Physics of Nanotechnology

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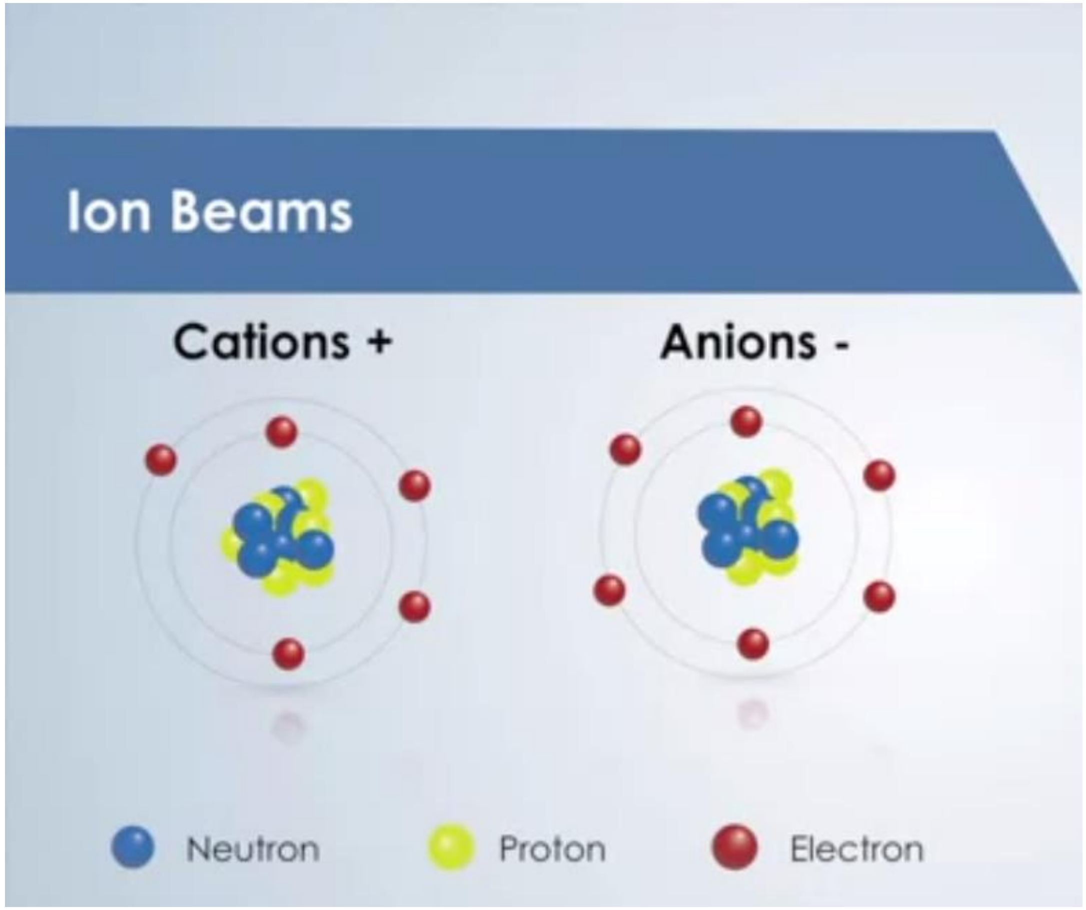
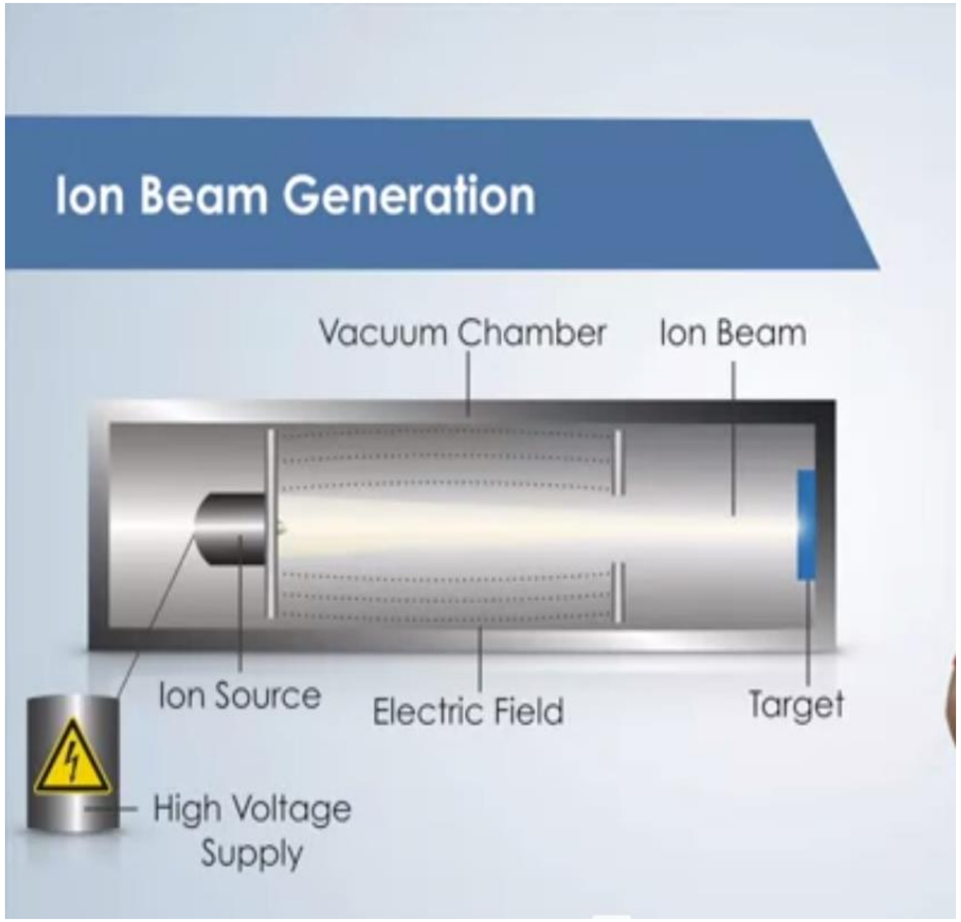
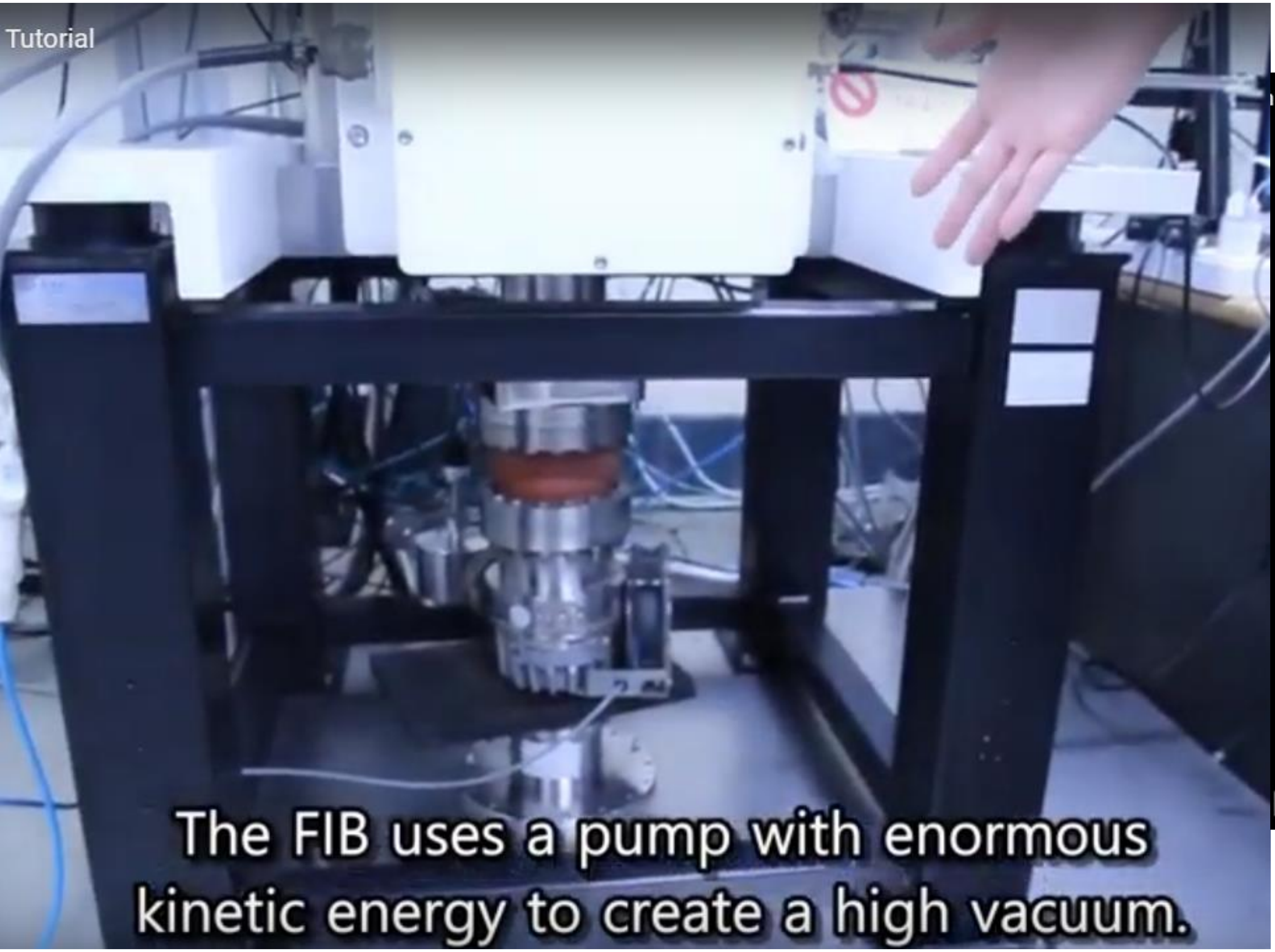
Foucused Ion Beam Lithography

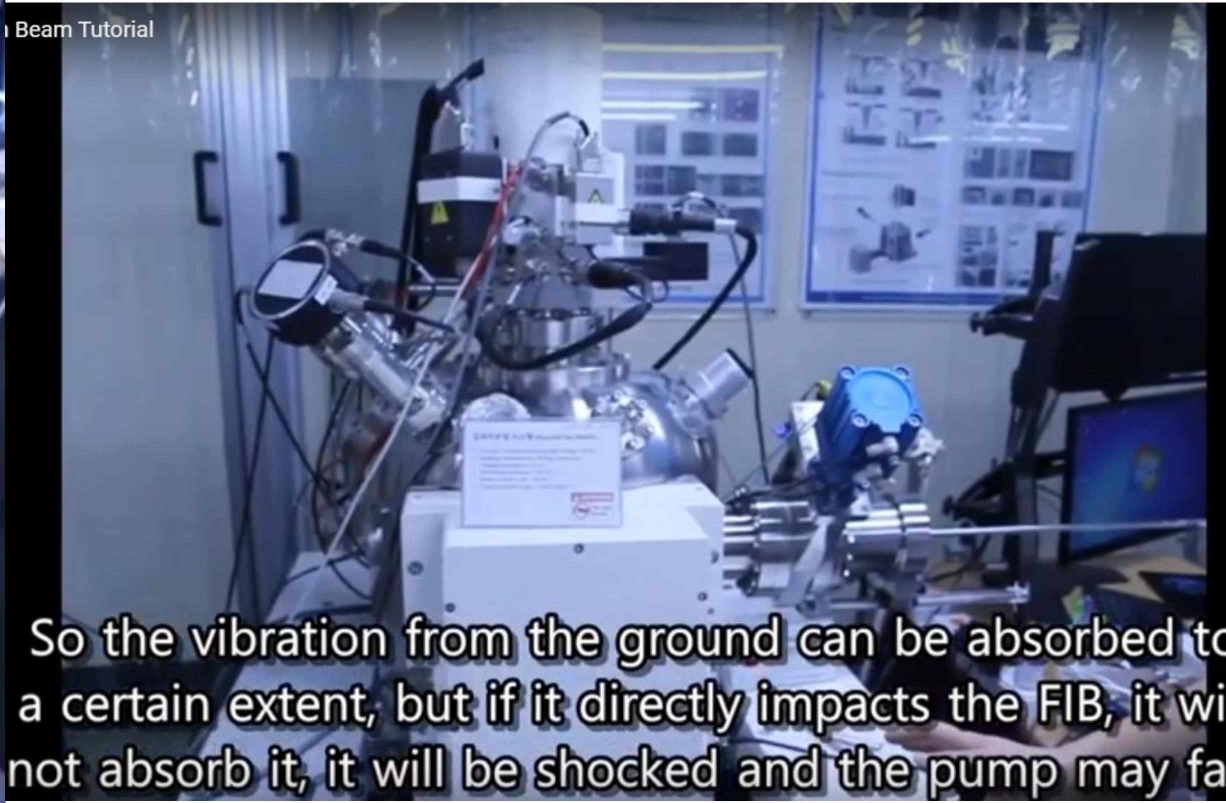
- **Description:**

This is a variation of the electron beam lithography technique, using an focused ion beam (FIB) instead of an electron beam. In a similar setup to scanning electon microscopes, an ion beam scans across the substrate surface and exposes electron sensitive coating. A grid of pixels is superimposed on the substrate surface, each pixel having a unique address. The pattern data is transfered to the controling computer, which then directs the electron beam as to realize the pattern on the substrate pixel by pixel. The ion beam used is either a Guassian round beam or Variable Shaped Beam (VSB). There are two methods of scanning the beam over the substrate surface to write the pattern data. With raster scan, the electron beam is scanned across lines of pixels and the wafer is shifted to the next line. With vector scan, an area of an individual chip is selected, and the beam draws out the features in that area one-by-one.


Ion Beams
Cations +
Anions -
Neutron
Proton
Electron


Ion Beam Generation
Vacuum Chamber
Ion Beam
Ion Source
Electric Field
Target
High Voltage
Supply


Tutorial
The FIB uses a pump with enormous kinetic energy to create a high vacuum.


Beam Tutorial
So the vibration from the ground can be absorbed to
a certain extent, but if it directly impacts the FIB, it wi
not absorb it, it will be shocked and the pump may fa

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7.1 Introduction

Nano-fabrication aims at building nanoscale structures, which can be used as components, devices, or systems, in large quantities with potentially low costs. Here, a nanoscale structure is characterized by a feature size in the range of 0.1 to 100 nm. Recently, ion beams have become increasingly popular tools for the fabrication of various types of nanoscale structures for different applications. In this chapter, the capabilities of the ion beam (IB) technology for nano-fabrication using the projection printing and direct writing approaches are discussed and examined.

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The IB technology has many advantages over other energetic particle beams in nano-fabrication. For example, when compared to electrons, ions are much heavier and can strike with much greater energy density on the target at relatively short wavelengths to directly transfer patterns on hard materials (such as semiconductors, metals, or ceramics) without producing forward- and backscattering. Thus, the feature size of the patterns is directly dictated by the beam size and the interaction of the beam with the material considered. On the other hand, the electron beam or photon beam can only effectively write on or expose soft materials (such as photo or e-beam resists), and the corresponding feature sizes are determined by the proximity of the backscattered electrons or wave diffraction limits. Furthermore, the lateral

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exposure in IB is very low; thus, just exposing the right areas. As a result, a fine beam of heavy ions can produce very narrow line widths in the substrate and has a better capability to directly fabricate nanoscale structures. The IB technology has become not only a powerful fabrication tool adopted by the semiconductor industry for mask repairing, device modification, failure analysis, and integrated circuit (IC) debugging, but also a popular tool in making high-quality and high-precision nanostructures [1–3].

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Two basic schemes, projection printing and direct writing, are used in IB nano-fabrication. In projection printing, a collimated beam of ions passes through a stencil mask and the image of the mask is projected onto the substrate using electrostatic lens systems, while in direct writing, a small spot of the focused ion beam (FIB) is struck directly onto the substrate without a mask. The technique of ion projection printing, also known as ion projection lithography (IPL), which originates from the semiconductor industry,

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enables parallel production of a large number of devices and has been one of the major candidates for next-generation lithography (NGL) to replace the currently used optical lithographic technique. Other types of printing schemes, including proximity printing and contact printing, are not included in this chapter because they offer limited flexibility and no rigorous development efforts have been reported for future industrial applications.

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7.2 Ion projection lithography (IPL)

Lithography is the process of transferring patterns from one medium to another. In this section, recent development related to the technology of IPL is presented.

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7.3 Direct writing

FIB is normally used for the direct writing of nanostructures. IB direct writing is a process of transferring patterns by using an energetic FIB to directly hit the target to cause physical and/or chemical changes in the target materials. Four major direct writing processes will be considered in this section milling, implantation, ion assisted etching, and ion induced deposition. While the first two are governed by physical alterations, the latter two are dominated by chemical transformation.

7.3.1 Ion source

FIBs use liquid-metal ion sources (LMIS), which are high brightness ion sources because they can produce a beam of heaver ions that can be focused into fine spots of the order of 10 nm with adequate current densities for direct writing. Almost all metals that have relatively low melting temperatures and low reactivity can be used as the sources. The range of materials being used in FIB systems is also expanding to further increase the extent of their applications. The ion sources that are currently available include Al, As, Au, Be, Bi, Cs, Cu, Ga, Ge, Er, Fe, In, Li, Ni, Pb, Pd, Pr, Pt, U, and Zn [1]. Among these, Ga is the most popular ion species used in FIB for direct writing. In order to lower the melting point and to control the reactivity, alloy sources, such as PdAs, PdAsB, AuSi, and AuSiBe, are frequently used to deliver the dopants for semiconductors [19].

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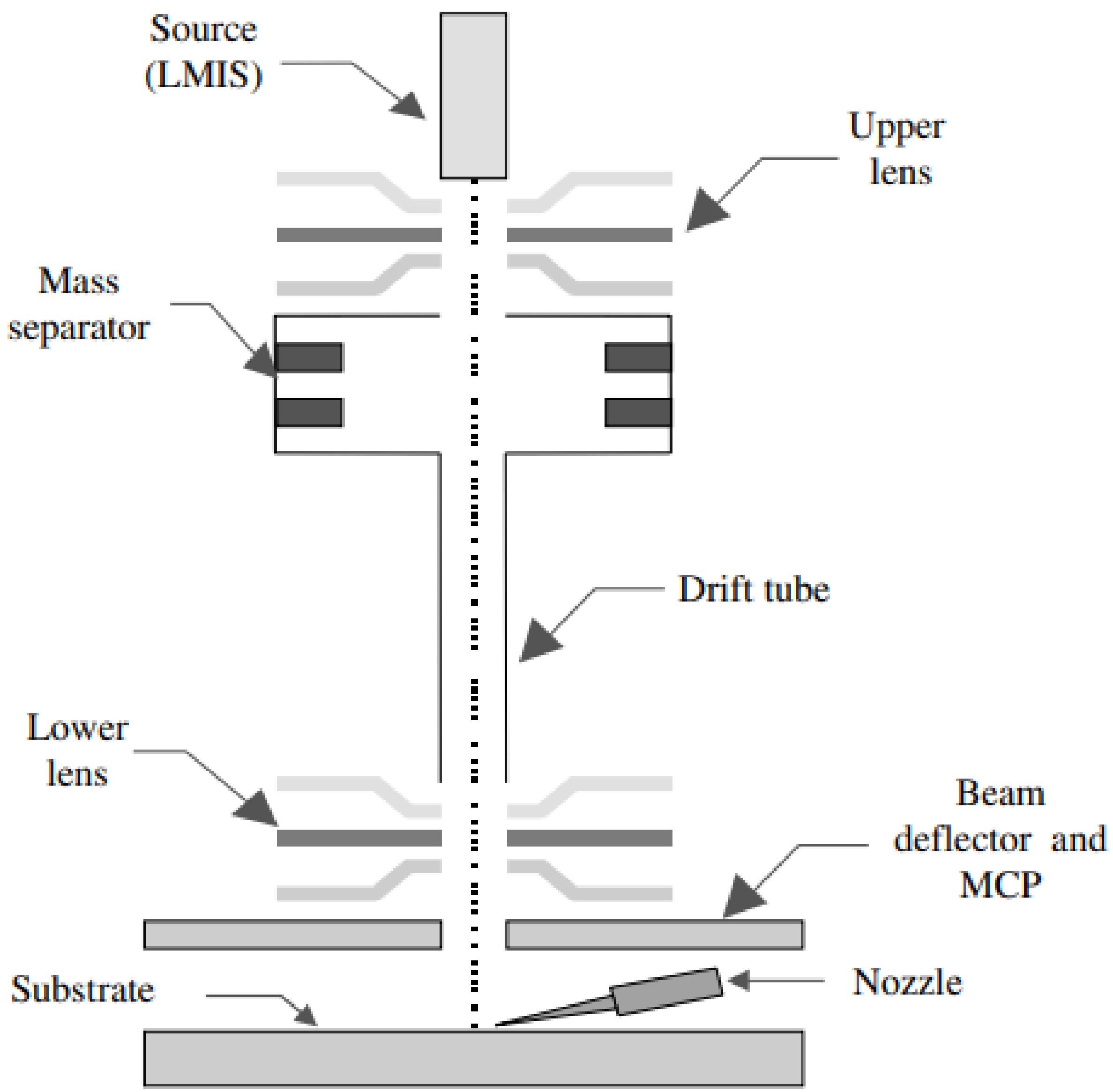
7.3.2 FIB systems

The basic components of an FIB system consist of an ion source, ion optics, a substrate stage, and a vacuum chamber with auxiliary equipment. Figure 7.5



'e 7.5 Schematic of FIB system.

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schematically shows an FIB system with an LMIS. The ions are focused and collimated into parallel beams by the upper (condenser) lens. Then, the ion beam is passed through a mass separator and a drift tube. A mass separator is only necessary for high-energy systems equipped with liquid alloy ion sources. It is set up to filter out unwanted ion species emitted from the alloy ion sources by allowing only the required ions with a fixed mass–charge ratio to pass through. Below the mass separator, there is a long collinear drift tube equipped with a stigmatic focusing lens for stigmatism and collimation, which eliminates the ions that are not directed vertically. The lower (objective) lens is located below the drift tube and helps in reducing the spot size and in improving the focus. Following the objective lens is an electrostatic beam deflector that controls the final trajectory or landing location of the ions on the substrate.

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- **Advantages:**
- Computer-controlled beam
- No mask is needed
- Can produce sub-1 μm features
- Resists are more sensitive than electron beam resists
- Diffraction effects are minimized
- Less backscattering occurs
- Higher resolution
- Ion beam can detect surface features for very accurate registration

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- **Disadvantages:**
- Reliable ion sources needed
- Swelling occurs when developing negative ion beam resists, limiting resolution
- Expensive as compared to light lithography systems
- Slower as compared to light lithography systems
- Tri-level processing required

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- **Ion Beam Resists:**
- These are materials which exhibit changes, whether physical or chemical, due to exposure to a high-energy ion beam. Most ion beam resists are polymer chains. Some optical resists can also be used. Several ion beam resists are self-developing, in that exposure to the ion beam completely disintegrates the substance.
- **Positive Resists**
- Positive ion beam resists break down into less complex fragments on exposure to an ion beam. Because the less complex fragments have a lower molecular weight, they are more soluable by the developer than the unexposed resist.
- **Negative Resists**
- Negative resists form complex molecular links when exposed to the ion beam, and so become insoluable in the original solvent, which removes the unexposed resist.
- Certain inorganic resists can also be used. A layer of GeSe onto which AgSe has been evaporated, acts as a negative resist. When exposed to the beam, the GeSe layer is filled with AgSe, and the combination can then be developed.