Abstract

Focused ion beam (also known as FIB) technique is used by the semiconductor industry particularly for failure analysis, material deposition, and ablation of materials. The FIB uses a beam of focused ions which bombard the surface of the material to knock off the atoms or to deposit on its surface.

Introduction

FIB incorporates both electron and ion beam columns, allowing the same feature to be investigated using either of the beams. In our experiment we used gallium ion beam to raster over the surface and generates secondary electrons or ions on the surface of the sample. The generated secondary electrons (or ions); which are knocked off the sample are collected to form an image of the surface. The ion beam allows milling of small holes in the sample at localized sites, so that cross-sectional images of the structure can be obtained or that modifications in the structures can be made. The ions are heavier slower and have higher momentum unlike electrons which are lighter and have lesser momentum. Therefore, generally ion beam will be used for milling and the electron beam for imaging. This allows non-destructive imaging at higher magnifications and with better image resolution, and also more accurate control of the mining progress.

The applications of FIB

- Modification of the semiconductor devices
- Failure analysis or troubleshooting
- Preparation for physico-chemical analysis
- Preparation of samples for transmission electron microscopy (TEM)
- Preparation of samples for AtomProbe analysis
- Micro-machining
- Mask repair
- Non-semiconductor applications

Description

We used FIB 611 to produce a high brightness Ga liquid metal ion source, coupled with a double lens focusing system. The system is capable of producing an intense beam of ions which can be focused to a 40 nm diameter spot. The system is equipped with a vacuum load lock to enable rapid transfer of samples up to 6" in diameter. 8" wafers can be loaded directly into the chamber.
# General Specification

<table>
<thead>
<tr>
<th>Equipment</th>
<th>FEI FIB 611</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Beam</td>
<td>Gallium Gun (Liquid Metal Ion)</td>
</tr>
<tr>
<td>Cathode</td>
<td>Mini Vogel Mount</td>
</tr>
<tr>
<td>Voltage</td>
<td>2 kV to 30 kV</td>
</tr>
<tr>
<td>Beam current</td>
<td>1-3 microamps</td>
</tr>
<tr>
<td>Resolution</td>
<td>7.0 nm @ 30 kV</td>
</tr>
<tr>
<td>Detection</td>
<td>secondary electron and secondary ion (CDEM detector)</td>
</tr>
<tr>
<td>Specimen Stage</td>
<td>6” Eucentric computer and motor control</td>
</tr>
<tr>
<td>Computer/Software</td>
<td>Windows 3.11</td>
</tr>
<tr>
<td>Data Recording</td>
<td>Video Printer, TIFF image</td>
</tr>
<tr>
<td>Capability</td>
<td>metal etch, metal deposition, insulator etch, insulator etch</td>
</tr>
<tr>
<td>Vacuum</td>
<td>( \leq 5 \times 10^{-7} ) torr</td>
</tr>
<tr>
<td>Vacuum System</td>
<td>Turbo w/mech RP</td>
</tr>
<tr>
<td>Temperature</td>
<td>Room temperature</td>
</tr>
</tbody>
</table>

## Features

### Column Vacuum Chamber and Feedthroughs

The column vacuum chamber has various feedthroughs connected for; Lens 2, beam steering and measurement, and for Faraday cup beam current measurement. It also has knobs to align the emitter assembly to the first column lens.

### Magnetic Shield

A magnetic shield surrounds the chamber body to protect it from stray magnetic fields.

### Conflat Flange

The conflat flange mounts the columns to the chamber on the system.

### Column Isolation Valve (CIV)

The column isolation valve is used to vacuum seal LMIS/Lens 1 and Lens 2/Sample in the chamber.

### LIMS

The FEI 611 uses a field emission based LMIS (Liquid Metal Ion Source). The LMIS has an emitter in a conical shape and uses gallium LMIS, to provide very high brightness and high angular intensity operation.  
**Conditions to maximize lifespan:**  
- Vacuum pressure should be less than \( 5 \times 10^{-7} \) torr  
- Total current must be less than 3 \( \mu \)A  
- Source heating must be prudent and conservative.

### Lens

Two asymmetric three-element electrostatic lenses focus the emitted ions into a beam and determine the beam patterns.

### Differential Pumping Aperture

Differential pumping allows passage of ion beam while restricting conduction by ensuring operation of the source region at proper pressure levels.

### Quadrupole Steering Plates
A set of quadrupole plates located after the beam defining aperture, controls the internal alignment of the beam.

**Octupole Stigmator/Deflector**
The octupole, located below the Lens 2 assembly, provides scan and shift as well as beam astigmatism correction.

**Beam Breaking**
The beam breaking assembly provides beam breaking in the focusing column.

**Electronically Variable Aperture (EVA)**
The electronically variable aperture is used to change the ion probe diameter and current.

**Electronics**
*Ion Column Supply:*  
Ion column supply provides HVPS (high voltage power supply) for the beam operation and for the focusing column. The HVPS powers:  
- Source heating  
- Source Operation  
- Beam Voltage and focusing lens voltages  
- Lens wobbler  

**Lens Wobbler**

**Deflection Controller:**  
The deflection controller consists of a controller and post amplifier. The controller has various knobs and switches to controls the FIB. The deflection controller regulates:  
- Magnification  
- Deflection and Scanning  
- Stigmaton correction  
- Image Rotation  
- Beam Blanking  
- Scan Modes

**Operation of FIB 611**

**System preparation and checking**
The system is to be prepared and checked before operation. The sample holder must be placed in the main chamber at ‘loadlock’ position. The column isolation valve (CIV) has to be closed and the pressure in the column must be below 5x10^{-7} torr. Turn ON the power supply for the computer, FIB controller, CCD monitor, vacuum pumps and the camber lighting.

**Loading sample**
Place the sample in the loadlock and turn ON the molecular drag pump. Turn OFF the molecular drag pump when the pressure inside the loadlock chamber reaches the column pressure. Open the valve that connects loadlock chamber and to the column chamber. Use the mechanical arm to carefully load the sample onto the sample holder inside the column chamber. Bring back the arm to loadlock chamber and close the valve to isolate loadlock and column chambers.

**Imaging**
Turn ON the controller high voltage, adjust the lens voltage to get focused image typically at 10kV. Set the beam current to
about 60pA. Adjust brightness and contrast, and fine tune the focus to get perfect distortion less image. Use joystick to move to the desired location of the sample.

**Milling**

Stop imaging of the sample by clicking on ‘Image Stop’ in the software. Use software tools to design pattern on the image and set milling depth. Increase the beam current to 1400 pA for bulk milling or 63 pA for fine milling and start milling. Look for the milling progress on the computer monitor.

**Shut-down**

Turn OFF the high voltage, and bring down the beam current and lens voltages. Bring down the beam voltage to zero in 5kV steps in 5 sec intervals. Turn OFF the supply high voltage.

**Unloading sample**

Turn ON the loadlock molecular pump. When the pressure inside the loadlock chamber reaches the column pressure, open the valve that connects loadlock chamber and to the column chamber. Use the mechanical arm to carefully unload the sample from the sample holder to the loadlock chamber. Slowly open the vacuum valve to increase the loadlock pressure to atmospheric pressure.

**Results**

Various shapes and patterns were milled in using the focused ion beam process. Portland State University logo ‘PSU’ is milled using focused ion beam on the silicon wafer.

**Conclusion**

A brief overview of the milling technique using gallium ion beam is studied, some of the key advantages and limitations of this technique analyzed. Some of the key process factors involved in altering the energy levels of focused ion beam was examined. Specifically, we explored the role of beam current in the milling process. Furthermore, general operation of FEI 611 equipment is studied and practiced.

**References**

[1] FIB 611 Operating Procedure by Dr. Erick Sanchez  
[2] FEI FIB operation manual  