TWO-DIMENSIONAL NANOSTRUCTURES: FILMS

Top-down approaches

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Summary

Summary

- **Introduction**
- **Lithographic Methods**
- **Further Reading**

Types of Nanotechnologies

A) Top-Down (*scaling down*, larger to smaller size)

Here, the mechanisms and structures are miniaturized to a nanometer scale. This approach is widely following in the miniaturization of electronic products, and electronic components manufacturing processes.

B) Bottom-Up (*scaling up*, smaller to larger size)

Approach less complex, but difficult to control defects ('self-assembly' or auto-organization of monodisperse spheres, nanocrystallization).

Lithography

Lithography

Top-Down (*scaling down*, larger to smaller size)

Lithography was developed about 200 years ago as a method to print on paper. Print lithography involved the patterning of stone with wax. When water based ink is applied to a wax patterned stone, the ink will only stick to the exposed stone, not the wax. The stone effectively becomes a stamp to print on paper.

Introduction

Nanostructures Fabricated by Top- Down Processes

Lithographic techniques

- **Photo**lithography
- Phase shifting **optical** lithography
- **Electron beam** lithography
- **X-ray** lithography
- **Focused ion beam** lithography
- **Neutral atomic beam** lithography

Soft lithography

- **Microcontact printing**
- **Molding**
- **Nanoimprint**
- **Dip-pen nanolithography**

Lithographic Methods

Lithography

Lithography

Top-Down (*scaling down*, larger to smaller size)

1) Basic Nanolithography
2) e-BEAM Nanolithography
3) Dip Pen Nanolithography
4) Nanosphere Lift-off Lithography

Lithographic Methods

Lithography

1) Basic Nanolithography

A different form of lithography is used to make tiny channels and pathways on a computer chip. A silicon wafer is first coated with a thin layer of silicon dioxide or other material. Another chemical, called photoresist, is then layered on top of the silicon dioxide in the desired pattern of the channels and pathways. The photoresist is very durable and chemically resistant. A powerful chemical etch is then used to behind. The channels and pathways are still covered with photoresist, which is removed as the final step.

This process can then be repeated over and over to create a complex three dimensional structure containing many layers. In addition, the individual layers can be made of semiconductor materials with whatever properties are desired, enabling the creation of miniaturized transistors, resistors, etc..

Lithographic Methods

Lithography

2) e-Beam Nanolithography

In Basic Lithography one are limited to creating patterns and features no smaller than the wavelength of the light used. One could certainly use smaller and smaller EM radiation, but frequencies increase and, so does the energy that the EM radiation carries. Hence, electrons can be used instead of light. Because of their mass, electrons carry with them much less energy, despite exhibiting wavelengths smaller than that of light.

Lithography

3) Dip Pen Nanolithography

Dip Pen Nanolithography, sometimes referred to as DPN, was developed by Chad Mirkin at Northwestern and is the type of nanotechnology that Richard Feynman used to write his now-famous 1959 paragraph on the possibility of miniaturization. In this type of lithography the atoms / molecules act as a sort of ‘ink’ within a scanning probe tip, which is analogous to a pen.

The substrate is either polar or non-polar. As the tip scans across the surface, the atoms / molecules inside align themselves with the substrate in a manner similar to north and south poles of a magnet.

Lithography

4) Nanosphere Liftoff Lithography

If you imagine a bunch of spheres packed as closely together as possible, you should include in your imagination the fact that each of those spheres will be surrounded by exactly six other spheres, be they tennis balls, marbles, or nanoparticles.

If one were to spray a bunch of close-packed nanospheres with some sort of ‘nano-paint’ and then remove those spheres, one would have a repeating of paint that has bee left behind.

Lithographic Methods

Structure Generation and Fabrication of Lithographic Masks

Resists characteristics

(1) For all **lithographic processes** that utilize some type of **radiation**, the **resist** has to be **sensitive** to this **radiation**, which means that the **exposed part undergoes a local chemical change**, but the remaining area is unaffected.

(2) This **local chemical change** has to result in the **development of a relief in the resist**. Therefore, the change has to significantly affect the removal rate in an appropriate development

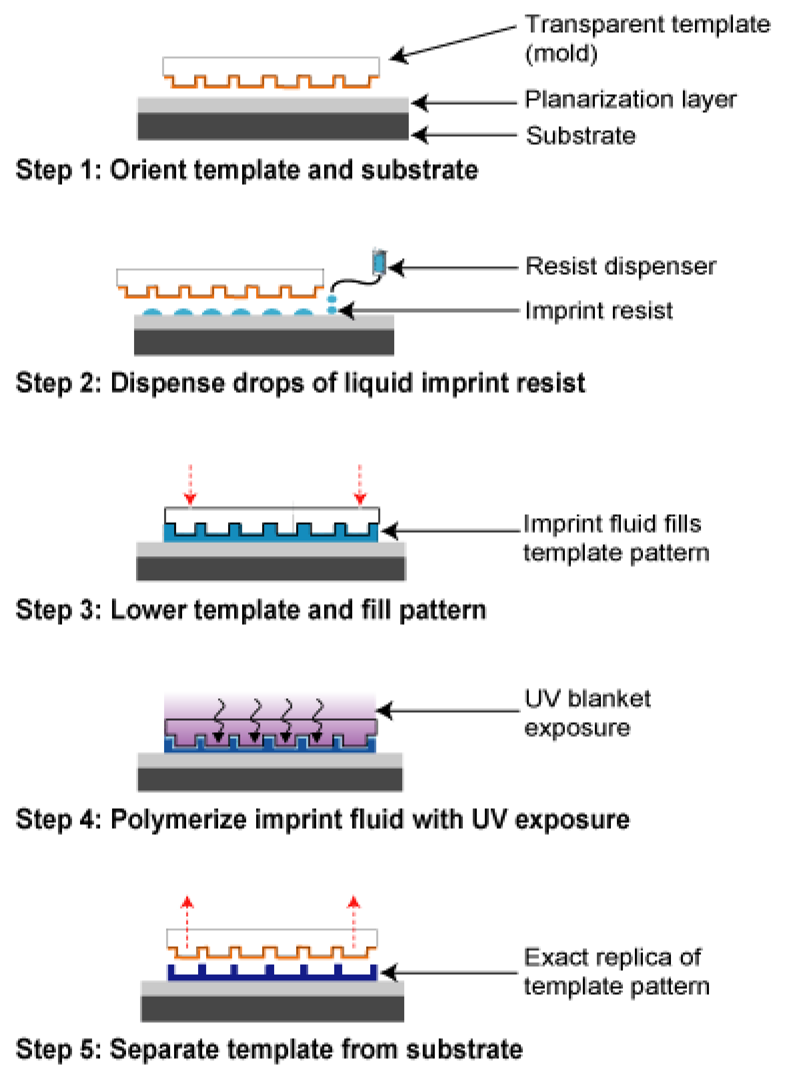
The **resists** should exhibit a **high gradation**, so that a small difference in dose results in a larger change in solubility.

(3) In subsequent processes the **remaining parts** have to exhibit a **protective property** with regard to the underlying material, so that the functional layers can be etched by dry or wet techniques.

(4) The **interface** between the **resist** and the **substrate** has to show a **high stability**. This is achieved by a certain density of strong covalent bonds or by a higher density of dipole-dipole, H bridge or Van der Waals interactions.

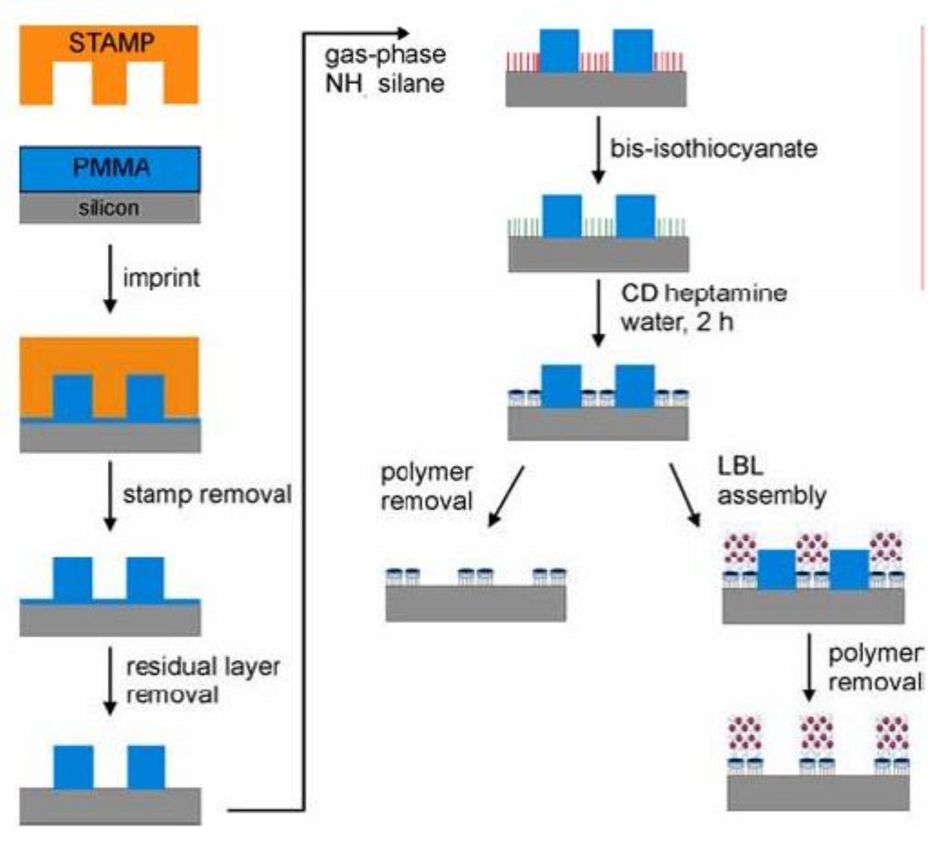
Lithographic Methods

Structure Generation and Fabrication of Lithographic Masks



Lithographic Methods

➡ *Structure Generation and Fabrication of Lithographic Masks*



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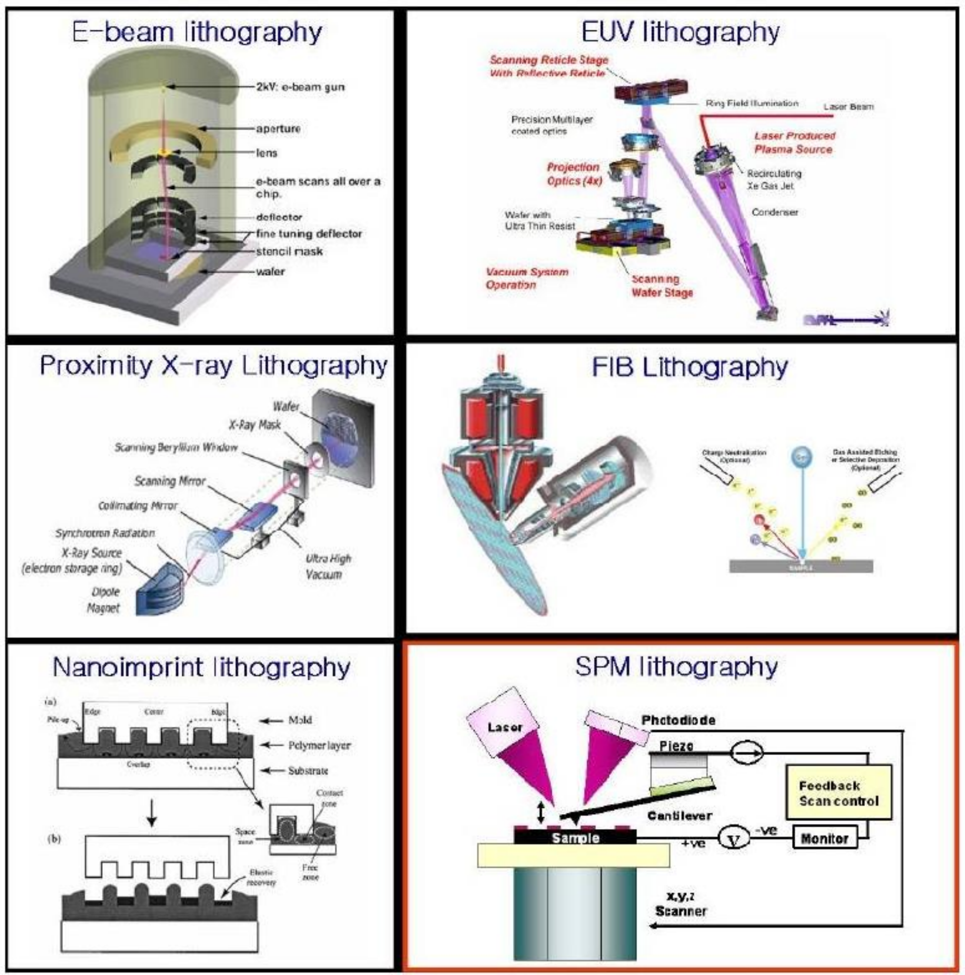
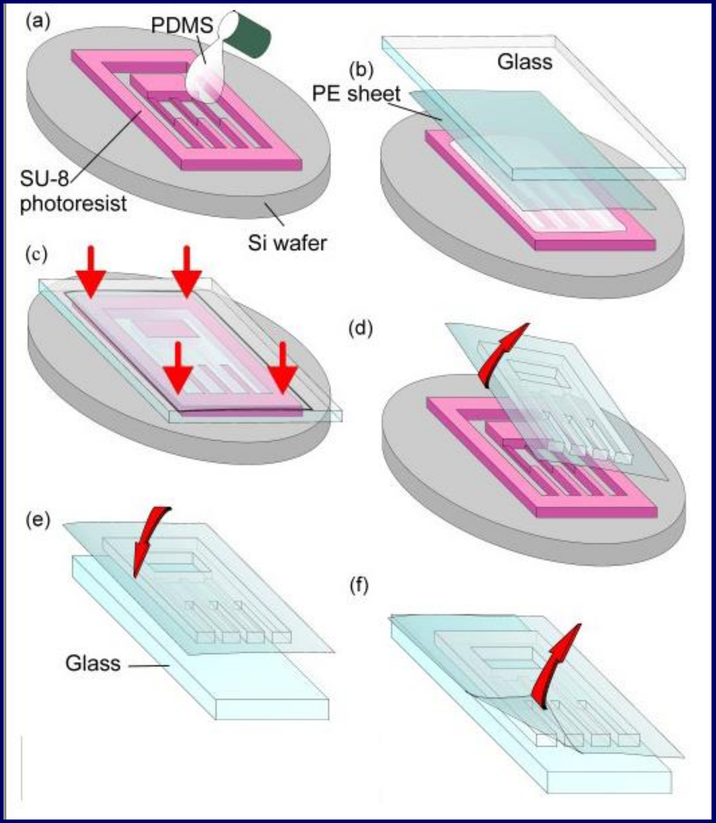
Lithographic Methods

Lithographic Methods

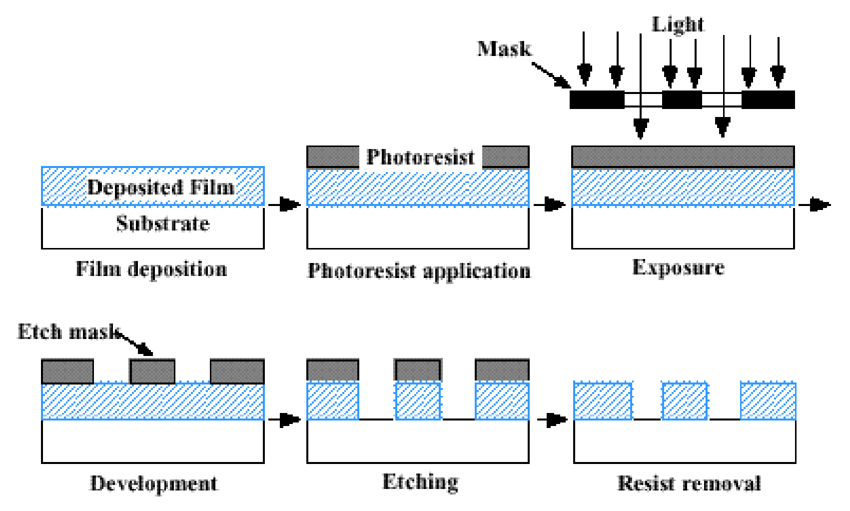


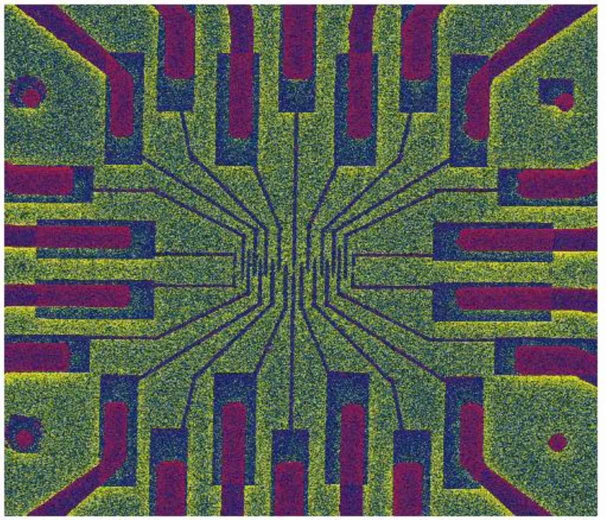
Photolithography



Photolithography

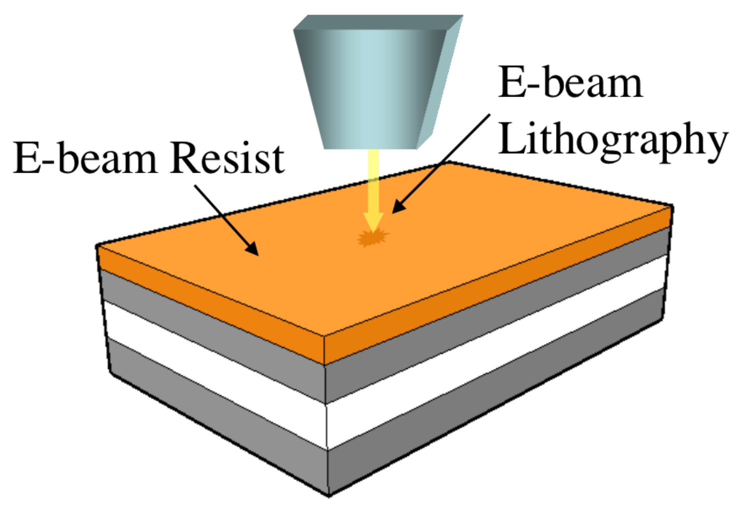
Photolithography

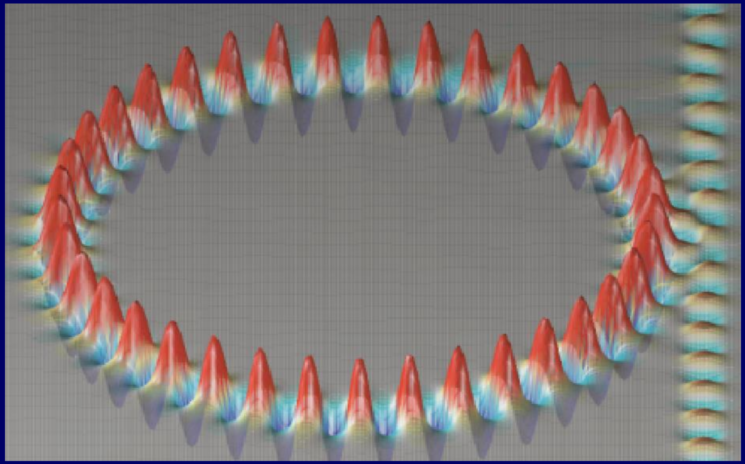




Electon Beam Lithography

Electron Beam lithography





Electon Beam Lithography

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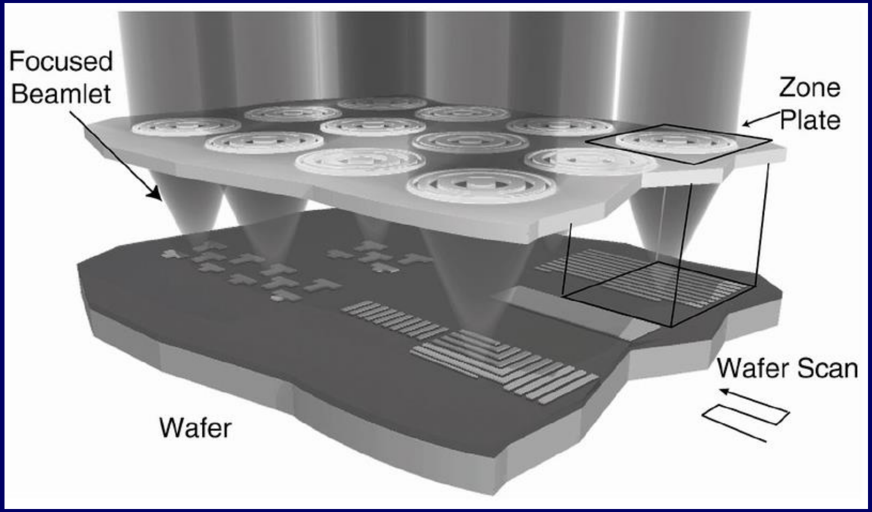
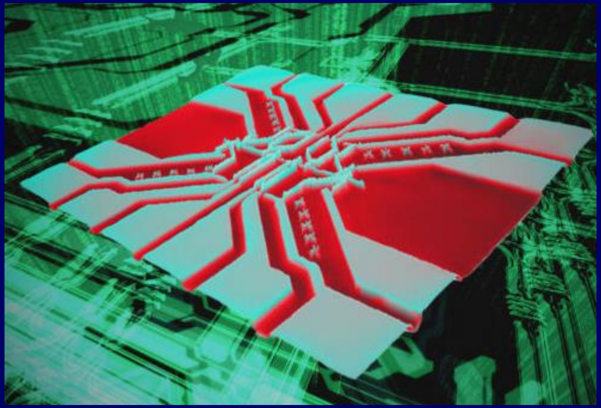
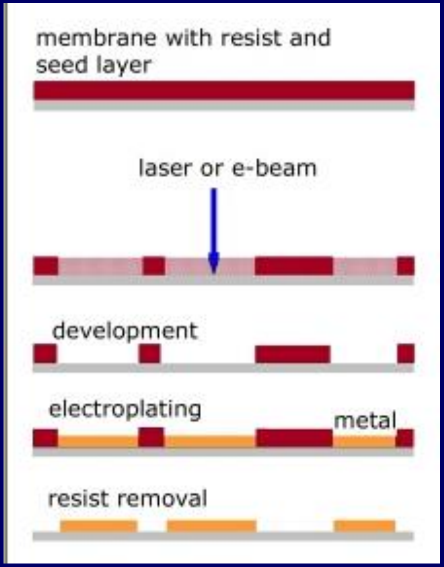
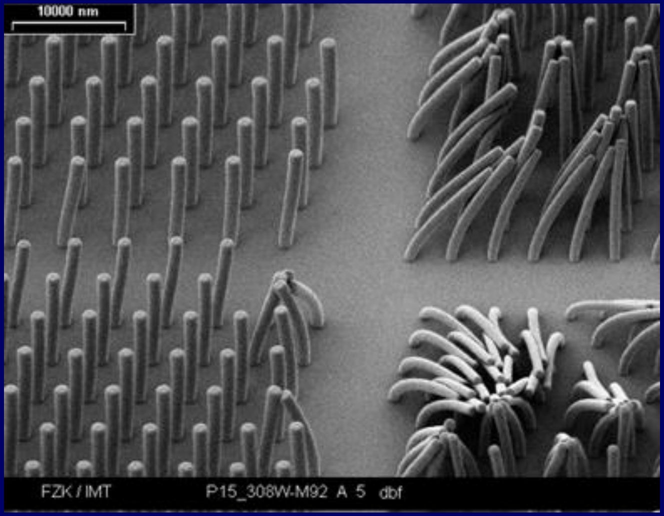




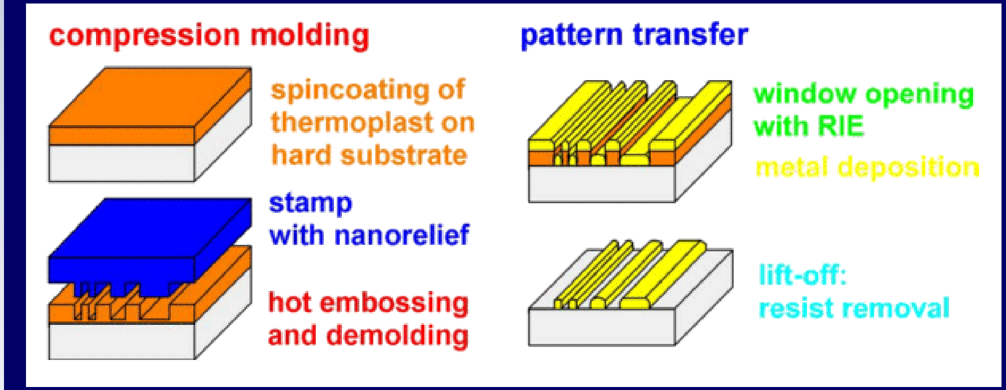
X-Ray Lithography

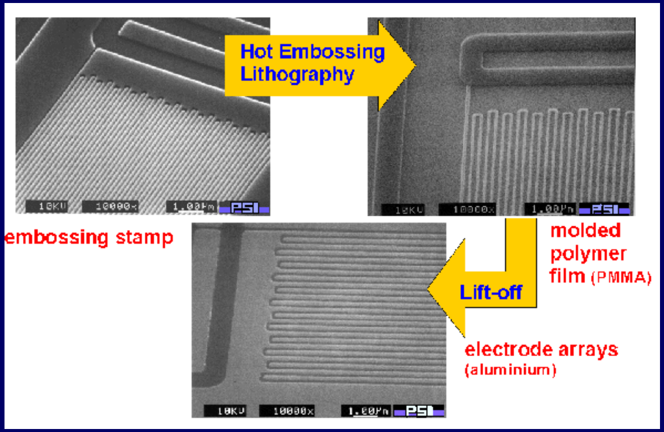
X-Ray Lithography





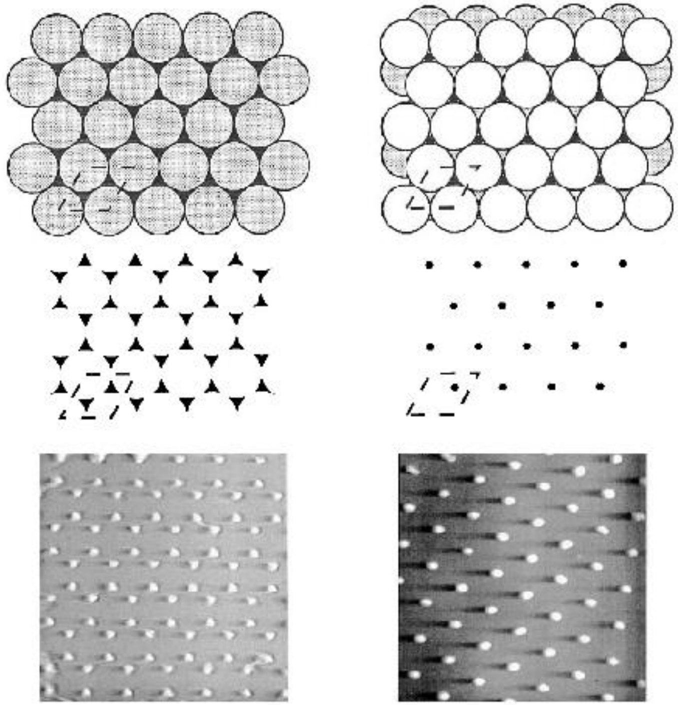
Nano Lithography





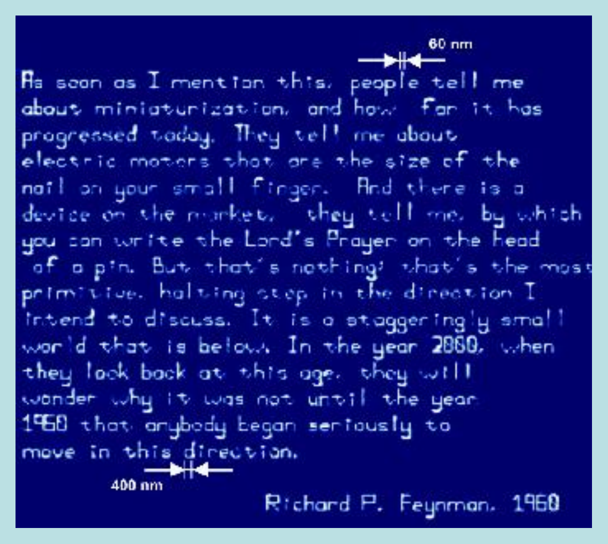
Nano Lithography

Nanospheres Lithography



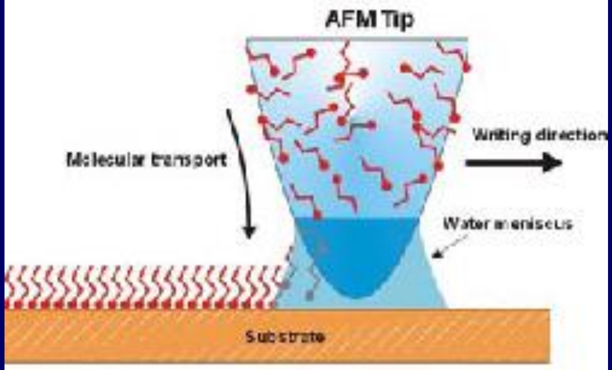
Single and double layer close-packed 265 nm polystyrene spheres on mica.
Deposition of Ag and nanosphere liftoff gives 50 nm particles.
Richard Van Duyne, *J. Vac. Sci. Technol. A* 13(3), 1553-1558 (1995)

Dip Pen Lithography



As soon as I mention this, people tell me
about miniaturization, and how far it has
progressed today. They tell me about
electric motors that are the size of the
nail on your small finger. And there is a
device on the market, they tell me, by which
you can write the Lord's Prayer on the head
of a pin. But that's nothing; that's the most
primitive, halting step in the direction I
intend to discuss. It is a staggeringly small
world that is below. In the year 2000, when
they look back at this age, they will
wonder why it was not until the year
1960 that anybody began seriously to
move in this direction.

Richard P. Feynman, 1960



Alkanethiols on gold

Chad Mirkin, http://www.chem.northwestern.edu/~mkngrp/dpn.htm

Further Reading

- Nanostructures and Nanomaterials. Synthesis, Properties & Applications, G. Cao, ICP Imperial College Press, 2007 (ISBN 1-86094-480-9).

- Nanotechnology. An Introduction to Nanostructuring techniques. M. Köhler, W. Fritzche, Wiley-VCH Verlag, 2004 (ISBN 3-527-30750-8).

- Nanotechnology. Basic Science and Emerging Technologies. M. Wilson, K. Kannagara, G. Smith, M. Simmons, B. Raguse, Chapman & Hall/CRC, 2002 (ISBN 1-58488-339-1).