spot size as a function of current for the FEG1000, operated at 10 keV on an ESCALAB 250 instrument.

The spot size achievable on other vacuum systems will depend upon a number of factors including the working distance of the gun and the degree of vibration isolation.

Auger Analysis

Figure 6 to Figure 8 show the results of a typical Auger analysis. Figure 6 shows an SEM image of the surface of a titanium/aluminium alloy which is used to identify the analysis positions, P1 and P2 on Figure 6.

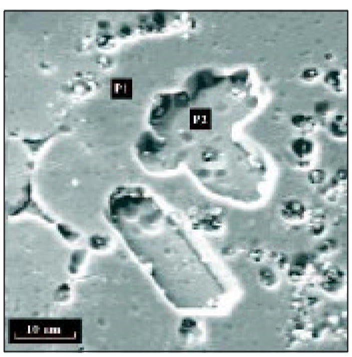

Figure 6: SEM taken from an alloy of aluminium and titanium showing the topography of the material and the points for Auger analysis.

Figure 7 shows the Auger spectra from P1 and P2. These show that point 2 is rich in titanium whereas point 1 shows titanium depletion.

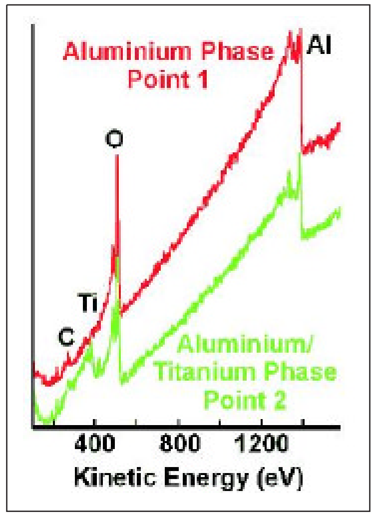

Figure 7: Spectra from the two points marked in Figure 6.

An overlay of the Auger images from Al and Ti are shown in Figure 8 and confirm the results obtained from the spectra.

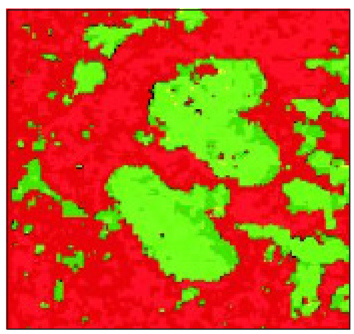

Figure 8: Overlay of Auger maps
(red = Al and green = Ti)

Electronics

The FEG1000 is supplied with digital electronics so that all of its functions are controlled via the *Avantage* data system. This allows full integration with other Thermo Electron components, including the Alpha110 electron energy analyser.

Options

A secondary electron detector is available for use with the FEG1000. This consists of a photomultiplier, scintillator and digital electronics. This allows SEM images to be acquired via the *Avantage* data system.