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The focused ion beam scanning electron microscope

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Abstract

The focused ion beam – Scanning Electron Microscope (FIB-SEM) is an instrument that has a widespread use in the field of material science because it is able to micromachining with high resolution imaging thus therefore enhancing a broad range of both fundamental and technological applications in material science. The FIB is based on a beam of gallium ions which sputter the sample enabling precise machining at the nanometer/micrometer scale. Over the past few years, the FIB has gained acceptance as more than just an expensive sample preparation tool and has taken its place among the suite of other instruments commonly available in forensic and analytical laboratories, universities, medical, biological and geological, research institutions. The combined SEM capability allows for real time monitoring of the FIB cuts with a higher resolution.

Keywords: Focused ion beam, FIB, Liquid metal ion source, LMIS

Introduction

The typical focused ion beam (FIB) instrument consists of a vacuum system, liquid metal ion source, ion column, stage, detectors, gas inlets and computer. The liquid metal ion source provides the finely focused ion beam that makes possible high lateral resolution removal of material. Five axis motorized eccentric stage motion allows rapid sputtering at various angles to the specimen. The ion beam interaction with organo-metallic species facilitates site specific deposition of metallic or insulating species. Other gases may be used for enhanced etching of materials. The combination of a scanning electron microscope column and FIB column forms a dual platform system that provides enhanced capabilities.

The basic FIB instrument

The basic FIB instrument consists of a vacuum system and chamber, a liquid metal ion source, an ion column, a sample stage, detectors, gas delivery system and a computer to run the complete instrument as shown schematically in Figure 1. The instrument is very similar to a scanning electron microscope (SEM). FIB instruments may be stand-alone single beam instruments. Alternatively, FIB columns have been incorporated into other analytical instruments either commercially or in research labs such as an SEM, Auger electron spectroscopy, transmission electron microscopy, or secondary ion mass spectrometry, the most common of which is a FIB/SEM dual platform instrument. The ion column in a single beam FIB instrument which is typically mounted vertically. In contrast, dual platform instruments usually have the FIB mounted at some angle with respect to vertical i.e., the SEM column. What follows below is a basic description of how a FIB instrument works.

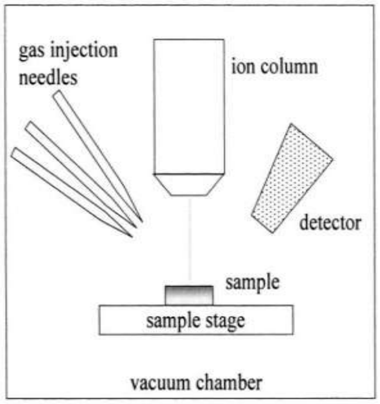

Figure 1 – Schematic diagram of a basic FIB system

Figure 2 – Dual-beam FIB-SEM system located at the University Science Park UNIZA

The vacuum system

A vacuum system is required to make use of the ion beam for analysis. The typical FIB system may have three vacuum pumping, regions, one for the source and ion column, one for the sample and detectors and a third for sample exchange. The source and column require a vacuum similar to that used for field emission SEM sources i.e., on the order of $1x10^{-8}$ torr to avoid contamination of the source and to prevent electrical discharges in the high voltage ion column. The sample chamber vacuum can be at gigher pressure and the system can be used with this chamber in the $1x10^{-6}$ torr range. Pressures in the $1x10^{-4}$ torr range will show evidence of interaction of the ion beam with gas molecules because the mean free path of the ions decreases as the chamber pressure is increased. The mean free path at high pressure is reduced to the point where the ions can no longer traverse the distance to the sample without undergoing collisions with the gas atoms or molecules. Ion pumps are normally used for the primary column and turbo molecular pumps backed by oil or dry forepumps are typically used for the sample exchange chambers.

The liquid metal ion source

The capabilities of the FIB for small probe sputtering are made possible by the liquid metal ion source (LMIS). The LMIS has the ability to provide a source of ions of ~ 5nm in diamater. Figure 3 shows a schematic diagram of a typical LMIS which contains a tungsten needle attached to a reservoir that holds the metal source material. There are several metallic elements or alloy sources that can be used in a LMIS. Gallium (Ga) is currently the most commonly used LMIS for commercial FIB instruments for a number of reasons: i) its low melting (T_{mp}=29,8°C) minimizes any reaction or interdiffusion between the liquid and the tungsten needle substrate, (ii) its low volatility at the melting point conserves the supply of metal and yields a long source life, (iii) its low surface free energy promotes viscous behaviour on the (usually W) substrate, (iv) its low vapor pressure allows Ga to be used in its pure form instead of in the form of an allows Ga to be used in its pure form instead of in the form of an alloy source and yields a long lifetime since the liquid will not evaporate, (v) it has excellent mechanical, electrical, and vacuum properties, and (vi) its emission characteristics enable high angular intensity with a small energy speed.

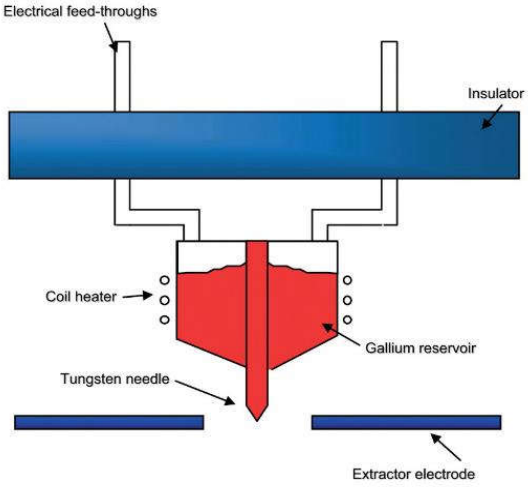

Figure 3 – Schematic diagram of a Ga LMIS

The ion column

Once the Ga^+ ions are extracted from the LMIS, they are accelerated through a potential down the ion column. Typical FIB accelerating voltages range from 5-50 keV.

A schematical diagram of the FIB column is shown in Figure 4. The ion column typically has two lenses i.e., a condenser lens and an objective lens. The condenser lens (lens 1) is the probe forming lens and the objective lens (lens 2) is used to focus the beam of ions at the sample surface. A set of apertures of various diameters also help in defining the probe size and provides a range of ion currents that may be used for different applications. Beam currents from a few pA to as high as 20 or 30 nA can be obtained. Methods for manual or automatic aperture selection have been developed. Optimizing the beam shape is obtained by centering each aparature, tuning the column lenses and fine tuning the beam with the use of stigmators. Cylindrical octopole lenses may be used to perform multiple functions such as beam deflection, alignment and stigmation correction. In addition, the scan field can be rotated using octopole lenses. Beam blankers are used to prevent unwanted erosion of the sample by deflecting the beam away from the center of the column.

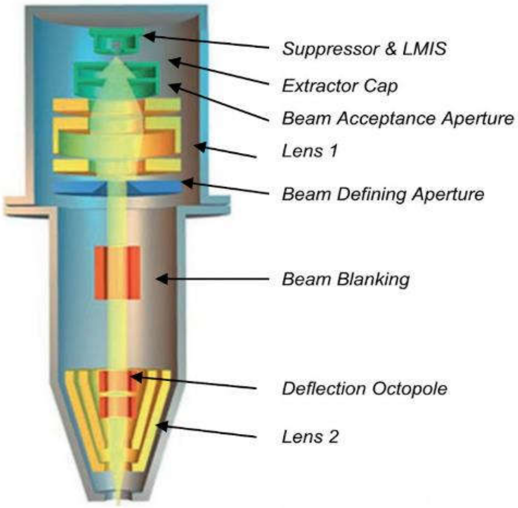

Figure 4 – The basic FIB column

The FIB has a relatively large working distance with a typical value of about 2 cm or less. This large working distance permits the introduction of samples with varied topography, without concern for field variations. When tha Ga^+ beam strikes the sample surface, many species are generated including sputtered atoms and molecules, secondary electrons and secondary ions.

The energy spread of a finely confined ion beam is generally larger than the energy spread of an electron beam and is ~5 eV. Since ions are much more masssive than electrons, space charge effects limit the apparent source size and increase the width of the energy distribution of the emitting ions. Thus, chromatic aberration is often the limiting fator in the resolution of a FIB system.

Possibilities of using FIB

Using FIB is possible to work practical any material that is resistant to low pressures in the microscope chamber (~ 10^{-4} Pa). It may be metals, semiconductors, ceramics, plastics or biological samples. The problem is not even hard materials including diamond.

Using a suitable detector, it is possible to use FIB (at lower currents) as well as scanning ionic microscopy (SIM) of the surface. Just like using electrons in a scanning electron microscope (SEM).

If the FIB is integrated in one device together with the SEM, it can be used to get more information about the surface and the structure of the sample It also allows for material tomography i.e., 3D material analysis and "live" observation of the ion machining process by electron beam. The FIB combined with the micromanipulator can be used not only for the preparation of nano and microstructures but also for manipulation with them. It follows from the above that although a focused ion beam is itself a useful tool in combination with other equipment, its possibilities are greatly expanded.

Conclusion

The combination of FIB and SEM is one of the most versatile instruments available for the examination and analysis of the micro and nano characteristics of solid objects. The main advantage of this state-of-the-art technique is the capability to analyze defects, microstructure, phases or interfaces in a specific region of interest.

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