Course Title: Processing & Fabrication Technology
Course No.: EEE 707

Class lecture -4

Introduction to Etching

Etching

- In Lithography technique, photo resist covering the surface of a semiconductor wafer. To produce circuit features, these resist patterns must be transferred into the underlying layers comprising the device. The pattern transfer is accomplished by an etching process that selectively removes unmasked portions of a layer.
- Simply, Etching is used to remove material from wafer.

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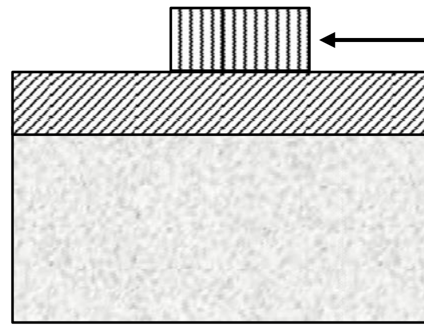
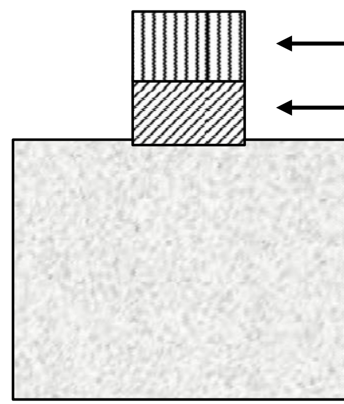
Etching…

Photo resist development



Etching



Material is removed from the areas of the wafer that are not covered by the photo-resist through etching process.

Etching Techniques

Two types of etching usually performed:

(i) Wet etching

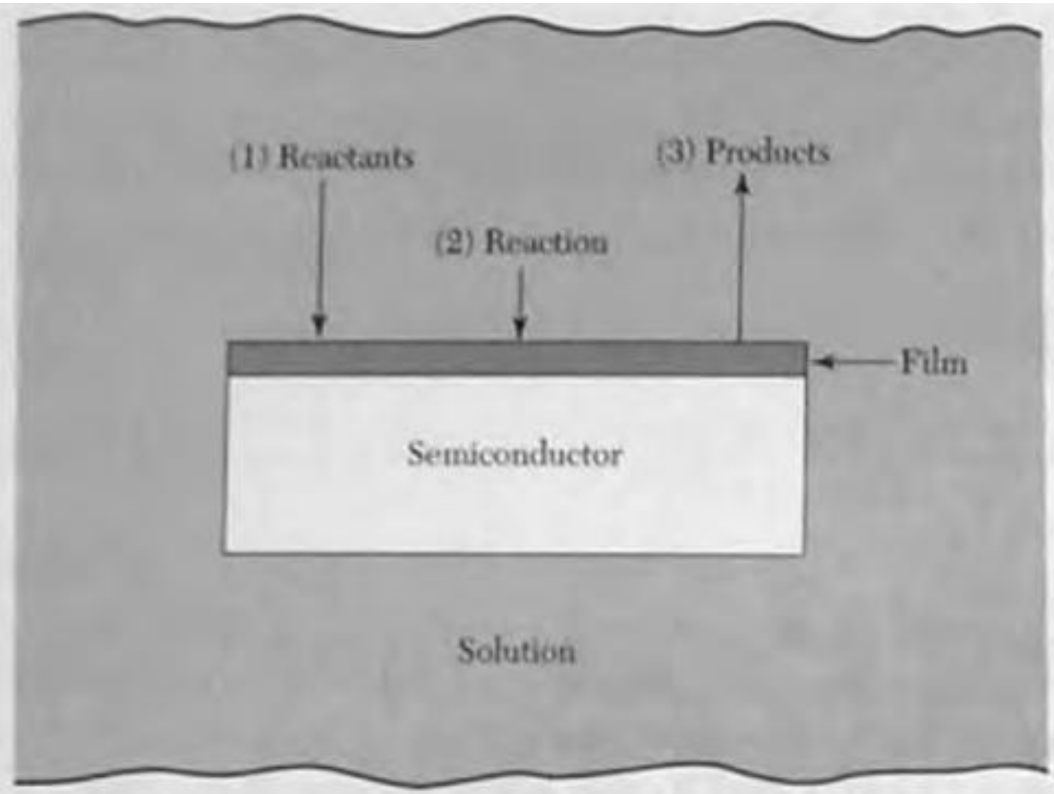
(ii) Dry etching

- Also called Plasma-assisted etching or Reactive Plasma etching or Plasma etching

Wet etching

- Wet etching is used extensively in semiconductor processing such as in wafers sliced from an ingot, in thermal oxidation or in epitaxial growth.
- Wet etching is especially suitable for blanket etches (i.e. over the whole wafer surface) of polysilicon, oxide, nitride, metals and III-V compounds.

Wet etching...



Basic mechanisms in wet etching

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. Both agitation and the temperature of the etchant solution influence the etch rate, which is the amount of film removed by etching per unit time.

Wet etching...

- In IC processing, most wet etches proceed by immersing the wafers in a chemical solution or by spraying the wafers with the etchant solution.
- For immersion etching, the wafer is immersed in the etch solution and mechanical agitation is usually required to ensure etch uniformity and a consistent etch rate.
- Spray etching has gradually replaced immersion etching because it greatly increases the etch rate and uniformity by constantly supplying fresh etchant to the wafer surface.

Wet etching...

Silicon Etching

- For semiconductor materials, wet etching usually proceeds by oxidation, followed by the dissolution of the oxide by a chemical reaction.
- For Silicon, the most common used etchants are mixtures of nitric acid (HNO_3) and hydrofluoric acid (HF) in water or acetic acid (CH_3COOH). Nitric acid oxidizes silicon to form a SiO_2 layer. The oxidation reaction is

$$Si + 4HNO_3 \rightarrow SiO_2 + 2H_2O + 4NO_2$$

- Hydrofluoric acid is used to dissolve the SiO_2 layer. The reaction is

$$SiO_2 + 6HF \rightarrow H_2SiF_6 + 2H_2O$$

Wet etching...

- Water can be used as diluent for this etchant. However, acetic acid is preferred because it reduces the dissolution of the nitric acid.

Silicon Dioxide Etching

- For instance, hydrochloric (HCl) acid buffered with ammonium fluoride (NH_4F) is typically used to etch SiO_2.

Dry Etching

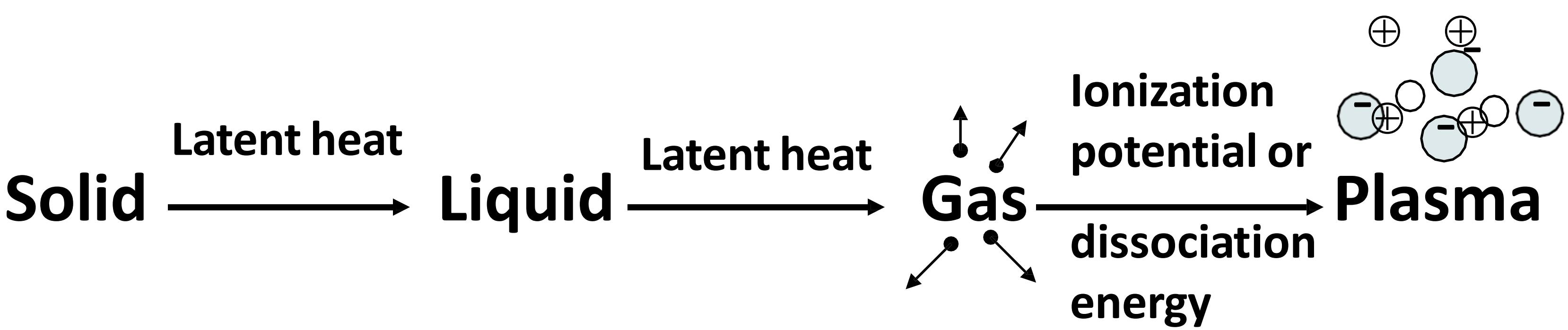
- The major disadvantage of wet etching in pattern transfer is the undercutting of the layer underneath the mask, resulting in a loss of resolution in the etched pattern.
- To achieve a high-fidelity transfer of the resist patterns required for ultralarge-scale integration (ULSI) processing, dry etching methods have been developed.
- Dry etching also known as Plasma-assisted etching or Reactive Plasma etching or Plasma etching.

Comparison between Wet and Dry Etching

	Wet	Dry
Method	Chemical Solutions	Ion Bombardment or Chemical Reactive
Environment and Equipment	Atmosphere, Bath	Vacuum Chamber
Advantage	1) Low cost, easy to implement 2) High etching rate 3) Good selectivity for most materials	1) Capable of defining small feature size (< 100 nm)
Disadvantage	1) Inadequate for defining feature size < 1um 2) Potential of chemical handling hazards 3) Wafer contamination issues	1) High cost, hard to implement 2) low throughput 3) Poor selectivity 4) Potential radiation damage
Directionality	Isotropic (Except for etching Crystalline Materials)	Anisotropic

Plasma Fundamentals

- Plasma State is the 4th state & dominant form of matters and 99% of the Universe is in Plasma State.
- Plasma is the mixture of electrons, positive & negative ions, neutral atoms & molecules and excited species.
- It is electrically neutral but a good conductor of electricity.



Plasma Fundamentals…

- A plasma is produced when an electric field of sufficient magnitude is applied to a gas, causing the gas to break down and become ionized.
- The plasma is initiated by free electrons that are released by some means, such as field emission from a negatively biased electrode.
- The free electrons gain kinetic energy from the electric field. In the course of their travel through the gas, the electrons collide with gas molecules to be ionized (i.e. to free electrons).
- The free electrons gain kinetic energy from the field, and the process continues. Therefore, when the applied voltage is larger than the breakdown potential, a sustained plasma is formed throughout the reaction chamber.

Plasma Fundamentals…

- The electron concentrations in the plasma for dry etchings are relatively low, typically on the order of 10^9 to 10^{12} cm^{-3}. At a pressure of 1 Torr, the concentrations of gas molecules are 10^4 to 10^7 times higher than the electron concentrations. This results in an average gas temperature in the range of 50^0C to 100^0C. Therefore, plasma-assisted dry etching is a low- temperature process.

How does Plasma sustain?

When external field is applied, electrons receive energy from the external field and translate the energy to gas species through inelastic collisions processes (dissociation, excitation, ionization, secondary ionization)

The following processes increase the species density in the plasma.

$AB + e \rightarrow A + B + e$ Dissociation

$AB + e \rightarrow A^- + B^+ + e$ Dissociative attachment

$A + e \rightarrow A^+ + 2e$ Ionization

The following processes decrease the species density in the plasma.

$A^- + B^+ \rightarrow A + B$ Ion-Ion recombination

$A^+ + e \rightarrow A$ Electron-ion recombination

When dynamic equilibrium reached (number of charged particles remains constant) the plasma is to be self-sustained.

Classification of Plasmas

- ***Based on particle density and distribution:***

1. Low pressure non-equilibrium plasmas
2. Atmospheric pressure non-equilibrium plasmas
3. High pressure equilibrium plasmas

- ***Based on generation techniques:***

1. Induction plasmas
2. Capacitively coupled plasmas
3. Arc plasmas (DC and AC)
4. Microwave plasmas
5. Dielectric barrier discharge etc.

Induction Plasma

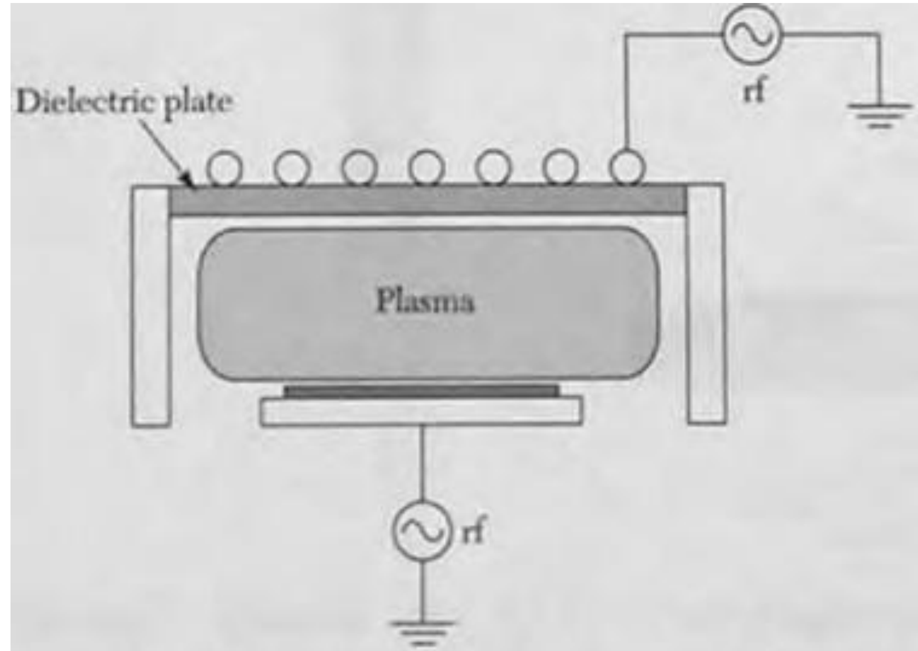
Induction plasma is a widely used plasma discharge due to some of its features. It offers several unique advantages over ARC plasma and other types of plasmas.

Advantages of Induction Plasmas:

- It is an electrodeless contamination free discharge, thus, very clean.
- It has several application in material processing.
- Highly chemically reactive.
- No corrosion and damage of apparatus, thus provide long lifetime of apparatus.
- It can be sustained over a wide rage of pressure i.e pressure variation can be possible (e.g- soft vacuum to several atm)
- It is a High-enthalpy and highly radiative plasma source.

Induction Plasma…

- A high-density, low pressure plasma is generated by a flat spiral coil that is separated from the plasma by a dielectric on the top of the reactor. The wafer is located away from the coil, so it is not affected by the electromagnetic filed generated by the coil. There is little plasma density loss because plasma is generated only a few mean free paths away from the wafer surface. Therefore, a high-density plasma and high etch rates are achieved.



Schematic of an induction plasma reactor

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Plasma Chemistry in Etching

- CF_4-O_2 Plasma is used to etch Si or SiO_2
- But, when Only CF_4-O_2 Plasma is used no appreciable etching occurs. Because, Atomic F is active etchant for Si and SiO_2 by the formation of volatile SiF_4 and O_2.

$$Si + 4F \rightarrow SiF_4 \uparrow$$

$$SiO_2 + 4F \rightarrow SiF_4 \uparrow + O_2 \uparrow$$

- CF_4 continuously undergoes dissociative collisions to form CF_X ($x \leq 3$) and F. At the same time recombination of these species occurs. Thus, concentration of F atoms is directly related to the difference of rate of two reactions.

Effects of O_2 and H_2 addition on etching rate

Effects of O_2 addition:

- Addition of O_2 to the plasma leads to formation of COF_2, CO and CO_2, which decreases the concentration of CF_x thereby decreasing the CF_x-F recombination rate.
- Thus, concentration of F atoms increases with the addition of O_2 and hence the etching rate increases.

Effects of O_2 and H_2 addition on etching rate…

Effects of H_2 addition:

$CF_x + Si \rightarrow C + SiF_y$

The reaction of C on the etching surface with F and/or H results in fluorocarbons and hydrocarbons, which polymerize on the Si surface, which reduces the etching rate.

In case of SiO_2, no polymerization occurs and in etching, H_2 addition does not have significant effect.

$CF_x + SiO_2 \rightarrow SiF_y + (CO, CO_2)$