Reduce k_1. k_1 is dependent on the imaging system. OAI, OPC, and PSM can all be used to reduce k_1.

Chapter 2: Next-Generation Lithographies (NGLs) and Lithography Research

Most of the questions by Mr. Chuan Zhang, UC Irvine

2.1:

Extreme ultraviolet lithography (EUVL) is one of the most promising future lithography techniques. Explain why EUVL increases the resolution dramatically. The high cost is the major obstacle for the commercialization of this technology; list the major reasons for the high cost of EUVL.

Answer:

Given that EUVL comes with a significant reduction in wavelength (13.4 nm) compared to current lithography wavelengths (193 nm), one expects significantly better resolution ($R = k_1\lambda/NA$). However, the resolution is ultimately determined by the interaction volume in the photoresist. Low energy electrons released by EUVL can blur the original EUVL image. The problems that arise leading to a high cost include the following: the whole process must take place in a vacuum; all the optical elements, including the photo-mask, make use of defect-free Mo/Si multi-layers which act to reflect light by means of interlayer interference and are very difficult to make, since the optics absorb a major fraction of the available EUV light; and the ideal EUV source needs to be sufficiently bright. Finally, the mirror responsible for collecting the EUV light coming from the plasma is directly exposed to that plasma and is therefore vulnerable to damage from the high-energy ions and other debris. The damage associated with the high-energy process of generating EUV radiation has precluded the successful implementation of practical EUV light sources for lithography so far.

2.2:

Compare the differences between traditional projection photolithography and extreme ultraviolet lithography. Why do reflective optics have to be used in an EUVL system?

Answer:

In many respects, EUVL may be viewed as a natural extension of optical projection lithography since it uses short wavelength radiation (light) to carry out projection imaging. In spite of this similarity, there are major differences between the two technologies. Most of these differences arise because the properties of materials in the EUV range are very different from their properties in the visible and UV ranges. Foremost among those differences is the fact that EUV radiation is strongly absorbed in virtually all materials, even gases. EUV imaging must therefore be carried out in a near vacuum. Absorption also rules out the use of refractive optical elements, such as lenses and transmission masks. Thus EUVL imaging systems are entirely reflective. Because the EUV reflectivity of individual materials at near-normal incidence is very low, in order to achieve reasonable reflectivities at near-normal incidence, surfaces must be coated with multilayer, thin-film coatings known as distributed Bragg reflectors. The best of these function in the region between 11 and 14 nm. EUV absorption in standard optical photoresists is very high, and new resist and processing techniques are also required for application in EUVL. Because EUVL utilizes short wavelength radiation for imaging, the mirrors that comprise the camera will be required to exhibit an unprecedented degree of perfection in surface figure and surface finish in order to achieve diffraction-limited imaging. Fabrication of mirrors exhibiting such perfection will require new and more accurate polishing and metrology techniques.

2.3:

Why does x-ray lithography have a high depth of focus? LIGA is less promising as a future MEMS technique due to the requirement of a synchrotron source. List the competing technologies and explain why they might replace LIGA.

Answer:

Because of the excellent collimation and large depth of focus, x-ray lithography, particularly produced by synchrotron sources, permits fabrication of extremely high aspect ratio structures in the micron and submicron dimensions. The proximity gap latitude corresponds to depth of focus (DOF) in x-ray projection lithography; therefore, DOF at a 0.15 µm line-and-space pattern is 40 µm in x-ray proximity printing. In general, there are no DOF problems in x-ray lithography.

Using techniques such as deep UV lithography and deep dry etching with dense plasmas, LIGA-like, high-aspect-ratio features have been produced, hemming in the potential for broader use of x-ray lithography for building 3D miniaturized machines. Both DUV and DRIE are more accessible than LIGA and will continue to improve. Other competing technologies for making metal masters are listed in the table below.

TABLE Comparison of Micromolds

Parameters	LIGA	DUV	DRIE	LASER	CNC	EDM
Aspect ratio	100	22	10-25	< 10	14 (hole drilling)	Up to 100
Wall roughness	< 20 nm	~ 1 µm	~ 2 µm	1µm-100 nm	Several microns	0.3-1 µm
Accuracy	< 1 µm	2-3 µm	< 1µm	A few microns	50 µm (x,y) nanometers in the z direction	Some microns
Mask needed?	Yes	Yes	Yes	No	No	No
Maximum height	A few 100 µm up to 1 cm	A few 100 µm	A few 100 µm	A few 100 µm	Unlimited	Microns to millimeters

2.4:

Is the resolution of e-beam lithography given by the spot size of the focused beam? Explain why or why not. What are proximity effects, and how can one minimize their impact on the resolution?

Answer:

The resolution of e-beam lithography tools is not simply the spot size of the focused beam; it also is affected by scattering of the e-beam inside the resist and substrate and by backscattering from the substrate exposing the resist over a greater area than the beam spot size. *Proximity effects* lead to scattering of electrons that partially expose the resist far beyond the point of impact. Line-width variations due to local feature density are an immediate result. Proximity correction algorithms are used to achieve more uniform resist exposure with EBL. Such corrections are computer intensive and time consuming, however, and make a slow technique even slower.

2.5:

What are the differences between thermionic emission (also called Schottky emission or SE) and cold field emission (CFE)? What are the advantages of low-energy electron beam lithography?

Answer:

Schottky emission (SE) and cold field emission (CFE) have been in common use, especially for nanometer-sized beams for electron focusing systems. Emission of electrons from a metal under the influence of a field occurs in both SE and CFE. During SE emission, a blunt tungsten emitter tip coated with a low work function material (ZrO) is heated to 1800K and thermionic emission takes place; that is, heat thermally excites the electrons enough to bring them out of the material. In other words, the field emission is helped along by thermal excitation of the electrons (the current in this case is given by the Richardson-Dushman equation). During CFE, a much smaller tungsten wire (radius of <0.1 μm) is used, and a very high field causes electrons to tunnel out of the material. In CFE sources, electrons tunnel from various energies below the Fermi level. With SE cathodes, thermally excited electrons (non-tunneling electrons) escape over a field-lowered potential energy barrier (the current in this case is given by the Fowler-Nordheim equation). Both SE and CFE sources display similar energy spreads, but their energy distributions are mirror images.

Attaining high current levels in a submicron electron beam at low voltages (500 eV to 1 keV) is of interest for e-beam lithography, and scanning electron microscopy (SEM). When sensitive biological samples or electron beam sensitive resists are involved, SEM pictures must be made at voltages below 1 keV. At these low voltages, high currents are required to attain the needed detail and to minimize edge effects.

2.6:

What is the difference between direct write e-beam lithography and electron projection lithography? Describe the working principle of SCALPEL (scattering with angular limitation projection electron beam lithography).

Answer:

In contrast with optical lithography, which uses light for the same purpose, electron lithography offers higher patterning resolution than optical lithography because of the shorter wavelength associated with the 10-50 keV electrons that it employs. Electrons are easily generated and can be used to either directly write the desired structure to the resist in electron-beam direct write, or in electron projection lithography flood exposure where a much wider beam is used [EPL, such as scattering with angular limitation projection electron beam lithography (SCALPEL)]. SCALPEL, a projection electron beam technique, employing a 4X reduction and a step-and-scan writing strategy, is the most prominent EPL technique. A SCALPEL mask consists of a low atomic number membrane covered with a layer of a high atomic number material: the pattern is delineated in the latter. While the mask is almost completely electron-transparent at the energies used (100 keV), utilizing the difference in electron scattering characteristics between the membrane and the patterned material generates contrast. The membrane scatters electrons weakly and to small angles, while the patterned layer scatters them strongly and to high angles. An aperture in the back-focal (pupil) plane of the projection optics blocks the strongly scattered electrons, forming a high contrast aerial image at the wafer plane.

2.7:

Describe the major procedures in nanoimprint lithography.

Answer:

Nanoimprint lithography (NIL) patterns a resist by deforming the resist shape through embossing (with a mold/stamp/template), rather than by altering resist chemical structures through radiation (with particle beams). After imprinting the resist, a dry anisotropic etch is used to remove the residual resist layer in the compressed area to expose the substrate underneath. In NIL, a template (the mold/stamp/template) is made of a hard material (usually Ni or Si) and is pressed against a layer of polymer. High temperature and pressure conditions mold and harden the polymer layer. The NIL technique is based on the craft of hot embossing, with an adaptation to modern semiconductor needs. The method relies on the excellent replication fidelity obtained with polymers and combines thermo-plastic molding with common pattern transfer methods. Once a solid stamp with a nanorelief on the surface is fabricated it can be used for the replication of many identical surface patterns. The resolution of the NIL process is a direct function of the resolution of the original template/stamp fabrication process. Electron beam writers that provide high resolution but lack the throughput required for mass production are used to make them.

2.8:

How can a diblock copolymer be used in lithography? List some of the merits of block copolymer lithography.

Answer:

Diblock copolymers are two different types of polymer chains connected at one end with a covalent bond. Most pairs of polymers are immiscible and blends of polymers tend to phase separate. In the case of diblock copolymers, however, the two polymers that constitute the material are unable to phase separate at macroscopic length scales and instead spontaneously form ordered structures at the molecular scale with domain dimensions of 5–50 nm. The size and shape of the domains in the bulk are dependent on the molecular weight and composition of the copolymer and typically assume morphologies of spheres, cylinders, and lamellae. Block copolymer lithography refers to the use of these ordered structures in the form of thin films as templates for patterning through selective etching or deposition. The obvious interest in using these materials for patterning is derived from the fact that they self-assemble to form dense arrays of nanostructures with dimensions and spacings that are difficult or impossible to create by other means or are prohibitively expensive to fabricate using conventional lithographic materials and processes.

2.9:

How does a Fresnel zone plate work? What are the major merits of Fresnel zone plates over diffractive optics lenses? Can they be applied in lithography?

Answer:

A Fresnel zone plate is a device used to focus light. Unlike lenses, zone plates use diffraction instead of refraction. A zone plate consists of a set of radially symmetric rings, known as Fresnel zones, which alternate between opaque and transparent. Light hitting the zone plate will diffract around the opaque zones. The zones can be spaced so that the diffracted light constructively interferes at the desired focus, creating an image there. Zone plates produce equivalent diffraction patterns no matter whether the central disk is opaque or transparent, as long as the zones alternate in opacity. Since a diffraction lens can be manufactured using planar technologies, it is easier to make than a traditional refractive lens. These Fresnel zone plates are very useful in lithography. The zone plate is especially useful in the ultraviolet and x-ray regions of the spectrum, for which other imaging devices are hard to find. Moreover it comes with a higher refractive index (NA), allowing for better contrast at the image plane. Unfortunately, the zone plate has low efficiency and suffers from veiling glare because most of the light incident on the zone plate passes through it undiffracted and falls onto the image plane. A Fresnel zone plate functions very much like an optical lens. Its optical properties do not depend on the material used though but are determined at the design time. The resolution depends only on Δr, the outermost zone width. Nanoimprint lithography and e-beam lithography can be used for the fabrication of large arrays of high numerical-aperture diffractive Fresnel lens arrays.

In optical lithography, a further increasing the numerical aperture NA of a lens is quite difficult and costly (a maximum NA of around 0.9 is projected). In diffractive optics making a high NA lens is not significantly different than making a low NA lens. At MIT, Fresnel lenses with an NA of 0.7 to 0.9 have been achieved already.

2.10:

What is the definition of scanning proximal probe lithography? Which technologies can be counted as scanning proximal probe lithography?

Answer:

Proximal probe techniques rely on the use of nanoscale probes, positioned and scanned in the immediate vicinity of the material surface. Proximal probes might involve electrical methods where a scanning tunneling microscope (STM) tip generates a local field/current that modifies the region directly under the tip (e.g., SiH $\rightarrow$ Si). A second approach involves mechanical methods where a scanning force microscope (SFM/AFM) tip scrapes, thermally deforms or transfers material at the surface, the latter material transfer method corresponds to dip-pen lithography (DPL). Thirdly it may involve a near-field optical scanning microscope (NSOM) tip or apertureless near-field scanning optical microscopy (ANSOM), which exposes photoresist under the tip only.

The use of single proximal probe tips poses a serious drawback in terms of processing speed. To use these techniques in the actual manufacture of ICs and data storage devices, it is necessary to devise a scheme for parallel processing by making arrays of these proximal probes.

2.11:

How does near-field optics break Abbe's diffraction limit? What is the difference between NSOM and ANSOM lithography?

Answer:

In near-field optics, the sample is illuminated by a nanoscopic light source located close to the surface (e.g., 10 nm) and the resolution is dictated by the source diameter a rather than Abbe's diffraction limit. This is achieved by using nanoscale apertures in NSOM or by using apertureless techniques in apertureless near-field scanning optical microscopy (ANSOM) or scattering NSOM. A typical NSOM probe is a commercial single mode optical fiber, tapered and coated by a thin CrAl film with an aperture of ~100 nm. In ANSOM, light interaction over nanoscale dimensions is enhanced with the use of scattering nanoscale tips, nanospheres etc.

2.12:

What are the major steps in soft lithography? Explain the reasons why they have not been widely used in industry.

Answer:

Soft lithography refers to a series of methods that use a patterned elastomer as a stamp, mold, or mask to generate micropatterns and microstructures instead of using a rigid photomask. Today the name is a collective term for a set of new techniques: micro-contact printing (μ-CP), micro-transfer molding (μ-TM), micromolding in capillaries (MIMIC), and micro-replica molding (REM). The method is a very exciting research tool and may offer advantages over conventional methods for patterning of nonplanar substrates, unusual materials, and large areas.

In soft lithography, a master mold is first made by lithographic techniques, and an elastomeric stamp (e.g., polydimethylsiloxane) is cast from this master mold. A simple procedure for making a polydimethylsiloxane (PDMS) stamp from a photolithographically patterned resist layer as master mold is as follows. A thin layer of SU-8 photoresist [SU-8 (50) from MicroChem, Newton, Mass.] is coated on a Si wafer. The resist is patterned by UV lithography. After development, the photoresist is treated with (tridecafluoro-1,1,2,2-tetrahydrooctyl)-1-trichlorosilane (Hüls Chemicals, http://www.degussa.com/) vapor to facilitate PDMS removal once cured. A 10:1 ratio of a PDMS mix is cast on the photoresist film and cured for 1 hour at 60°C in an oven. In micro contact printing (μ-CP), the PDMS rubber stamp is then coated with an ink of the molecules (say, alkylthiols or a protein) that one wants to print in selected patterns on a solid substrate. During stamping, only the raised parts of the stamp collect the "ink." The inking of the substrate consists of self-assembled monolayers on the solid surface formed by covalent chemical reaction. The inked areas are self-passivating and exhibit very low interfacial tension that repels additional molecular layers so that SAM forms only in areas of conformal contact between polymer and substrate. The SAM pattern acts as a highly localized and efficient barrier to some wet etches. This lithographic technique—once the master is made—is not subject to diffraction or DOF limitations. The deformability of the elastomeric stamp allows it to accommodate rough surfaces.

2.13:

How would you make a conical shaped PMMA structure that is 150 μm tall and features a top angle of 45°?

Answer:

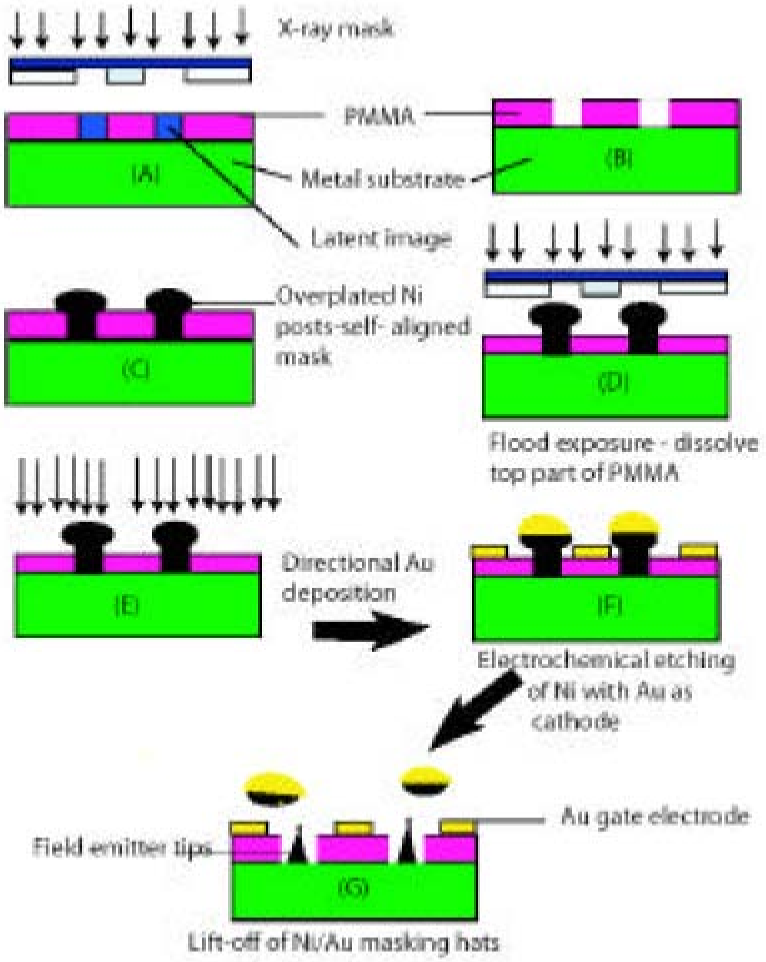
A possible tool to use here is an x-ray scanner such as the IMM/Jenoptik instrument, which allows continuous tilt angles of the mask/substrate assembly with respect to the x-ray beam and rotation of the mask/substrate. The system also contains an internal mask alignment system for different masks for multiple exposures. Using the IMM/Jenoptik scanner a vertical resist wall with a precision of less than 0.05 μm was demonstrated, and resist walls inclined at a 45° angle were made with an accuracy of 1 µm over a height of up to 500 µm.

2.14:

Design a miniaturized device incorporating both a lift-off process and a self-aligned mask step in its manufacture.

Answer:

In the figure below we show an example process incorporating both lift-off and self-alignment. The process is meant to result in a set of sharp Ni field emitters surrounded by an Au gate electrode. (A) PMMA radiation using x-rays; (B) development; (C) overplating of Ni in PMMA holes to create mushrooms, i.e., making the self-aligned mask; (D) flood exposure of PMMA and dissolution of a thin top layer of PMMA to provide access for Ni etchant, i.e., to create the right profile for lift-off; (E) Au evaporation is directional and the hat of the mushroom masks the underlying PMMA; (F) using the Au gate electrode as cathode, the Ni posts of the mushrooms are electrochemically sharpened; (G) the mushroom hats, because of the lift-off profile, fall off by undercutting.



2.15:

Why can only proximity masking be used in the case of x-ray lithography? What about projection printing with x-rays? Sketch the process for fabricating an x-ray mask. What are some of the positive attributes of x-ray lithography? What are the negative attributes?

Answer:
Proximity printing in x-ray lithography. In x-ray lithography there is essentially no optics involved and although this sounds like an advantage it also presents one major disadvantage—one can only work with 1:1 shadow printing. Given the expense of an x-ray mask, contact printing is not a viable approach as it would shorten the lifetime of the masks dramatically.

Projection printing in x-ray lithography. A "simple" downscaling of the optical projection techniques below 193 nm is not feasible because of the lack of refractive lenses and the problems involved in the fabrication of pure reflective systems with high enough numerical apertures (NA). Imagine the issues involved with making a reflective optical system for x-rays (say at 20 Å) by considering the problems encountered in manufacturing the all-reflective optics for EUV (at 13 nm). Absorption on transmission and lens damage precludes catadioptric systems[1] in the EUV regime. Instead, all-reflective systems must be introduced. But a system consisting of, e.g., seven mirrors leaves on the wafer surface only 8% of the intensity available from the light source. Both, coatings with higher reflectivity and lower defect density as well as brighter light sources, have to be developed. To achieve diffraction limited performance, the surface figure accuracy of the lenses has to be less than 1 nm at 13 nm wavelengths. Obviously x-ray reflective optics for projection printing at 20 Å will be much harder yet.

Making of an x-ray mask. Here is an example of an x-ray mask making process:
1. x-ray graphite blank mask preparation (100 µm thick base).
   a. Lapping base.
   b. Titanium dc sputtering base (for adhesion).
   c. Copper dc sputtering base.
2. Contact photolithography (SU-8).
   a. Dehydration bake base.
   b. Photoresist coating (SU-8) from 1 to 400 µm high.
   c. SU-8 prebake.
   d. Contact alignment.
   e. Contact exposure (SU-8).
   f. Photoresist develop (SU-8).
   g. SU-8 post-exposure bake.
3. Plating preparation of the base.
   a. Ashing to descum.
4. Gold electroplate the base.
5. Photoresist ashing (SU-8) base.
6. X-ray graphite mask mounting base process.
   Mounting of x-ray graphite mask on 4-in steel ring.

Positive attributes of x-ray lithography. In contrast with electron lithography and ion-beam lithography, no charged particles are directly involved in x-ray exposures, which, in principle, eliminates the need for a vacuum. Another advantage of x-rays is that one

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[1] An optical system in which both reflecting and refracting curved surfaces are used to form an image. Some "reflecting" objective lenses, as well as video projection systems, are catadioptric; the latter uses a Schmidt plate to correct the spherical aberration introduced by the spherical reflecting mirror.

can use flood exposure of resist-coated wafers, ensuring higher throughput than when writing with a narrow electron or ion beam. X-ray lithography is superior to optical lithography because of the use of shorter wavelengths and a very large DOF and because exposure time and development conditions are not as stringent. Reproducibility is high as results are independent of substrate type, surface reflections, and wafer topography.
Another important benefit is that x-ray lithography is immune to low-atomic-number (Z) particle contamination (dust). With an x-ray wavelength on the order of 10 Å or less, diffraction effects generally are negligible and proximity masking can be used, increasing the lifetime of the mask.

Negative attributes of x-ray lithography. A major challenge in x-ray lithography, besides the low sensitivity of the resists and the high cost of sufficiently bright x-ray sources, is the mask making—already complex for producing DRAMs, but even more complex for 3D structures with high aspect ratios. No projection lithography is possible with x-rays.

2.16:
Compare UV, x-ray, ion-beam, and electron-beam lithography. Summarize in a comparison table. Which techniques are used mostly in the IC industry today? How are the photons or charged particles created in each case?

Answer:
Comparison of lithographies. A graphical comparison of various lithographies is shown in Figure 2.16.1.

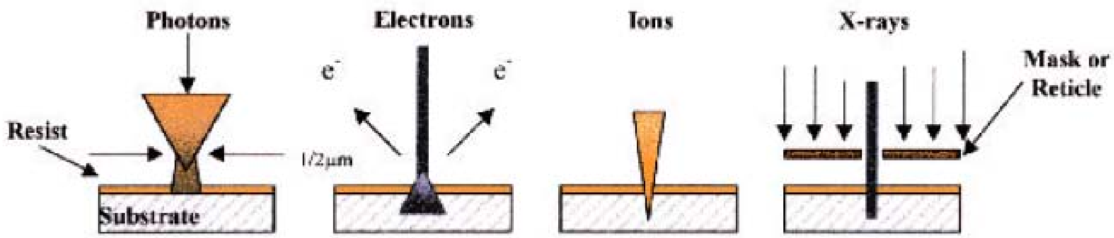

FIGURE 2.16.1: Lithography methods compared.

In terms of ultimate attainable resolution, the borderline between the different technologies is quite fuzzy. Optical lithography is considered impossible for a design rule of less than 45 nm. For deep sub-micrometer CDs, extreme UV, electron beam, and x-ray lithography are three options. Extreme ultraviolet (EUV) lithography is a strong candidate for achieving critical dimensions of 32 nm and below. This approach uses the same principle of conventional optical-projection lithography, enables flood exposure, and obeys Rayleigh's criterion. With an exposure wavelength in the range of 11–13 nm, this suggests CDs of 32 nm and below. With x-rays flood exposure is possible as well but perfect x-ray masks are difficult to make. Narrow beam electron- and ion-lithography can both produce features much smaller than 0.1 micron, but these methods are unable to manufacture a sufficient volume of chips to be economical. Prospects to improve throughput of these high-resolution techniques are scattering angular-limited projection electron-beam lithography (SCALPEL) and ion-projection lithography (IPL). Of the two methods SCALPEL is the more advanced. It uses a projection optical system that is geometrically equivalent to that used in optical lithography: the image of an arbitrary circuit is projected from a mask. IPL, in which the e-beam is replaced by an ion beam, is conceptually related to SCALPEL. In IPL a uniform, collimated beam of light ions (H^+, H^+_2, H_3^+, or He^+) back illuminates a stencil mask. The image of this stencil mask is projected through a series of electrostatic lenses and demagnified onto the substrate. IPL operates under vacuum and uses ions instead of photons to expose the mask features onto a resist-coated wafer. In principle, the much higher mass of ions should result in imaging capabilities that are less prone to distortions due to backscattering from the substrate. But high-resolution ion-beam systems remain in a primitive state of development compared to that of electron-beam systems.

Summary Table

	UV	**X-Ray**	**Ion lithography**	**Electron lithography**
Flood exposure	Yes	Yes	Mostly narrow beam but projection lithography is also possible (see IPL)	Mostly narrow beam but projection lithography is also possible (see also SCAPLEL)
Environment	Air	Vacuum/Air	Vacuum	Vacuum
Cost	Low for DUV but very high for EUV	Very high	Very high	Medium for direct write; very high for projection
Optics	Diffractive and catadioptric for DUV and reflective for EUV	None. Diffraction is not an issue but shadowing is (penumbral blurring)	Electrostatic lenses. No diffraction limit and better resolution than e-beam because there is no	Electrostatic lenses. No diffraction but backscattering and secondary electrons
CDs	45 nm for DUV; 32 nm and below for EUV	32 nm and below	32 nm and below	32 nm limited by backscattering
Mask	4 X	1 X	4 X	4 X
Exposure tool	Lamp or laser for DUV and laser plasma source for EUV	Synchrotron source	Multicusp ion source	Filament source

Current lithography practice. In industry UV lithography is still used most of the time. Electron-beam is used for mask making and x-ray is a very distant third in lithography. EUV is now widely seen as the next-generation lithography. Ion-beam lithography is used mostly in R&D settings.

Energy sources. DUV exposure tools are UV lamps or lasers. X-ray exposure tools are synchrotrons, electron impact x-ray sources, and plasma heated x-ray sources (laser or e-beam heated). Electron sources include thermionic emitters where electrons are “boiled” off the surface by giving them thermal energy to overcome the surface barrier (work function), and field emitters take advantage of the quantum mechanical properties of electrons that tunnel out when the surface barrier becomes very narrow. Finally in photo emitters energy to escape the surface of an emitter is provided by incident photons. A number of sources of EUV radiation have been used to date in the development of EUVL. Radiation has been obtained from a variety of laser-produced plasmas and from the bending magnets and the undulators associated with synchrotrons. Eventually a source will be required that reliably provides sufficient power to yield adequate wafer throughput in a manufacturing tool. Ion-beam sources are typically multicusp ion sources, as shown in Figure 2.16.2.

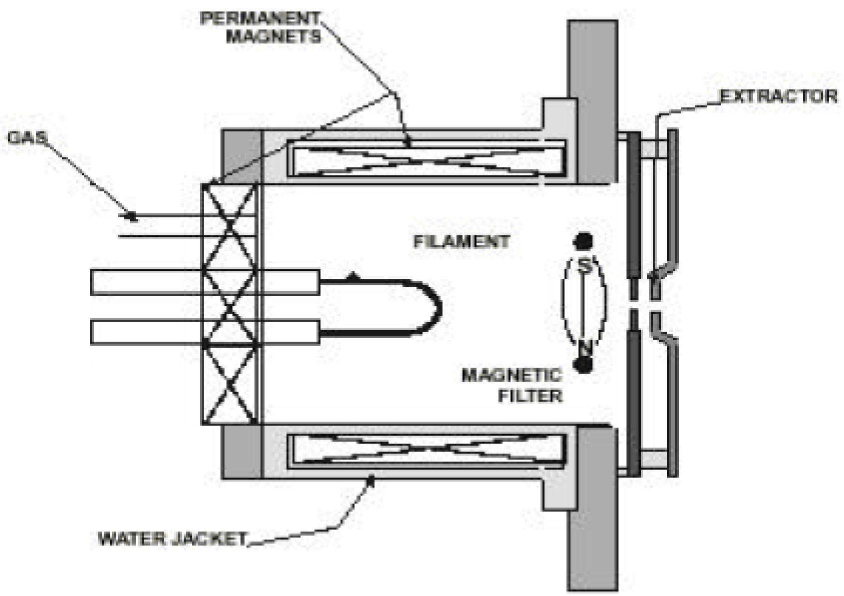

FIGURE 2.16.2: Schematic diagram of a multicusp ion source with a planar magnetic filter

2.17:
Most lithographies provide projected shapes. A truly 3D shape (e.g., a contact lens) is harder to make. Which lithographies are capable of providing 3D shapes?

Answer:
Laser and electron- or ion-beams with a high-precision linear and rotary positioning stage have the capability of generating 3D photoresist shapes. Stereo-lithography also can make 3D shapes and soft lithography can be used to pattern non-flat surfaces.

2.18:
How could one make scanning tunneling microscopy (STM) into a mass production ready lithography technique? What type of resists would you use?

Answer:
One might use a massive parallel array of STM tips so one can increase the throughput of the technique. Usable resists are e-beam resists and also includes amorphous silicon, very thin resist layers, and self assembled monolayers (SAMs).

2.19:
Compare masks for the next-generation lithography. Consider the need for vacuum, materials, feature size, cost, etc.

Answer:

	EPL (e.g., SCALPEL)	EUV	IPL	X-Ray
Masks	Projection	Reflective	Projection	Proximity and also Fresnel

				lenses are possible
Feature size	> 10 nm	> 10 nm	Smallest 1-10 nm	< 10 nm
Cost	Expensive	Cheaper due to present infrastructure	Expensive	Most expensive
Vacuum	Needed	Not needed	Needed	Not needed

2.20:
What are the advantages and disadvantages of using e-beam lithography compared to typical photolithography?

Answer:
There are several advantages associated with e-beam lithography compared to photolithography:

1. No physical mask is required
2. Higher resolution
3. Good depth of focus
4. Could even write on non-planar substrates

Disadvantages are:

1. It is a serial slow technique
2. Needs a vacuum to operate

2.21:
What difficulties do you expect in trying to implement immersion lithography commercially?

Answer:
Finding a transparent liquid that has a high refractive index (>>1) and does not contaminate or corrode is a first challenge. Add to this the cost and complexity of the exposure equipment which must maintain a stagnant thin film of liquid below a fast moving lens in order to achieve high throughput while maintaining a high resolution image.

Chapter: 3 Dry Etching

3.1:
How is a dc plasma created, and how does an rf plasma differ? Why is a plasma always positive with respect to the reactor vessel walls? In which etching setup would you prefer to etch an insulator?

Answer:
Ac and dc plasmas. A dc plasma is created by applying a dc bias between two conductive electrodes in a reaction chamber filled with an inert gas such as argon at a reduced pressure. Electrical breakdown of the argon gas in this reactor occurs when electrons, accelerated in the existing field, ionize an argon atom generating a second free electron and a positive ion for each successful strike. Both free electrons