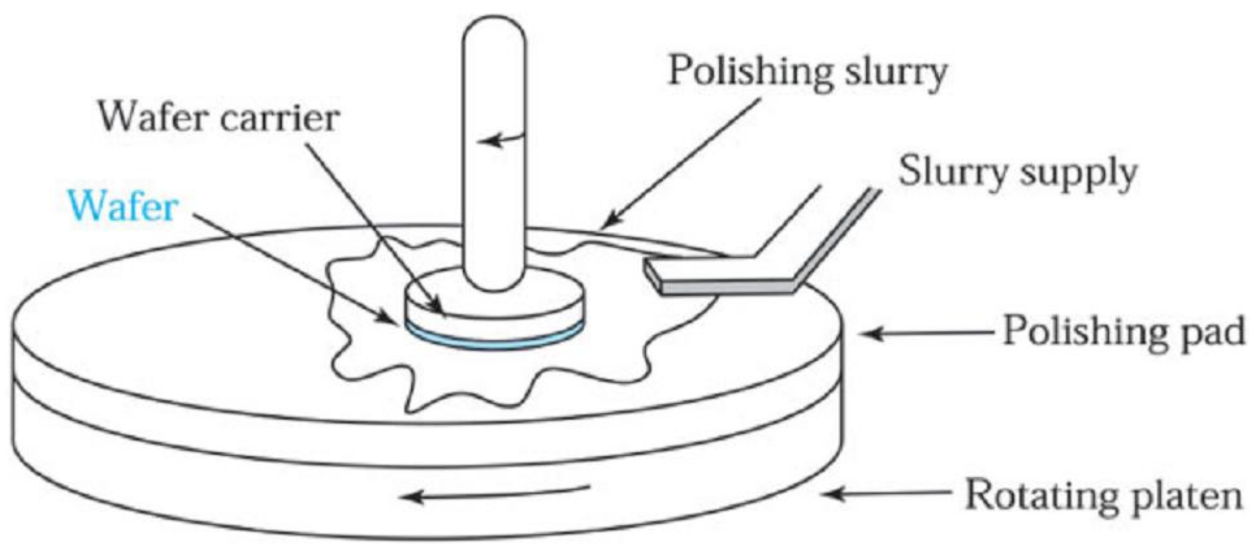
Chemical-Mechanical Polishing (2)

- Mechanical grinding alone can theoretically achieve the desired planarization but is not desirable because of extensive associated damage to the material surfaces
- There are three main parts of the process: the surface to be polished, the pad—the key medium enabling the transfer of mechanical action to the surface being polished—and the slurry, which provides both chemical and mechanical effects
- Figure shows

  CMP Polisher



Lithography and Etching

Semiconductor Devices – Physics and Technology

Chapter 13

Introduction

- Lithography is the process of transferring patterns of geometric shapes on a mask to a thin layer of radiation sensitive material (called resist) covering the surface of a semiconductor wafer
- These patterns define the various regions in an integrated circuit such as the implantation regions, the contact windows, and the bonding-pad areas
- The resist patterns defined by the lithographic process are not permanent elements of the final device but only replicas of circuit features. To produce circuit features, these resist patterns must be transferred once more into the underlying layers comprising the device
- The pattern transfer is accomplished by an etching process that selectively removes unmasked portions of a layer

Optical Lithography

- The vast majority of lithographic equipment for IC fabrication is optical equipment using ultraviolet light ($\lambda \cong 0.2–0.4$ μm)
- The pattern transfer process is accomplished by using lithographic exposure equipment
- The performance of exposure equipment is determined by three parameters: resolution, registration, and throughput
- Resolution is the minimum feature dimension that can be transferred with high fidelity to a resist film on a semiconductor wafer
- Registration is a measure of how accurately patterns on successive masks can be aligned (or overlaid) on previously defined patterns on the wafer
- Throughput is the number of wafers that can be exposed per hour for a given mask level

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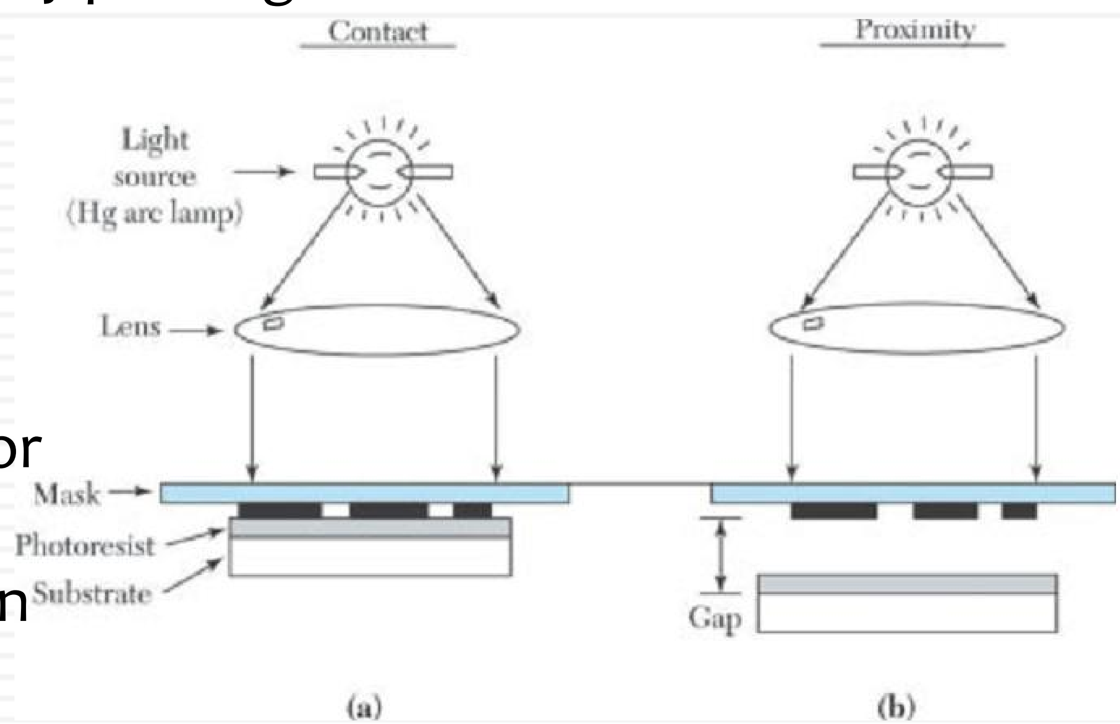
Shadow Printing

- There are basically two optical exposure methods: shadow printing and projection or proximity printing
- Shadow printing may have the mask and wafer in direct contact with each other as in contact printing, or in close proximity as in proximity printing
- The intimate contact between resists and mask provides a resolution of ~1 μm
- However, contact printing suffers a major drawback caused by dust particles between the mask and wafer



Projection Printing

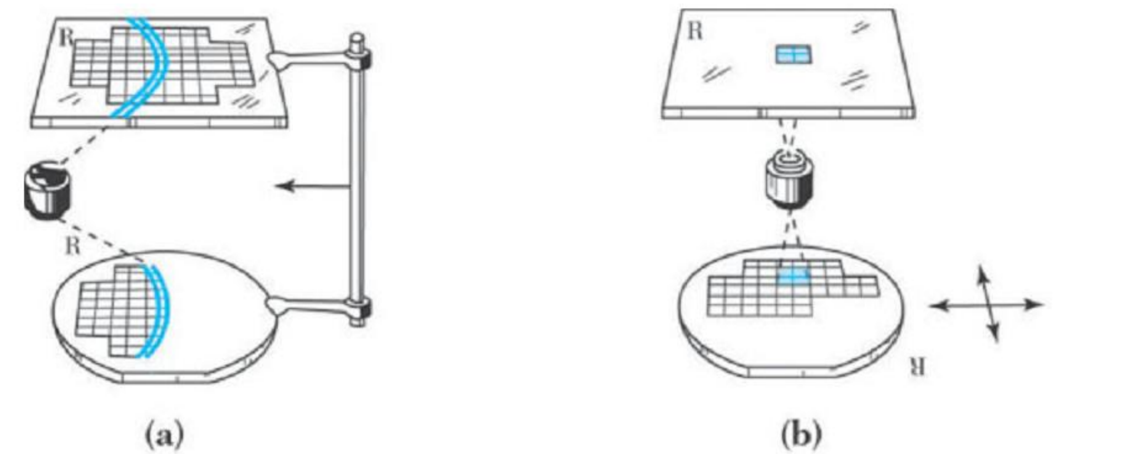
- To avoid the mask damage problem associated with shadow printing, projection-printing exposure equipment has been developed to project an image of the mask patterns onto a resist-coated wafer many centimeters away from the mask
- In projection printing, the minimum linewidth [or critical dimension (CD)] that can be printed is roughly

$$\mathrm{CD} \cong \sqrt{\lambda g},$$

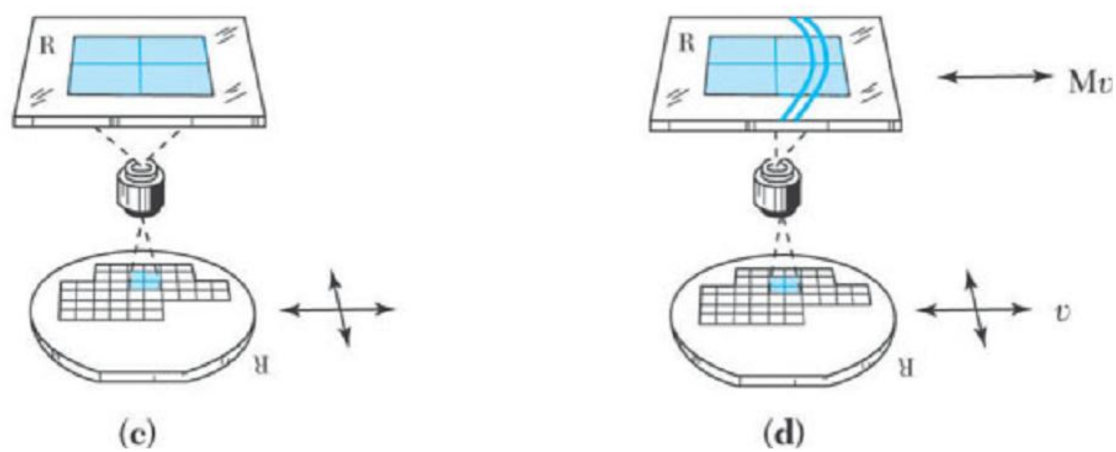
where λ is the wavelength of the exposure radiation and g is the gap between the mask and wafer including the thickness of the resist

- To increase resolution, only a small portion of the mask is exposed at a time, allowing a uniform source of light
- The small image area is scanned or stepped over the wafer to cover the entire wafer surface.

Projection Printing Techniques



annual-field wafer scan 1:1 step-and-repeat



M:1 reduction step-and repeat M:1 reduction step-and-scan

Masks

- The first step in mask making is to use a computer-aided design (CAD) system in which designers can completely describe the circuit patterns electrically
- The digital data produced by the CAD system then drives a pattern generator, which is an electronbeam lithographic system that transfers the patterns directly to electron-sensitized mask
- The mask consists of a fused silica substrate covered with a chrominum layer
- The circuit pattern is first transferred to the electron-sensitized layer (electron resist), which is transferred once more into the underlying chrominum layer for the finished mask
- The patterns on a mask represent one level of an IC design
- The composite layout is broken into mask levels that correspond to the IC process sequence such as the isolation region on one level, the gate region on another, and so on
- Typically, 15–20 different mask levels are required for a complete IC process cycle

Masks (2)

- One of the major concerns about masks is the defect density
- Mask defects can be introduced during the manufacture of the mask or during subsequent lithographic processes
- Even a small mask-defect density has a profound effect on the final IC yield
- The yield is defined as the ratio of good chips per wafer to the total number of chips per wafer
- As a first-order approximation, the yield Y for a given masking level can be expressed as $Y \simeq e^{-DA}$,

where D is the average number of "fatal" defects per unit area and A is the area of an IC chip

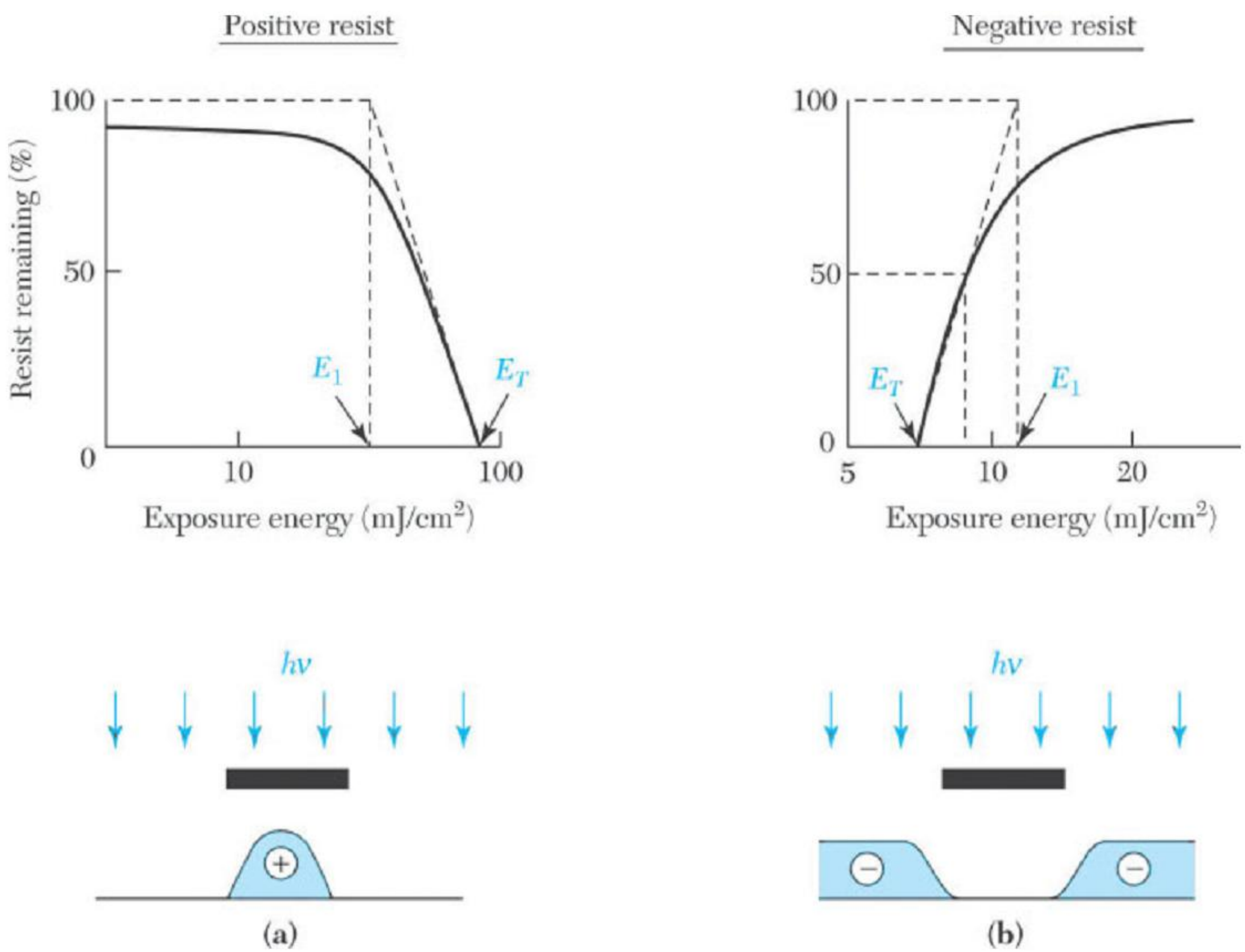
- If D remains the same for all mask levels (e.g., N = 10 levels), then the final yield becomes $Y \simeq e^{-NDA}$.

Photoresist

- The photoresist is a radiation-sensitive compound
- Photoresists are classified as positive and negative, depending on how they respond to radiation
- For positive resists, the exposed regions become more soluble and thus more easily removed in the development process
- The net result is that the patterns formed (also called images) in the positive resist are the same as those on the mask
- For negative resists, the exposed regions become less soluble, and the patterns formed in the negative resist are the reverse of the mask patterns

Photoresist (2)

- Figure shows a typical exposure response curve and image cross section for a positive and negative resist
- The response curve describes the percentage of resist remaining after exposure and development versus the exposure energy



Photoresist (3)

- As the exposure energy increases, the solubility gradually increases until at a threshold energy E_T, the resist becomes completely soluble
- The sensitivity of a positive resist is defined as the energy required to produce complete solubility in the exposed region
- Thus, E_T corresponds to the sensitivity
- In addition to E_T, a parameter γ, the contrast ratio, is defined to characterize the resist:

$$\gamma \equiv \left[\ln\left(\frac{E_T}{E_1} \right) \right]^{-1},$$

where E_1 is the energy obtained by drawing the tangent at E_T to reach 100% resist thickness

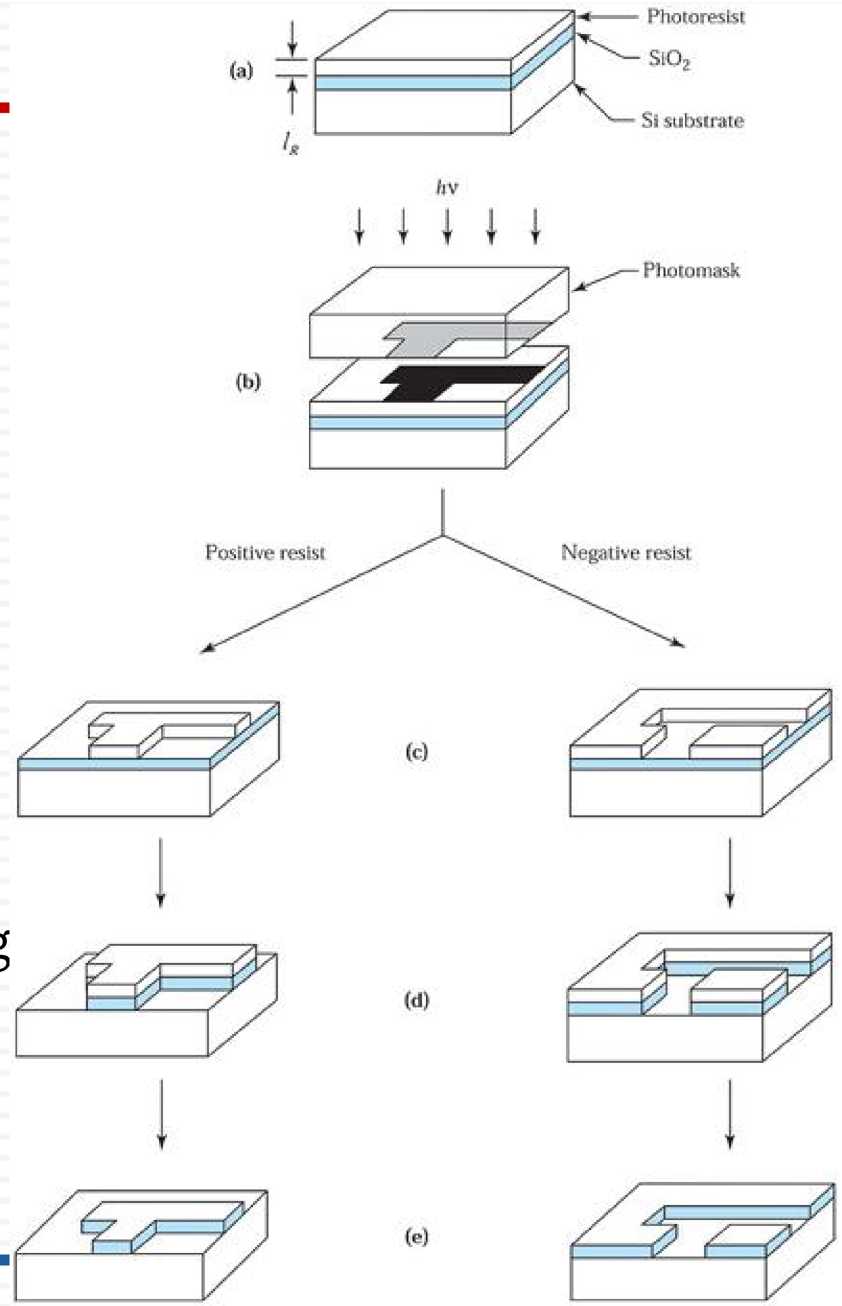
- A larger γ implies a higher solubility of the resist with an incremental increase of exposure energy and yields sharper images
- The edges of the resist image are generally not at the vertically projected positions of the mask edges because of diffraction

Pattern Transfer

- Procedures for pattern transfer are:

a) Application of resist
b) Resist exposure through the mask
c) Development of resist
d) Etching of SiO_2
e) Removal of resist

- Photoresist can be stripped with either:
  - Wet Photoresist stripping using strong acid (liquid)
  - Dry Photoresist stripping using either oxygen plasma, Ozone, ultraviolet

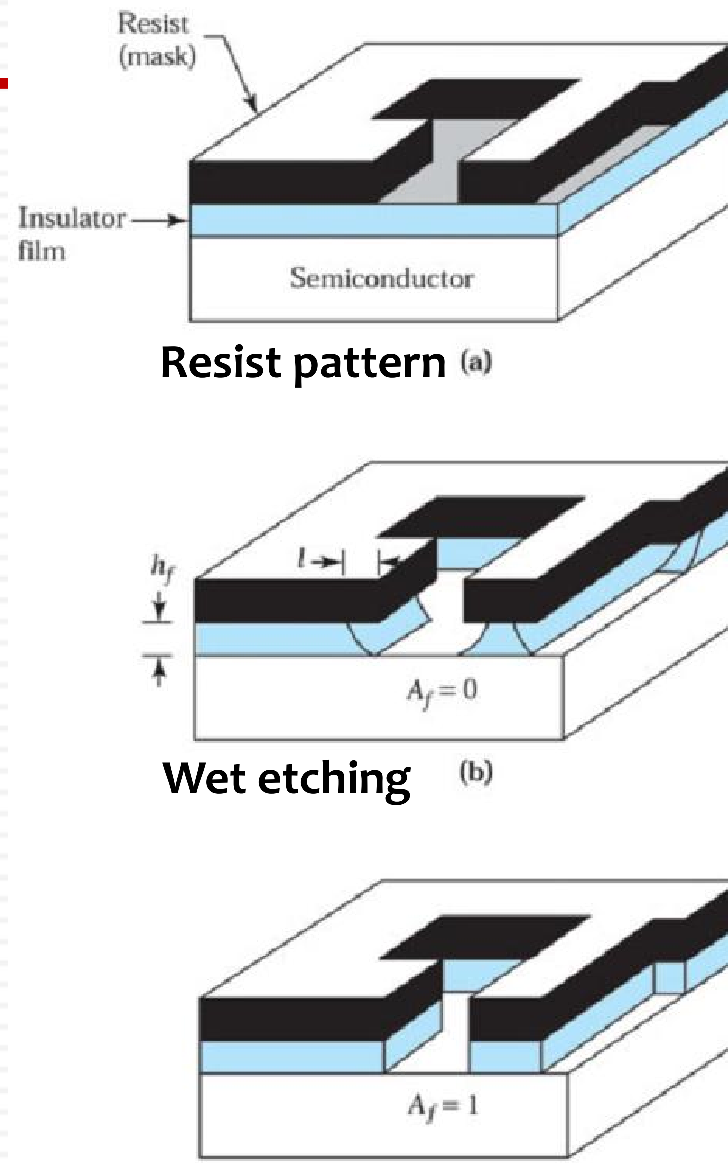


Wet Chemical Etching

- Etching is the process of selectively removing a material on the surface and it can also be used for lapping and polishing the whole surface
- The mechanisms for wet chemical etching involve three essential steps:
  - the reactants are transported by diffusion to the reacting surface,
  - chemical reactions occur at the surface,
  - and the products from the surface are removed by diffusion
- Etch rates must be uniform across a wafer, from wafer to wafer, from run to run, and for any variations in feature sizes and pattern densities
- For semiconductor materials, wet chemical etching usually starts with oxidation followed by dissolution of the oxide by a chemical reaction
- Different etchants are used for Silicon, SiO_2, Silicon Nitride, and Aluminum etching
- The etching rate varies with etchant concentration, temperature, surface orientation, and the etched material.

Dry Etching

- In pattern-transfer operations, a resist pattern is defined by a lithographic process to serve as a mask for etching of its underlying layer
- Most of the layer materials (e.g., SiO_2, Si_3N_4, and deposited metals) are amorphous or polycrystalline thin films
- If they are etched in a wet chemical etchant, the etch rate is generally isotropic (i.e., the lateral and vertical etch rates are the same), as illustrated in Figure.



Resist pattern (a)

Wet etching (b)

Dry etching (c)

Dry Etching (2)

- The major disadvantage of wet chemical etching for pattern transfer is the undercutting of the layer underneath the mask, resulting in a loss of resolution in the etched pattern
- In practice, for isotropic etching, the film thickness should be about one-third or less of the resolution required
- If patterns are required with resolutions much smaller than the film thickness, anisotropic etching must be used
- To achieve high-fidelity transfer of the resist patterns required for ultra large-scale integration processing, dry etching methods have been developed
- Dry etching is synonymous with plasma-assisted etching, which denotes several techniques that use plasma in the form of low-pressure discharges