Nanomanufacturing-Ion Beam Lithography

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Abstract: ***Nanomanufacturing involves production of nanoscale materials, structure as well as devices with dimensions between one to one hundred nanometres. It is the recent branch of manufacturing that represents both a new field of science and also a new market place. Ion beam lithography plays a vital role in the nanomanufacturing process, by using beam of ions across the surface to create the structure at nanoscale. It consists the ion beam a smaller wavelength than even an e-beam and therefore almost no diffraction takes place. At this time there are only two techniques for writing original patterns (as opposed to replicating them) at 0.1 mum and below; electron beams and ion beams. Electron beams are at a mature state of development and have advantages in absence of shot noise and in fast deflection capability. In this paper we summarize the working and applications of ion beam lithography in nanomanufacturing.***

Keywords: nanomanufacturing, ion beam, nanoscale materials, electron beams, shot noise

Objectives

- Understand the working principle of an ion beam lithography.
- Familiarize with nanofabrication/manufacturing.

1. Introduction

1.1 . Nanomanufacturing

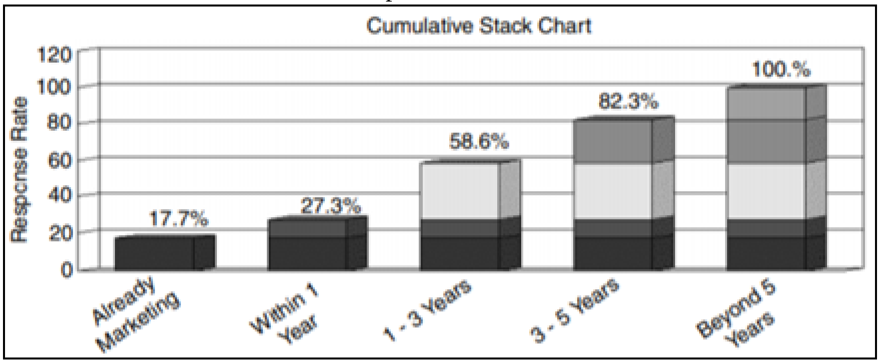
Manufacturing at the nanoscale is known as **nanomanufacturing**. Nanomanufacturing involves scaled up, reliable, and cost-effective manufacturing of nanoscale materials, structures, devices, and systems. It also includes research, development, and integration of top-down processes and increasingly complex bottom-up or self-assembly processes. Nanomanufacturing enables the creation of new materials and products that have applications such as material removal processes, device assembly, medical devices, electrostatic coating and fibers, and lithography.In more simple terms, nanomanufacturing leads to the production of improved materials and new products. As mentioned above, there are two basic approaches to nanomanufacturing, either **top-down** or **bottom-up**. Top-down fabrication reduces large pieces of materials all the way down to the nanoscale, like someone carving a model airplane out of a block of wood. This approach requires larger amounts of materials and can lead to waste if excess material is discarded. The bottom-up approach to nanomanufacturing creates products by building them up from atomic- and molecular-scale components, which can be time-consuming. Scientists are exploring the concept of placing certain molecular-scale components together that will spontaneously "self-assemble," from the bottom up into ordered structures.

- **Nanomanufacturing Challenges**

Nanomanufacturing is the recent technology in manufacturing industry, so there are some barriers present, which are as follows.

a) How can we control the assembly of 3D heterogeneous systems, including the alignment, registration, and interconnection at three dimensions and with multiple functionalities?
b) Controlling the precision of the assembly of nanostructures.
c) How can we handle and process nanoscale structures in a high-rate/ high-volume manner, without compromising the beneficial nanoscale properties?
d) Maintaining nano-scale properties and quality of nano-system during high-rate and high-volume production as well as during the lifetime of the product after production

Table 1.1: New nanoproduct introduction in2007-11



- **Top-Down Approach**

Top-down approaches using many relatively new techniques such as ion beam assisted deposition (IBAD), FIB, EUV lithography, e-beam lithography, AFM (DIP Pen or AFM field evaporation) lithography, plasmonic imaging lithography and nanoimprint lithography and many others have been pursued for many years.

- **Bottom- Up Approach**

Patterning, templating, and surface functionalization are commonly used for directed assembly. Geometrical shaping and structuring processes at the nanoscale are used in many applications to produce functional devices, templates or integrated multi-element systems. For example, many lithography techniques could be combined with focused ion beam, two-photon lithography, or probe-based methods including AFM, STM, near-field optical and mechanical tip scribing, as well as soft lithography techniques. These could also be extended to 3-dimensional patterning by processes such as stereolithographic layering. These approaches lead to many different barriers, but what is consistent is that all will need repeatable, scalable, and controllable processes. The above-mentioned patterned substrates could be used as nano templates to enable precise assembly of various nanoelements. However, in order to extend these tools to a true nanomanufacturing a process, the assembly needs to be conducted in a continuous or high-rate/high-volume processes (for example multi-step or reel-to-reel processes). This way, nano building blocks and block copolymers can be guided to assemble in prescribed patterns (2-D or 3-D) over large areas in high-rate, scale able, commercially relevant processes such injection moulding or extrusion.

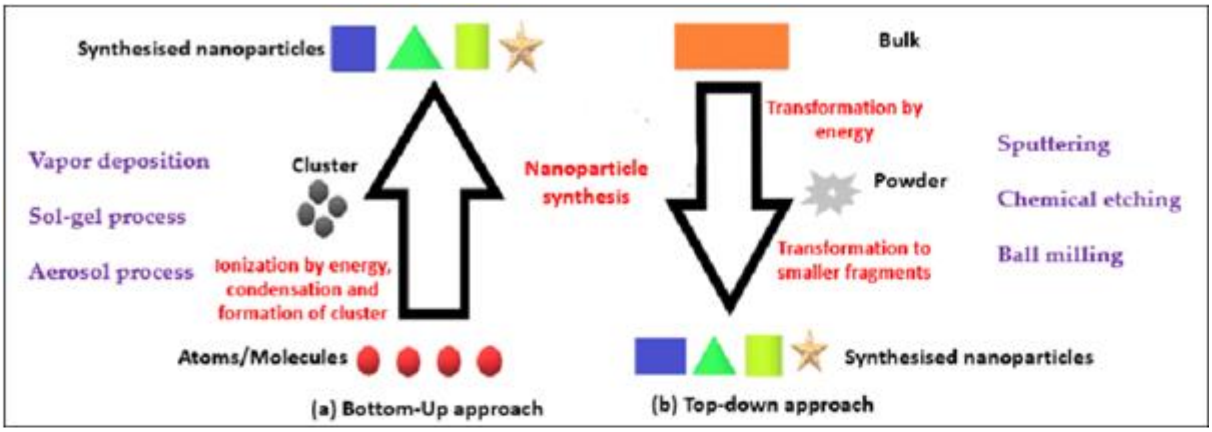


Figure 1.1: Schematic representation of bottom-up and top-down approach

1.2. Ion Beam Lithography

Ion beam lithography has high potential to play an important role in nanomanufacturing in which a focused beam of ions in a patterned fashion across a surface in order to create very small structures such as integrated circuits or other nanodevices.Ion-beam lithography, or ion-projection lithography, is similar to Electron beam lithography, but uses much heavier charged particles, ions. In addition to diffraction being negligible, ions move in straighter paths than electrons do both through vacuum and through matter, so there seems be a potential for very high resolution. Secondary particles (electrons and atoms) have very short range, because of the lower speed of the ions. Ion-beam lithography is a new technique which, although still in an early development stage, already shows great promise for the fabrication of devices with submicron details. The reasons for this are the high resolution possible with ions and the high sensitivity of resists to ions. The sensitivity of resists to ions is higher than to electrons and x rays, because the energy deposition per unit path length is higher for ions. Therefore, a lower exposure dose is required. The reasons for the high resolution are that ions do not suffer from the so-called proximity effect of electrons, which iscaused by fast backscattered and secondary electrons, and do not produce photoelectrons as in the case of x rays (200 -eV to 2 keV, depending on the wavelength). Ions produce only low-energy secondary electrons (5 eV to 50 eV). Therefore, the structures are defined by the primary ion beam, and are limited only by the straggling of the ions, which is less than the range of the electrons produced by electron beams and x rays. On the other hand, intense sources are more difficult to make and higher acceleration voltages are needed for a given range. Due to the higher energy loss rate, higher particle energy for a given range and the absence of significant space charge effects, shot noise will tend to be greater.

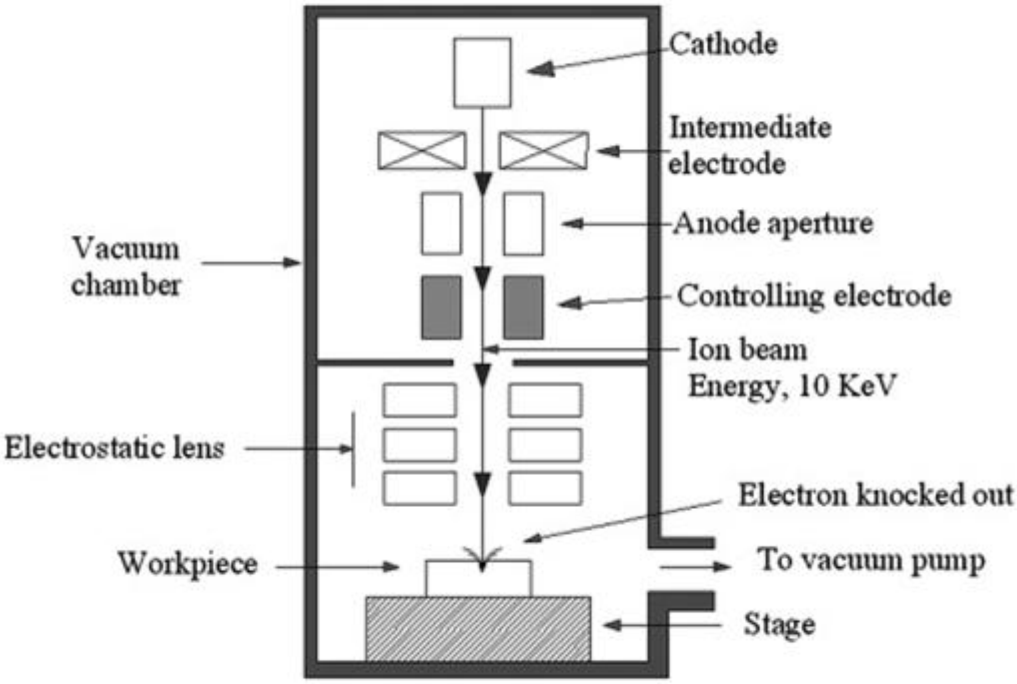


Figure 1.2.1: Schematic diagram of ion beam lithography

2. Methodology

Now a day's industries are leading to develop new technologies and to improve the quality of products, they are willing to use latest machineries to work at nanoscale.

The methodology use for this paper is by making survey and visiting the industries which are recently induce the ion beam lithography technique.

The lithography uses the various sources of ion beam such as **gas source** which generally consist of **Hydrogen** and **Helium.**

Metal Sources

- It includesthe most common used metal **Gallium (Ga).**
- **Aurum/Silicon** alloys are also used in lithography because these sources can supply lighter mass ions.

Features

- Penetration of ion beam is very small, compared to electron beam.
- Reduce blurring resulting from beam scattering.

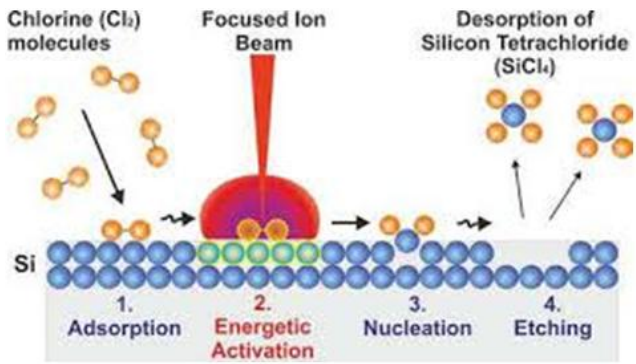


Figure 2.1: Basic methodology of ion beam

3. Ion Beam Lithography Instruments Requirement

Instrument component	Important features, requirements, and options
Ion source and ion optics	Highly bright, small spot ion source Long-term source emission stability and a reasonable lifetime Optics design and lens operation optimized for best focus and optimal beam profile, high on-axis angular intensity at various currents, easily changeable for the smallest features as well as form, mm, and perhaps cm sized patterns Accurate beam placement and low distortion beam deflection
Sample stage	Accurate stage translation with nm steps and high repeatability Rotation and tilt for 3D applications and process development Sample size from mm² for process development to wafer-scale, supporting mix and match with other lithography techniques Exact absolute position addressing for blind navigation High position stability by sample mounts and stage concept

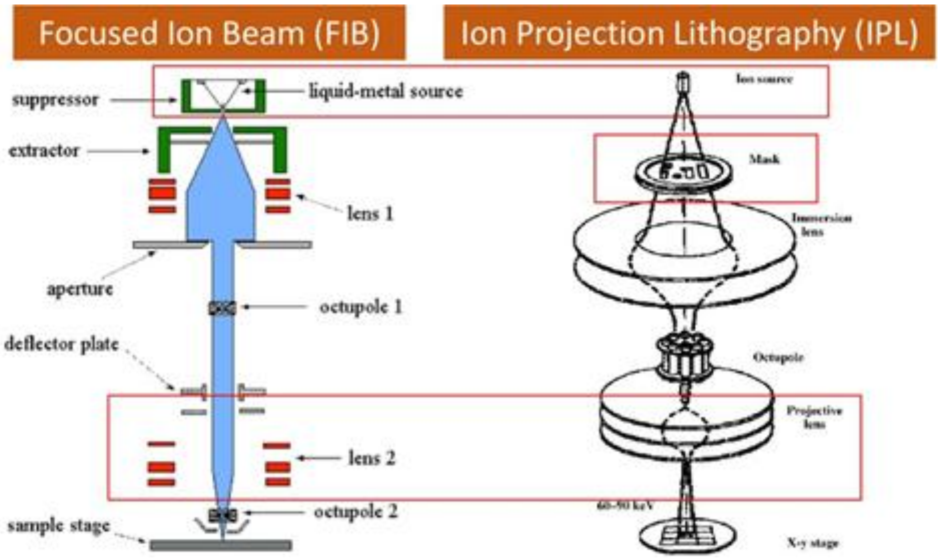
	Position monitoring, control, and automatic corrections
Pattern generation electronics and beam control	Suitable patterning electronics speed, buffer memory size, andDAC resolution Stable, low-noise electronics (pattern generator, amplifier, supplies) Fast beam blanking and accurate timing of blanking Available various beam deflection styles and built-in patterns
Software	Offering both intuitive manual and automated, unattended operation Supporting lithography pattern design file formats, like GDSII Handling all basic patterning parameters and advanced features like groups, higher level ordering and repetition, pattern alignments, or automatic corrections (see Section 4 for patterning concepts) Allowing user defined sample coordinate-based navigation Available live feedback and end-point detection techniques
Sample chamber and additional capabilities	Architecture and overall arrangement of stage and column should support the main purpose of the instrument Accommodating samples and wafers of appropriate size Suitable loading mechanisms possibly through load lock

4. Techniques in Ion Beam Lithography

There are two methods which are commonly used in ion beam lithography, which are as follows.

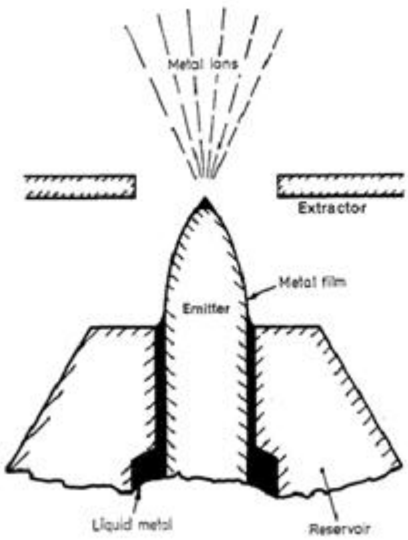
a) Focused ion beam (FIB)
b) Ion projection lithography (IPL)

Working principle of both FIB and IPL are same only the difference is use of ion sources.



- **Liquid metal ion Source**

In a **Liquid metal ion source (LMIS)**, a metal (typically gallium) is heated to the liquid state and provided at the end of a capillary or a needle. Then a Taylor cone is formed under the application of a strong electric field. As the cone's tip get sharper, the electric field becomes stronger, until ions are produced by field evaporation. These ion sources are particularly used in ion implantation or in focused ion beam instruments.



Advantages and Disadvantages of ion beam lithography

Advantages

- High exposer sensitivity
- Negligible ion scattering in the resist

- Can be used as physical sputtering etch and chemical assisted etch.

Disadvantages
- Lower throughput
- Substrate damage

5. Conclusion

Today, the only industry where nanoscale manufacturing technologies are employed on a large scale is the semiconductor industry, where device structures have reached the single nanometres scale. of course, the chemical industry has long been working with nanoscale particles and pigments, but this falls more into the realm of chemistry rather than nanomanufacturing.Ion beam lithography is a versatile technique with several variation of the process. It has been found to be useful for transferring high- fidelity patterns one dimensional surfaces. In this paper we define the importance of nanomanufacturing and ion beam lithography in this era of new technology.

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