INRF BiON

Etching

Physical vs. Chemical Etching

(Dry vs. Wet Etching)

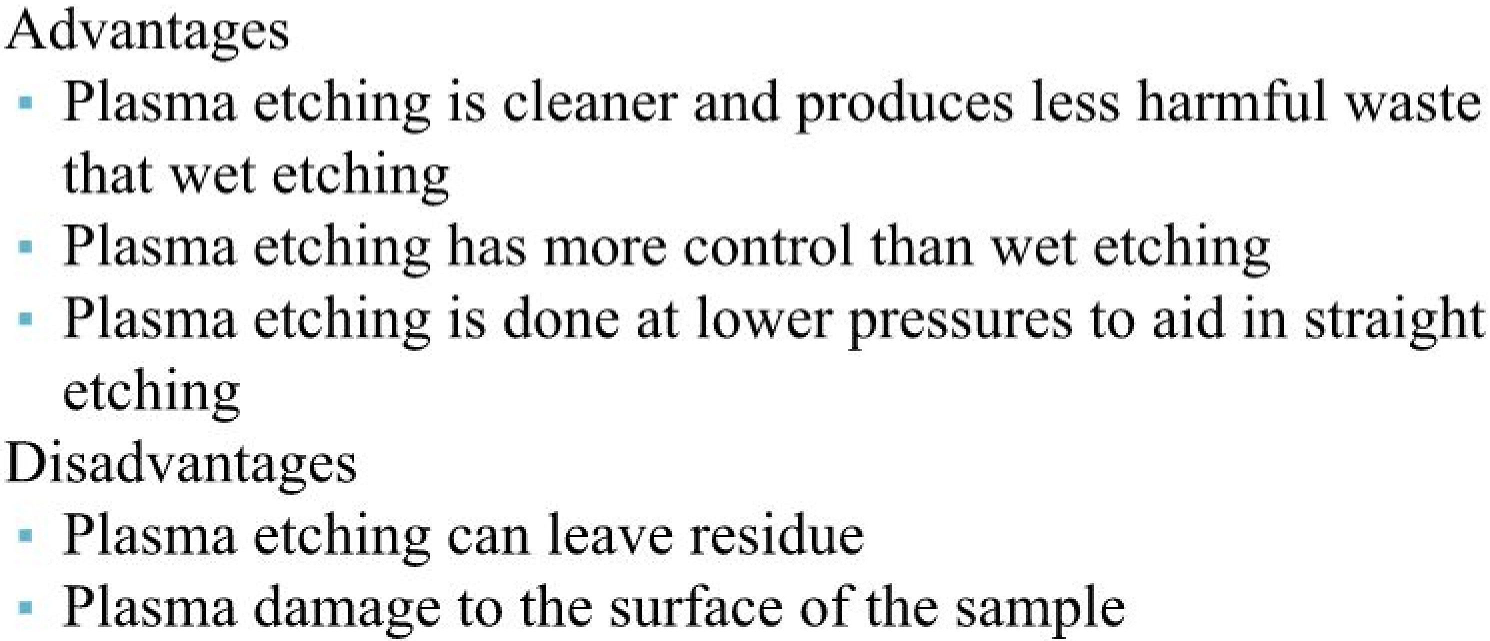
Plasma etching is a form of plasma processing used to fabricate integrated circuits. It involves a high-speed stream of glow discharge (plasma) of an appropriate gas mixture being shot (in pulses) at a sample. The plasma source, known as etch species, can be either charged (ions) or neutral (atoms and radicals). During the process, the plasma will generate volatile etch products at room temperature from the chemical reactions between the elements of the material etched and the reactive species generated by the plasma. Eventually the atoms of the shot element embed themselves at or just below the surface of the target, thus modifying the physical properties of the target.

Wet etchants are usually isotropic, which leads to large bias when etching thick films. They also require the disposal of large amounts of toxic waste. For these reasons, they are seldom used in state-of-the-art processes. However, the photographic developer used for photoresist resembles wet etching.

Different specialised etchants can be used to characterise the surface etched.The first etching processes used liquid-phase ("wet") etchants. The wafer can be immersed in a bath of etchant, which must be agitated to achieve good process control. For instance, buffered hydrofluoric acid (BHF) is used commonly to etch silicon dioxide over a silicon substrate.

- Physical Etching
  - Bombardment of ions on the surface of the sample
- Chemical Etching
  - Reaction of ions with surface bonds molecules together, extracting them off the lattice

Plasma vs. Wet Etching



Advantages

- Plasma etching is cleaner and produces less harmful waste that wet etching
- Plasma etching has more control than wet etching
- Plasma etching is done at lower pressures to aid in straight etching

Disadvantages

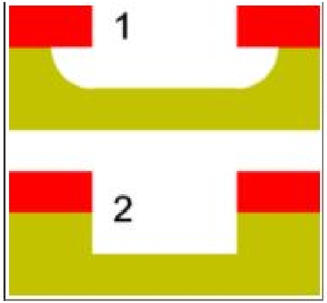
- Plasma etching can leave residue
- Plasma damage to the surface of the sample

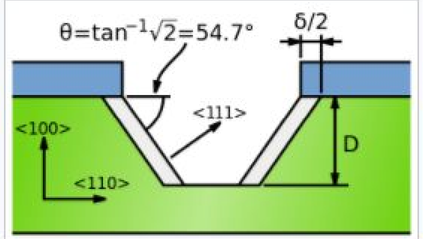
Mask

For many etch steps, part of the wafer is protected from the etchant by a "masking" material which resists etching. In some cases, the masking material is a photoresist which has been patterned using photolithography. Other situations require a more durable mask, such as silicon nitride.

Isotropic vs. Anisotropic

- Isotropic etching is non-directional etching, typically associated with large undercut etching.
  - Wet etching is mostly isotropic etching.
- Anisotropic etching is directional etching, typically yields identical etching across a wafer as well as repeatable results.
  - Dry etching is mostly anisotropic etching.

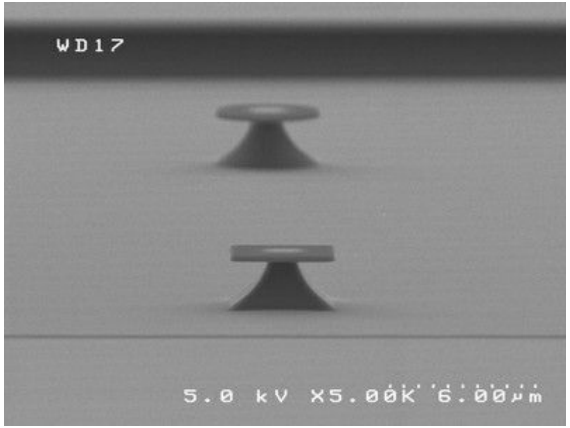
Isotropy	 	Red: masking layer; yellow: layer to be removed 1. A perfectly isotropic etch produces round sidewalls. 2. A perfectly anisotropic etch produces vertical sidewalls.

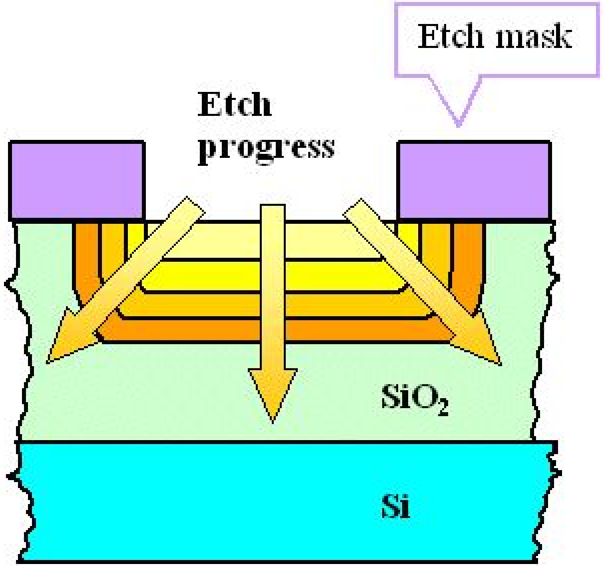


An anisotropic wet etch on a silicon wafer creates a cavity with a trapezoidal cross-section. The bottom of the cavity is a {100} plane (see Miller indices), and the sides are {111} planes. The blue material is an etch mask, and the green material is silicon.

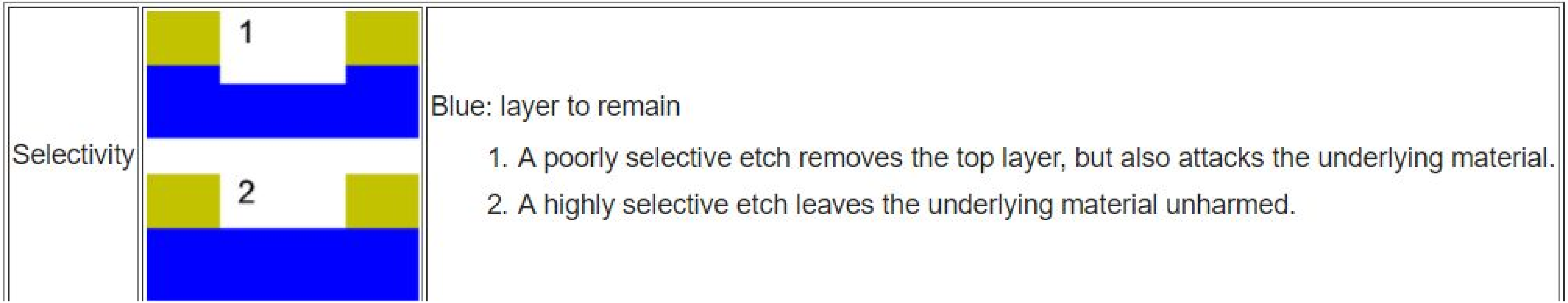
Isotropic vs. Anisotropic

- Isotropic– etch rate is same in all directions
- Anisotropic– etch rate is orientation dependent

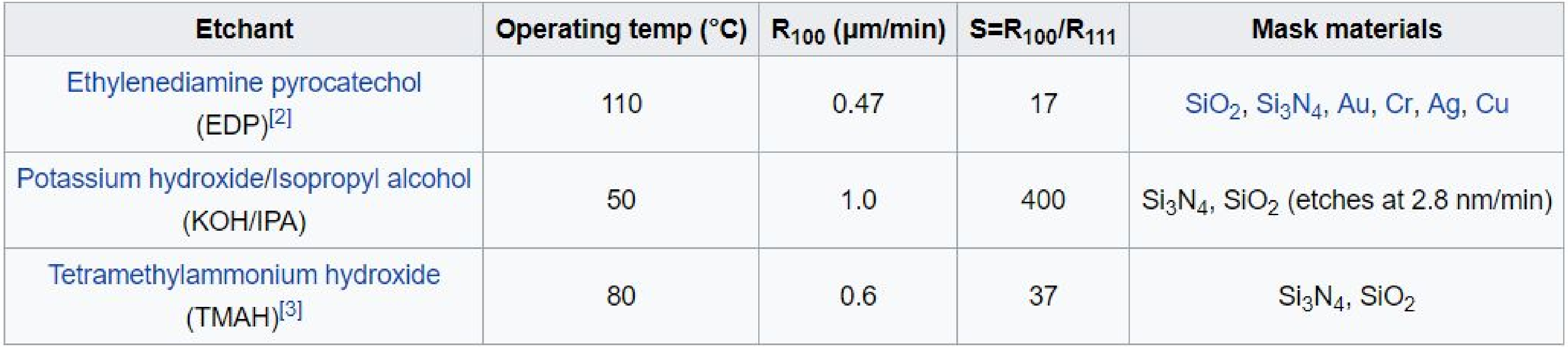




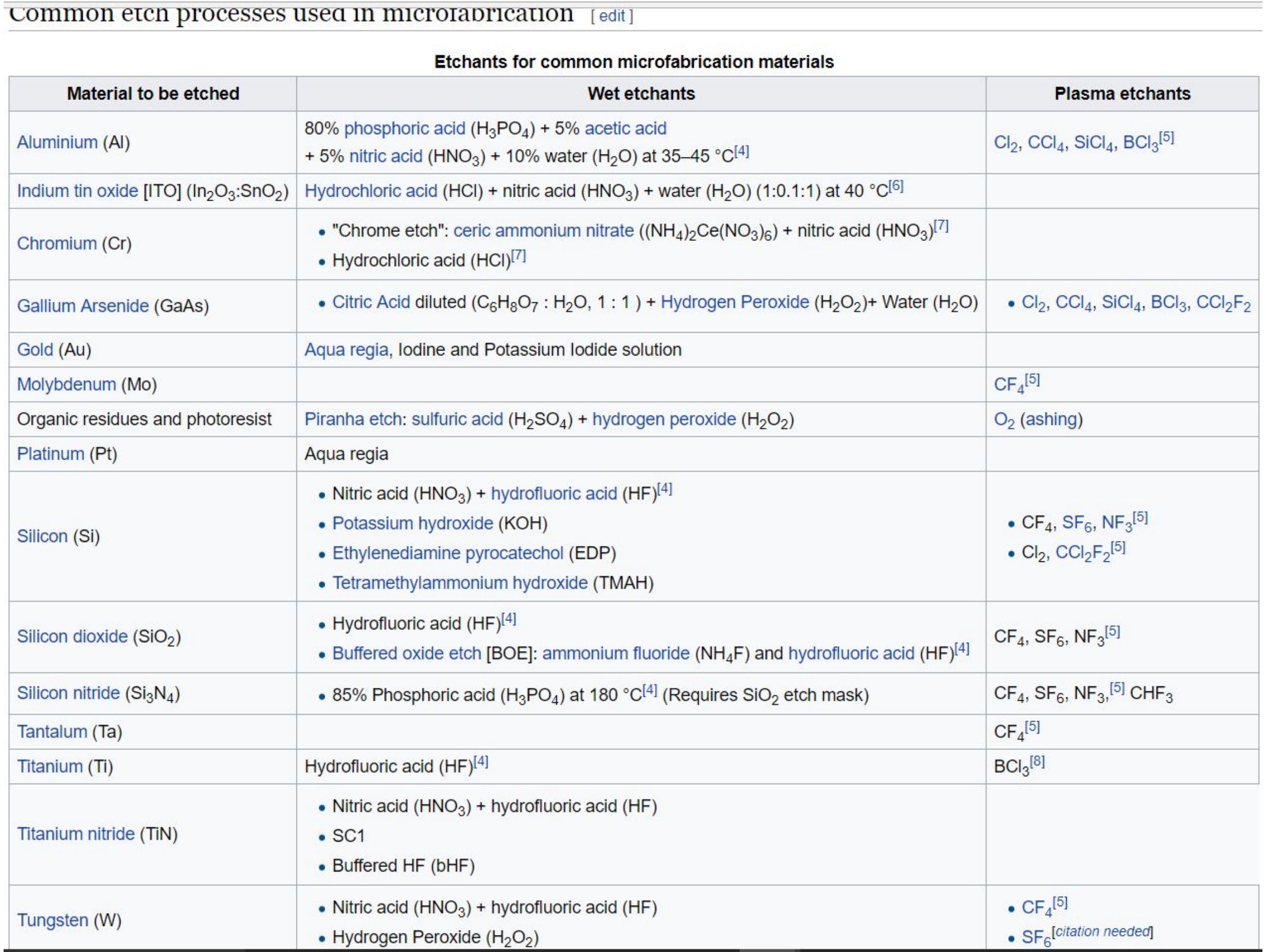
Selectivity



Selectivity		Blue: layer to remain 1. A poorly selective etch removes the top layer, but also attacks the underlying material. 2. A highly selective etch leaves the underlying material unharmed.



Etchant	Operating temp (°C)	R_{100} (μm/min)	$S=R_{100}/R_{111}$	Mask materials
Ethylenediamine pyrocatechol (EDP)[2]	110	0.47	17	SiO_2, Si_3N_4, Au, Cr, Ag, Cu
Potassium hydroxide/Isopropyl alcohol (KOH/IPA)	50	1.0	400	Si_3N_4, SiO_2 (etches at 2.8 nm/min)
Tetramethylammonium hydroxide (TMAH)[3]	80	0.6	37	Si_3N_4, SiO_2



Common etch processes used in microfabrication [edit]

Etchants for common microfabrication materials

Material to be etched	Wet etchants	Plasma etchants
Aluminium (Al)	80% phosphoric acid (H_3PO_4) + 5% acetic acid + 5% nitric acid (HNO_3) + 10% water (H_2O) at 35–45 °C[4]	Cl_2, CCl_4, $SiCl_4$, BCl_3[5]
Indium tin oxide [ITO] (In_2O_3:SnO_2)	Hydrochloric acid (HCl) + nitric acid (HNO_3) + water (H_2O) (1:0.1:1) at 40 °C[6]	
Chromium (Cr)	• "Chrome etch": ceric ammonium nitrate ($(NH_4)_2Ce(NO_3)_6$) + nitric acid (HNO_3)[7] • Hydrochloric acid (HCl)[7]	
Gallium Arsenide (GaAs)	• Citric Acid diluted ($C_6H_8O_7$: H_2O, 1 : 1) + Hydrogen Peroxide (H_2O_2)+ Water (H_2O)	• Cl_2, CCl_4, $SiCl_4$, BCl_3, CCl_2F_2
Gold (Au)	Aqua regia, Iodine and Potassium Iodide solution	
Molybdenum (Mo)		CF_4[5]
Organic residues and photoresist	Piranha etch: sulfuric acid (H_2SO_4) + hydrogen peroxide (H_2O_2)	O_2 (ashing)
Platinum (Pt)	Aqua regia	
Silicon (Si)	• Nitric acid (HNO_3) + hydrofluoric acid (HF)[4] • Potassium hydroxide (KOH) • Ethylenediamine pyrocatechol (EDP) • Tetramethylammonium hydroxide (TMAH)	• CF_4, SF_6, NF_3[5] • Cl_2, CCl_2F_2[5]
Silicon dioxide (SiO_2)	• Hydrofluoric acid (HF)[4] • Buffered oxide etch [BOE]: ammonium fluoride (NH_4F) and hydrofluoric acid (HF)[4]	CF_4, SF_6, NF_3[5]
Silicon nitride (Si_3N_4)	• 85% Phosphoric acid (H_3PO_4) at 180 °C[4] (Requires SiO_2 etch mask)	CF_4, SF_6, NF_3,[5] CHF_3
Tantalum (Ta)		CF_4[5]
Titanium (Ti)	Hydrofluoric acid (HF)[4]	BCl_3[8]
Titanium nitride (TiN)	• Nitric acid (HNO_3) + hydrofluoric acid (HF) • SC1 • Buffered HF (bHF)	
Tungsten (W)	• Nitric acid (HNO_3) + hydrofluoric acid (HF) • Hydrogen Peroxide (H_2O_2)	• CF_4[5] • SF_6[citation needed]

Si run 43sec etch intro video: https://www.youtube.com/watch?v=5B3v1c_keNQ

3min etch and ALD video https://www.youtube.com/watch?v=4G8wXQGEBrA

Reactive Ion Etching Plasma is initiated in the system by applying a strong RF (radio frequency) electromagnetic field to the wafer platter. The field is typically set to a frequency of 13.56 Megahertz, applied at a few hundred watts. The oscillating electric field ionizes the gas molecules by stripping them of electrons, creating a plasma.

In each cycle of the field, the electrons are electrically accelerated up and down in the chamber, sometimes striking both the upper wall of the chamber and the wafer platter. At the same time, the much more massive ions move relatively little in response to the RF electric field. When electrons are absorbed into the chamber walls they are simply fed out to ground and do not alter the electronic state of the system. However, electrons deposited on the wafer platter cause the platter to build up charge due to its DC isolation. This charge build up develops a large negative voltage on the platter, typically around a few hundred volts. The plasma itself develops a slightly positive charge due to the higher concentration of positive ions compared to free electrons.

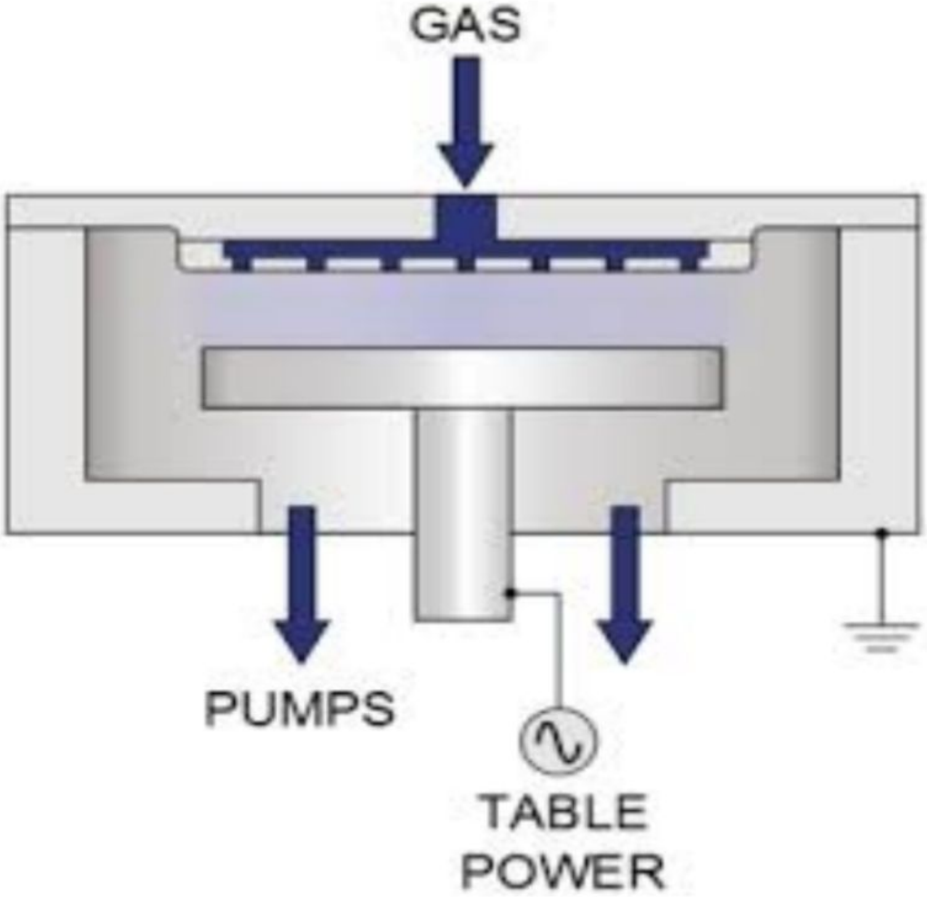
Because of the large voltage difference, the positive ions tend to drift toward the wafer platter, where they collide with the samples to be etched. The ions react chemically with the materials on the surface of the samples, but can also knock off (sputter) some material by transferring some of their kinetic energy. Due to the mostly vertical delivery of reactive ions, reactive-ion etching can produce very anisotropic etch profiles, which contrast with the typically isotropic profiles of wet chemical etching.

Etch conditions in an RIE system depend strongly on the many process parameters, such as pressure, gas flows, and RF power. A modified version of RIE is deep reactive-ion etching, used to excavate deep features.

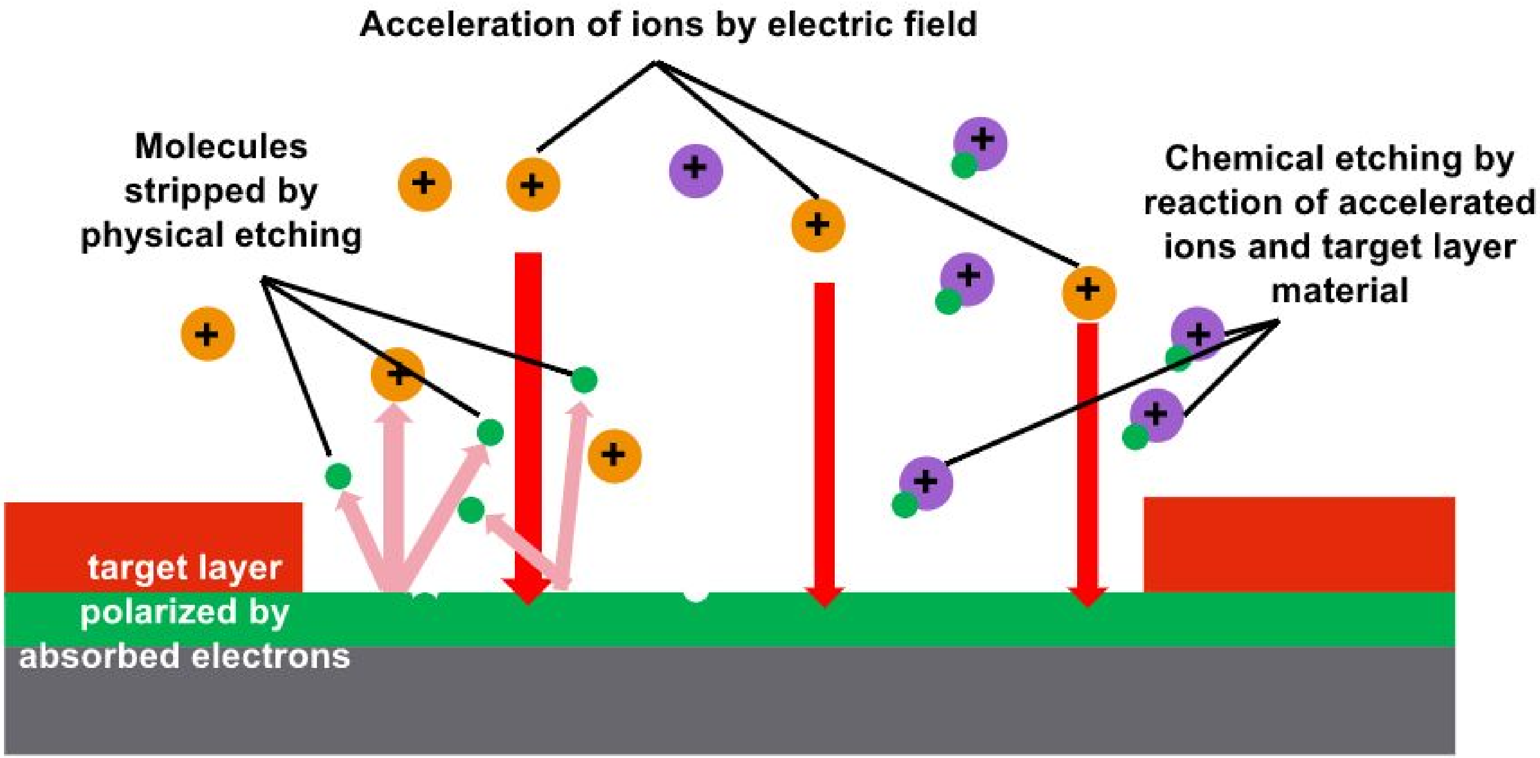

PUMP
TRION
TECHNOLOGY
TRION


Plasma-Therm
790 SERIES
78162 - Dual 7
Plasma-Therm
790 SERIES

Reactive ion etching



Plasma Etching



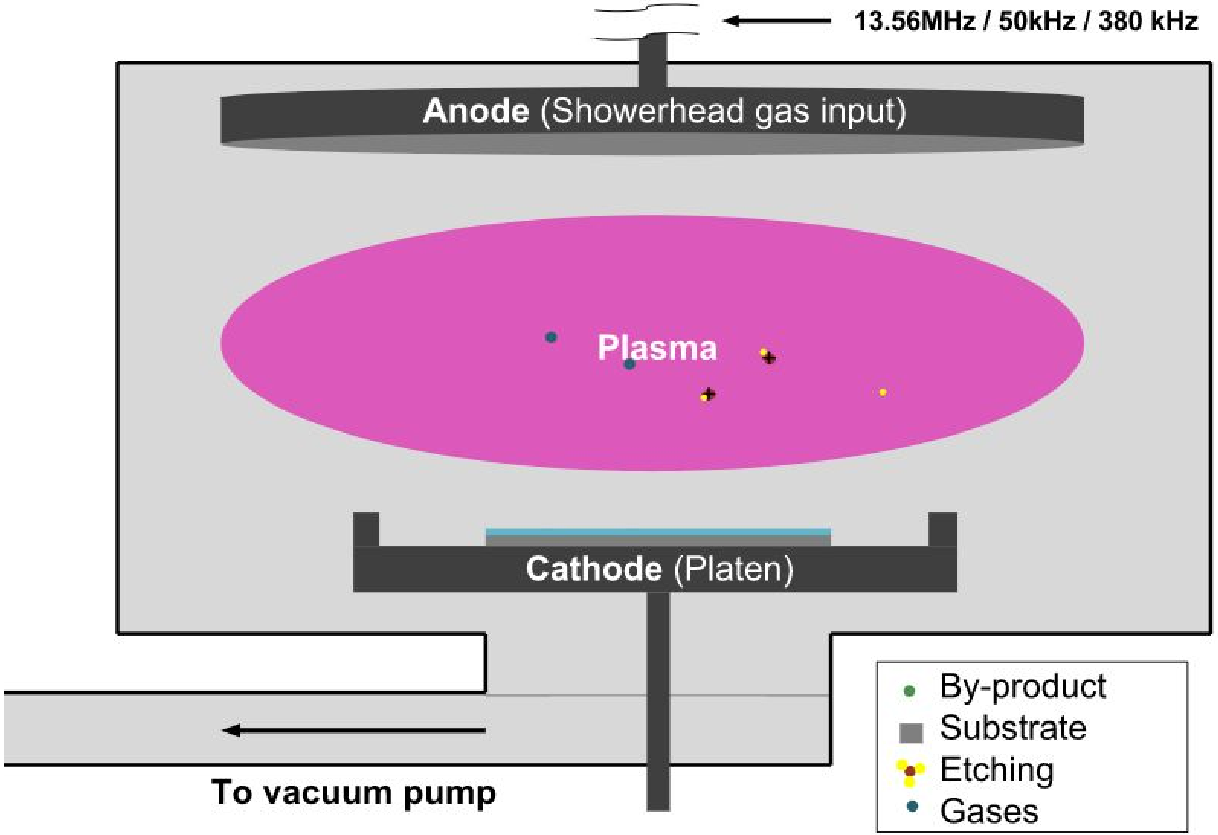
Different Ways to Plasma Etch

Reactive Ion Etching (RIE)

Inductively Coupled Plasma (ICP)

- High Rate Magnet (HRM)

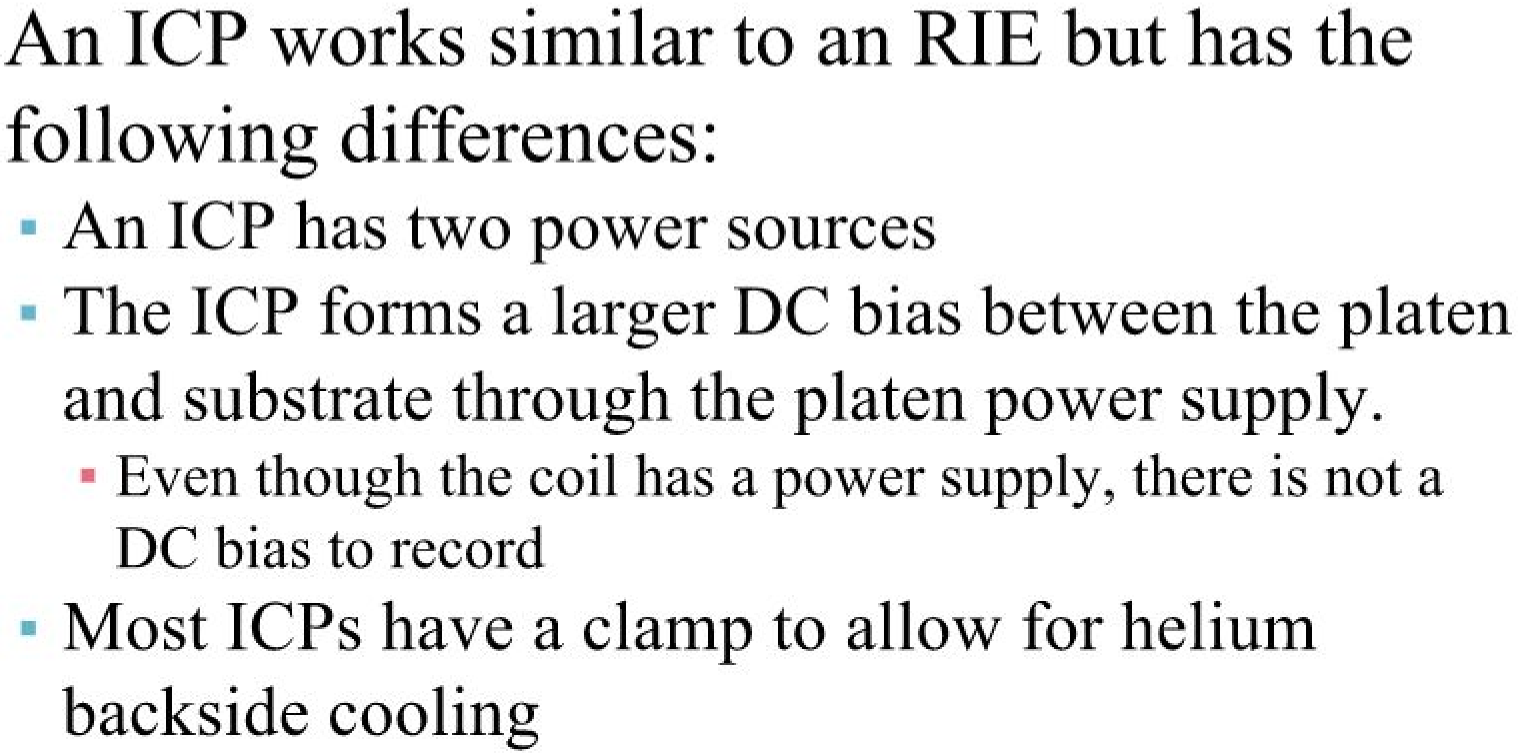
Reactive Ion Etching
(RIE)



Possible materials to etch:

- Aluminum
- Aluminum gallium arsenide
- Chrome
- Gallium arsenide
- Indium phosphide
- Silicon dioxide
- Silicon nitride
- Titanium

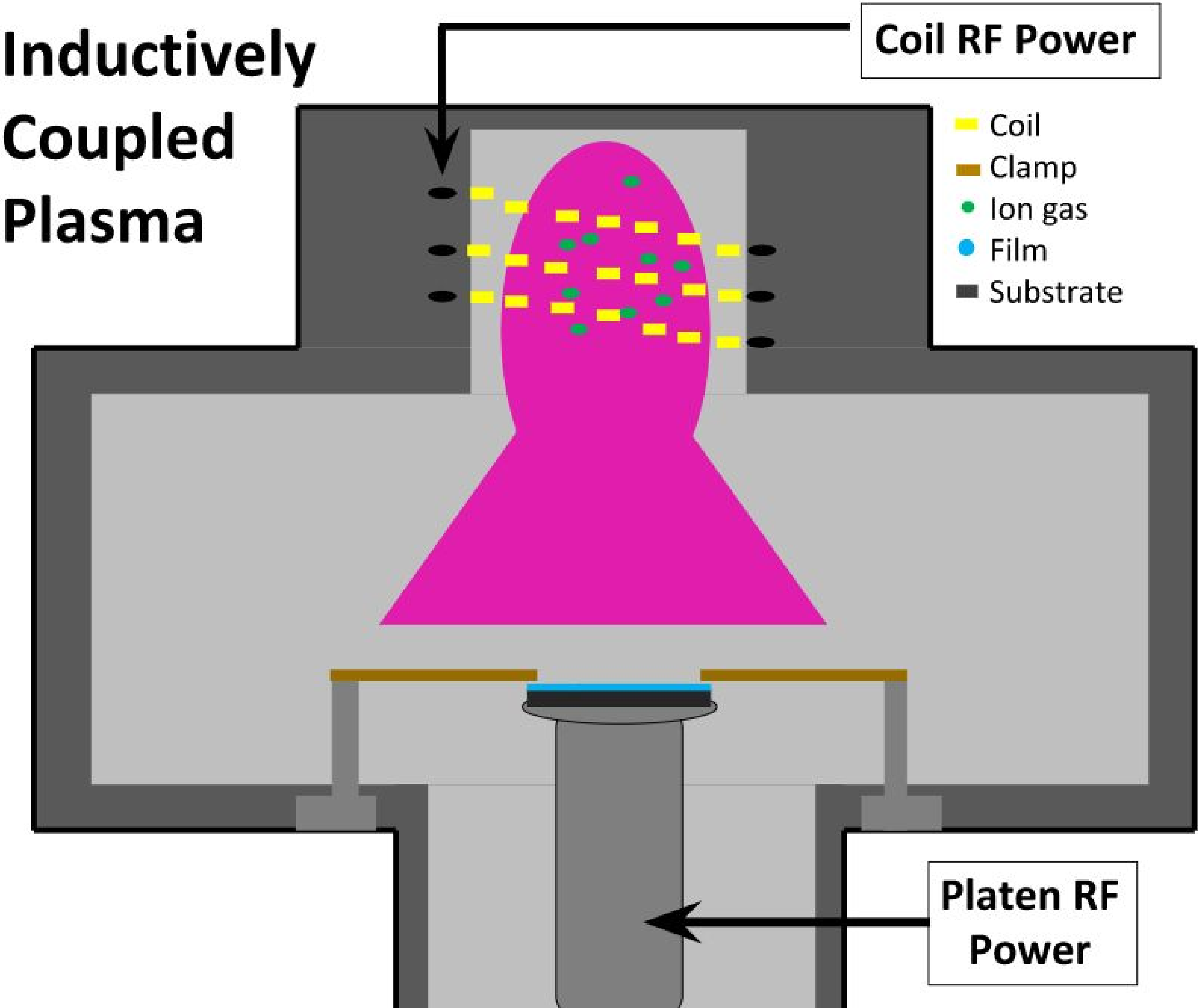
ICP - RIE



An ICP works similar to an RIE but has the following differences:

- An ICP has two power sources
- The ICP forms a larger DC bias between the platen and substrate through the platen power supply.
    - Even though the coil has a power supply, there is not a DC bias to record
- Most ICPs have a clamp to allow for helium backside cooling

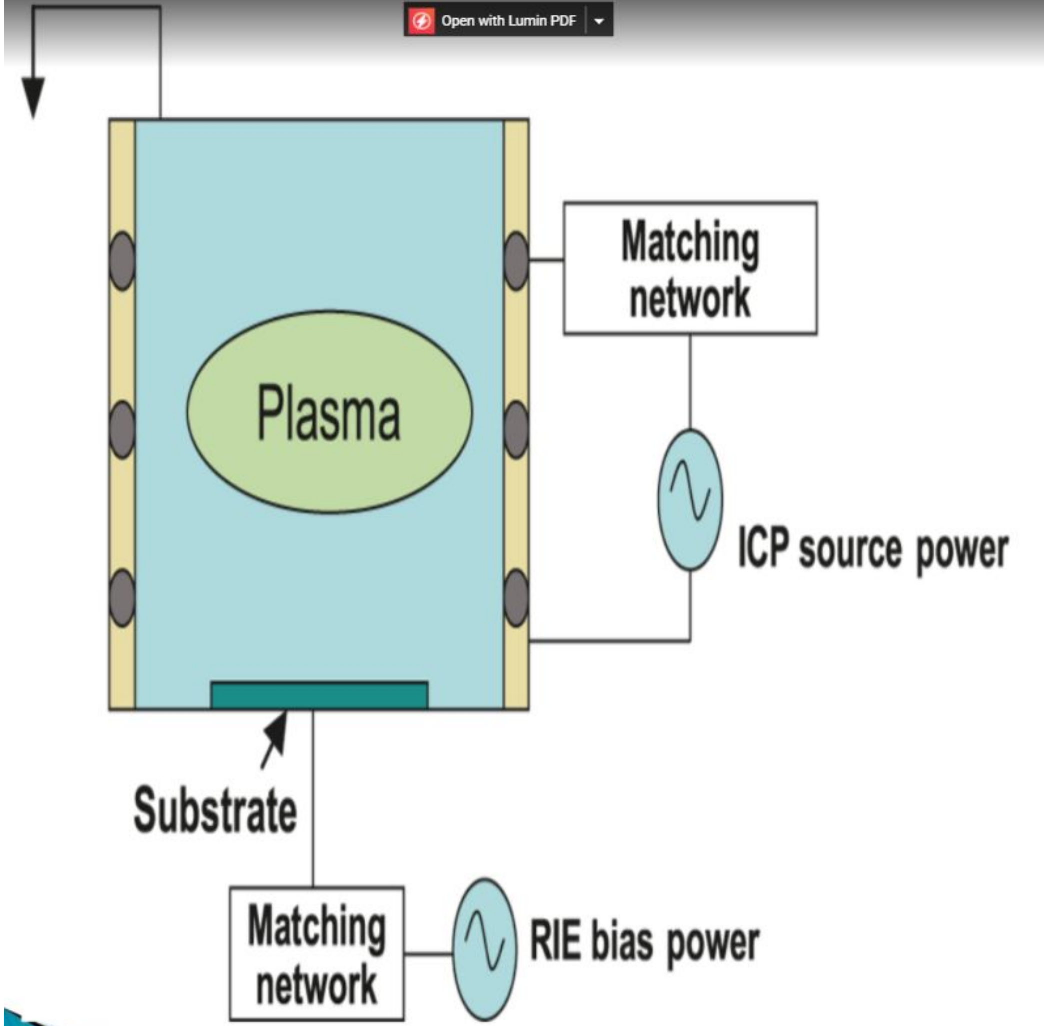
Inductively Coupled Plasma

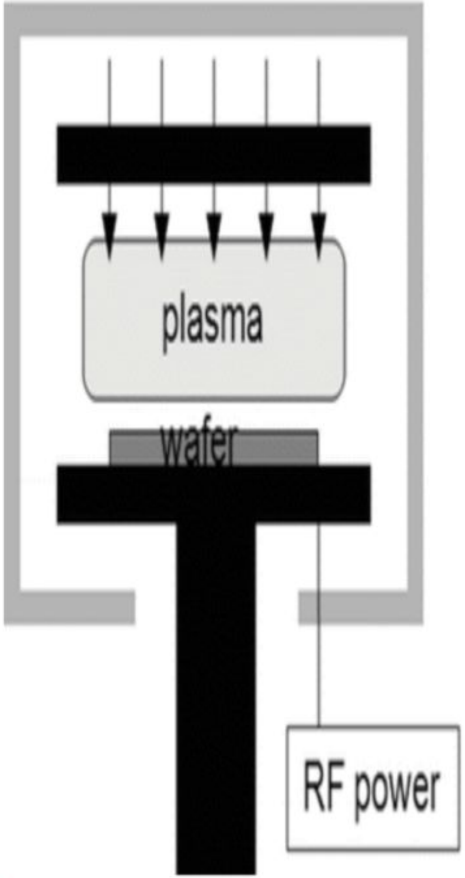


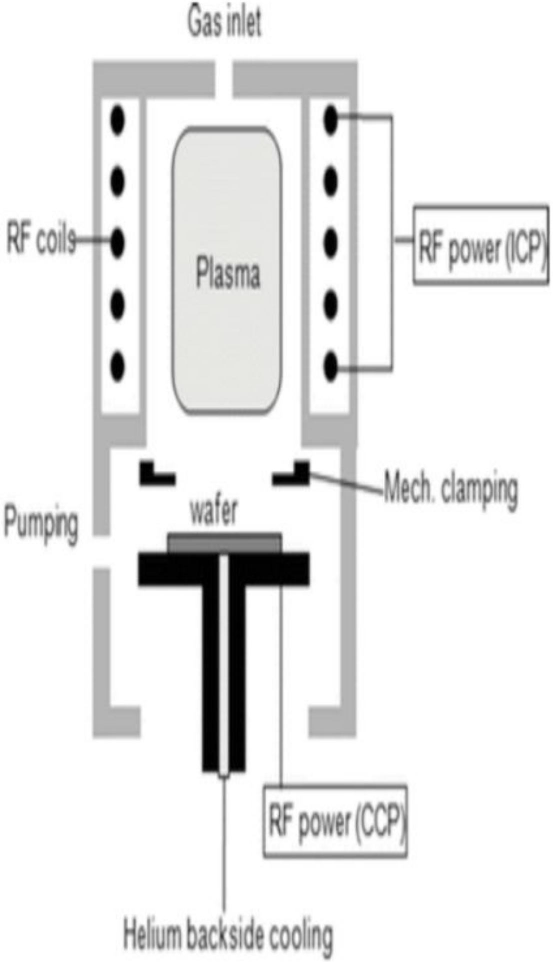
Coil RF Power

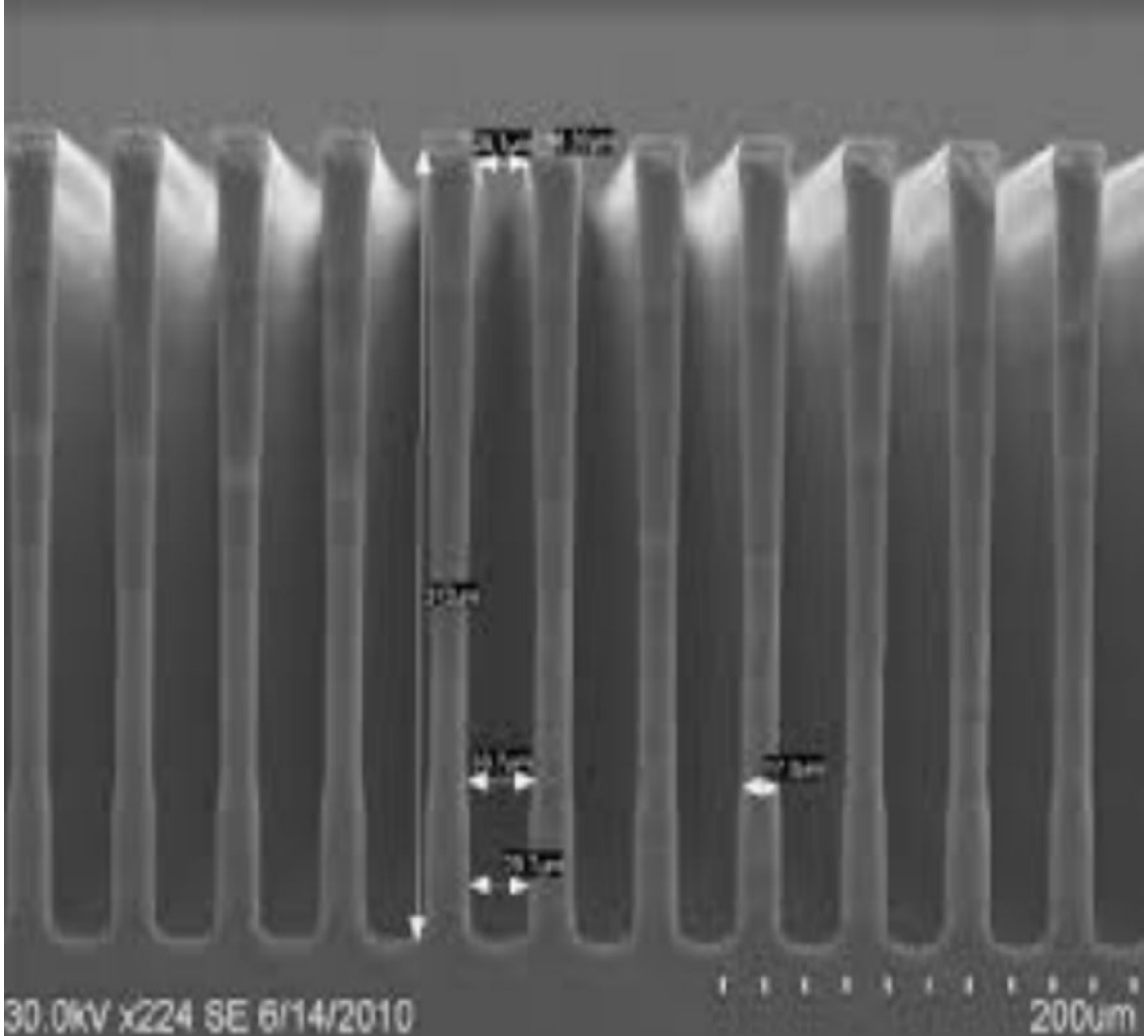
🟨 Coil
🟫 Clamp
● Ion gas
● Film
■ Substrate

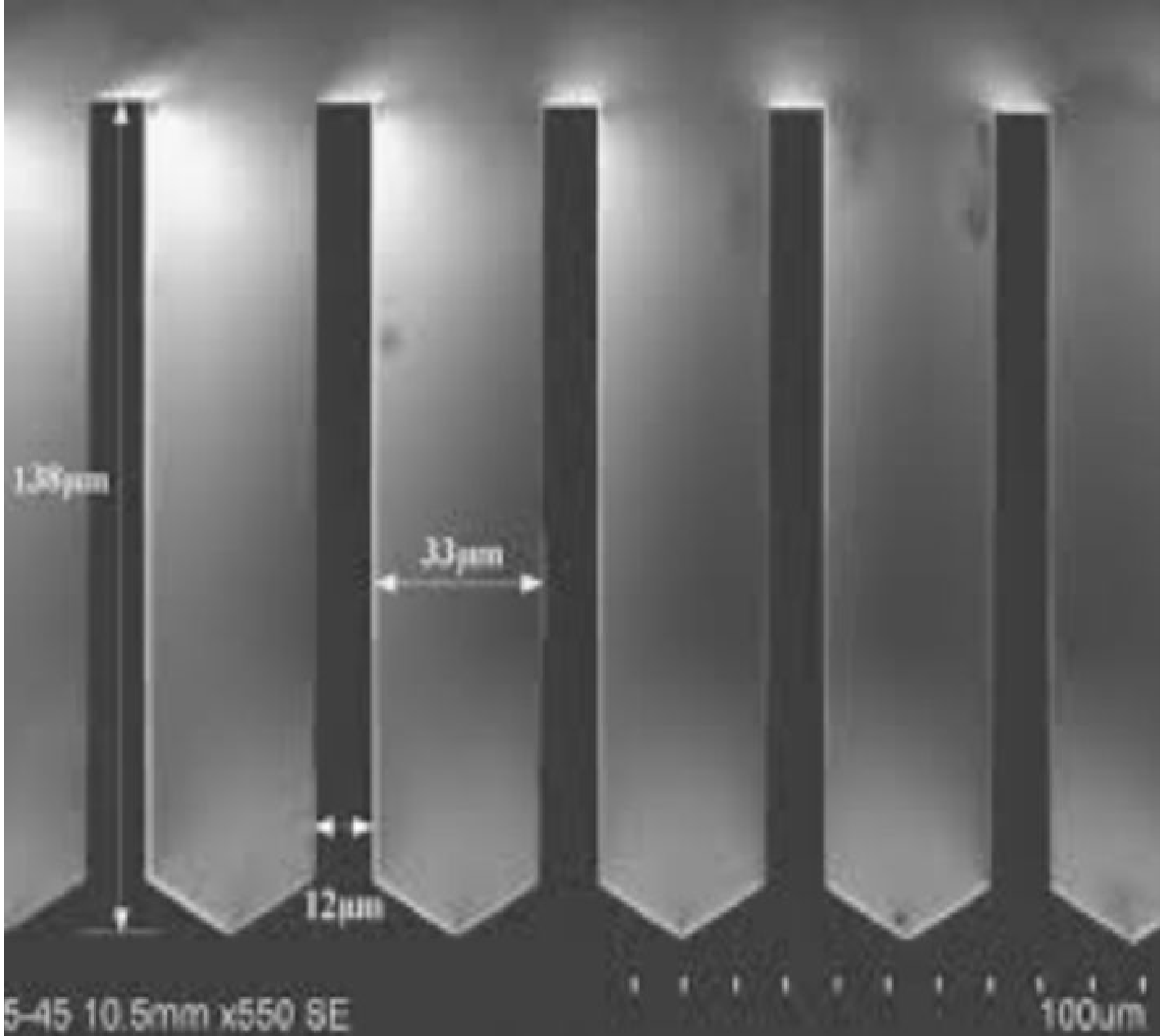
Platen RF Power


Matching network
Plasma
ICP source power
Substrate
Matching network
RIE bias power


plasma
wafer
RF power


Gas inlet
RF coils
Plasma
RF power (ICP)
Mech. clamping
Pumping
wafer
RF power (CCP)
Helium backside cooling


30.0kV x224 SE 6/14/2010
200um


138μm
33μm
12μm
5-45 10.5mm x550 SE
100μm

Commonly etched materials:

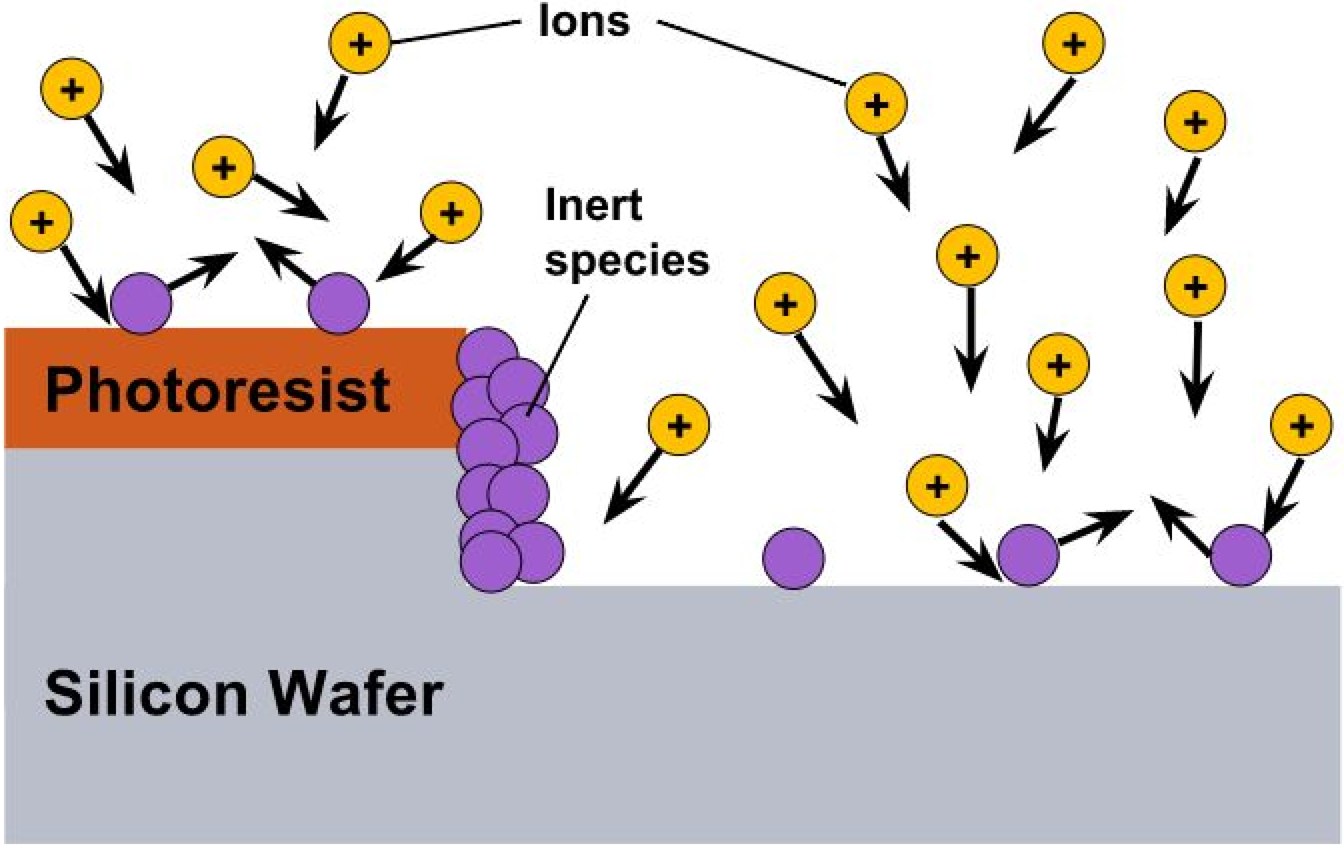
- Aluminum
- Chromium
- Copper
- Fused Silica
- Gallium Nitride
- Pyrex
- Quartz
- Silicon
- Silicon Dioxide (SiO_2)
- Silicon Nitride (Si_3N_4)
- Titanium

Silicon etching occurs in cycles

- Known as a Bosch Process
- Typically there is one passivation step followed by an etch step which is then repeated for the necessary number of cycles
- A cycle typically takes 10-20 seconds

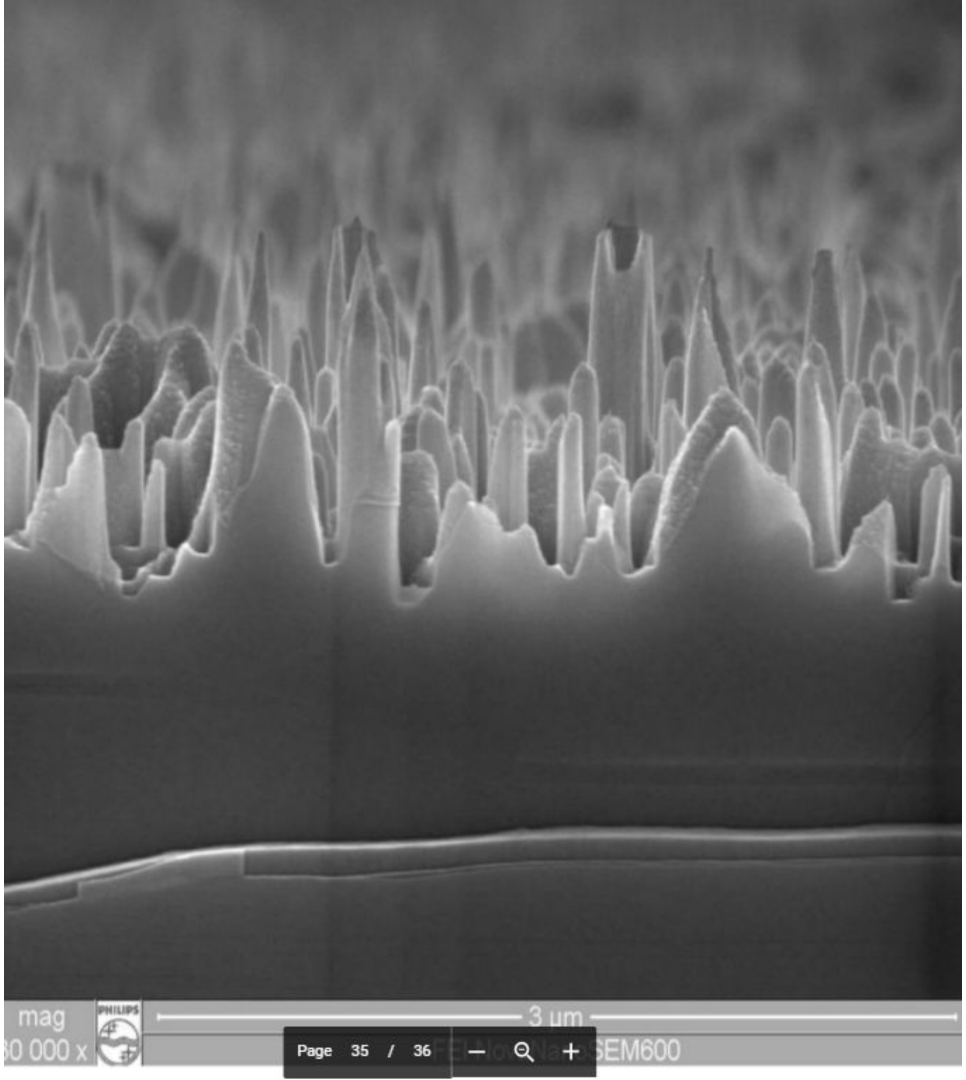
When silicon etching, record parameters for each part of the cycle

- Passivation
- Etch


Ions
Inert species
Photoresist
Silicon Wafer

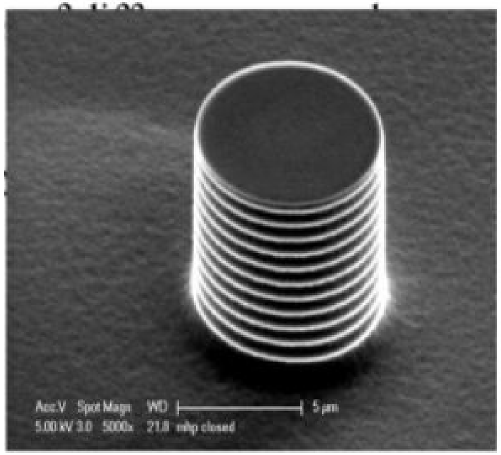
Typical Problems with Silicon Etching

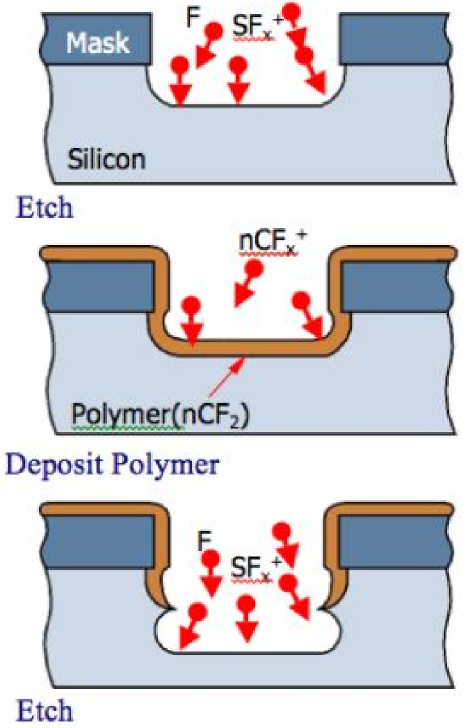
- Grassing
  - Sample undergoes micro-masking
    - Foreign species deposit on surface or residue from etch redeposits on surface
    - Redeposited material acts as a mask during the etch


mag
0 000 x
PHILIPS
3 µm
SEM600

Typical Problems with Silicon Etching

- Scalloping
  - Passivation layer blocks some of the undercutting, but the next etch undercuts the passivation layer





High Rate Magnet

- An HRM is a type of ICP
  - HRM can also use Bosch process for etching
- HRM applies a magnetic current in the chamber
- This electro-magnetic field removes the large bombarding molecules to focus the process on chemical etching

Differences among RIE, ICP, and HRM

- The RIE is typically used for shallow etching
- ICP and HRM are typically used for deep etching
- ICP and HRM have two power sources while the RIE has only one
- ICP and HRM have a higher intensity plasma for the deep etching
- The HRM offers better selectivity and aspect ratios by removing the bombardment molecules with the high rate magnet

Write down the following parameters when applicable:

- Process name
- Process time (and what time the rest of the data was recorded)
- Etch Rate
- Power
  - RF (1 & 2)
  - Ref
  - DC Bias
- Pressure
- Temperature
- Gas flows
- Load/Tune/Match
- Plasma color

	RF Power	**Ref Power**	**DC Bias**
What does it mean?	The power input from the tool	The power lost	Potential difference between the plasma and the sample
What if it is 10% lower than setpoint or than previously observed?	Contact staff	n/a	Try running the clean recipe. If this does not help, contact staff.
What if it is 10% higher than setpoint or than previously observed?	Contact staff	The chamber is most likely dirty. Run the clean process and try again.	Try running the clean recipe. If this does not help, contact staff.

	Pressure	**Gas Flows**	**Temperature**
What does it mean?	The pressure of the process chamber	Gas flow rates into the process chamber	The temperature of the platen or showerhead
What if it is 10% lower than setpoint or than previously observed?	Typically no error	The bottle is empty. Contact staff	Contact staff If in ICP and the helium flow rate is too high (max value depends on the tool), check the back side of the sample. A dirty backside or poor sample mounting could cause problems with heat dissipation.
What if it is10% higher than setpoint or than previously observed?	If not within 10%, stop process and check the o-ring. If it is still alarming contact staff	n/a	

Chamber Cleaning

- Make sure that the clean process has been run
- If the clean process was not run, run it
- Check to make sure the o-ring is clean and in place
- Run the clean process after your process is finished
- If the clean process is running, the chamber cleanliness can be determined by the DC Bias.
  - DC Bias depends on the tool.

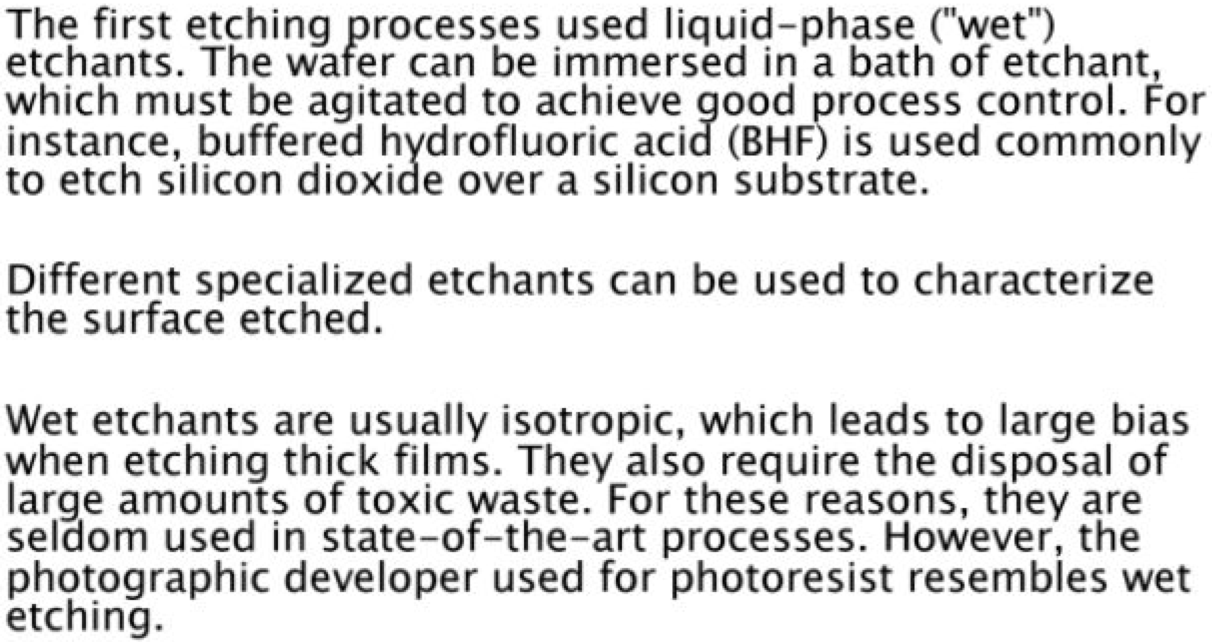
Wafer Cleaning

- The back side of the sample must be completely free of any debris, photoresist, or epoxy
- The top of the sample should be free of debris that could compromise the etch

Things to consider when etching:

- The loading effect occurs with smaller trenches requiring less etching material than wider trenches
- Smaller trenches etch slower than wider trenches
- Make sure the mask you choose is appropriate for the material you are etching
- **More power does not necessarily mean a faster etch!!!**

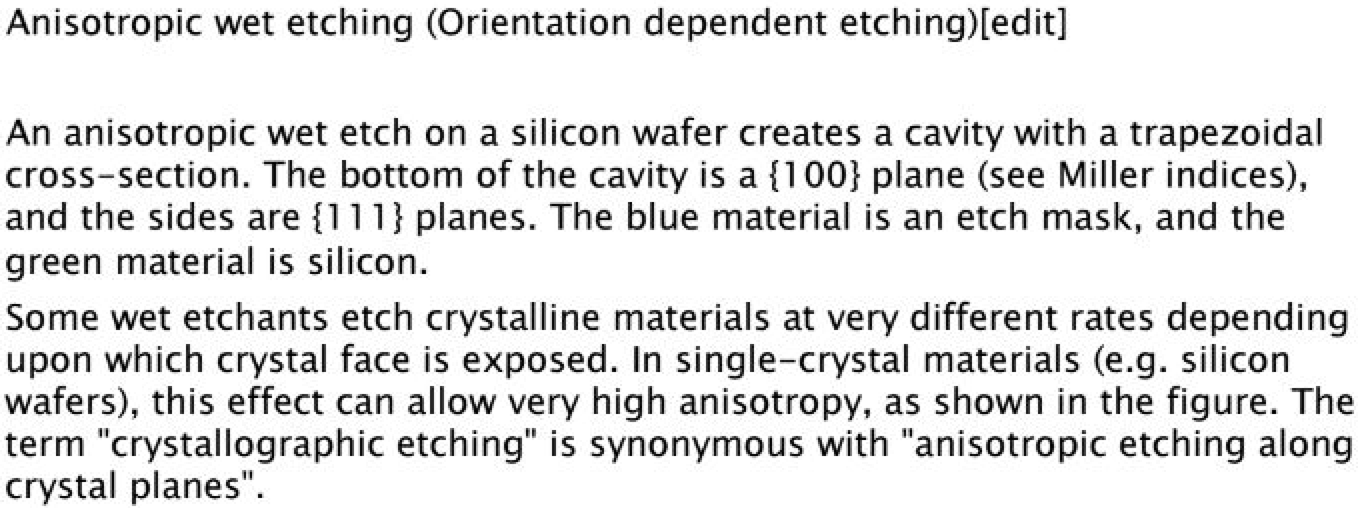
Wet Etching



The first etching processes used liquid-phase ("wet") etchants. The wafer can be immersed in a bath of etchant, which must be agitated to achieve good process control. For instance, buffered hydrofluoric acid (BHF) is used commonly to etch silicon dioxide over a silicon substrate.

Different specialized etchants can be used to characterize the surface etched.

Wet etchants are usually isotropic, which leads to large bias when etching thick films. They also require the disposal of large amounts of toxic waste. For these reasons, they are seldom used in state-of-the-art processes. However, the photographic developer used for photoresist resembles wet etching.



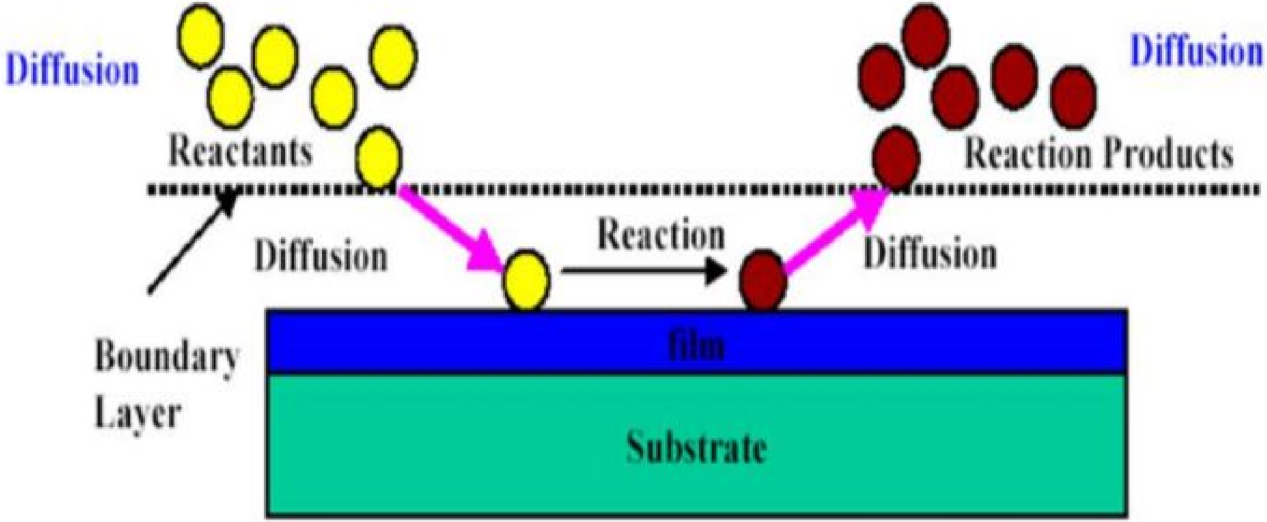
Anisotropic wet etching (Orientation dependent etching)[edit]

An anisotropic wet etch on a silicon wafer creates a cavity with a trapezoidal cross-section. The bottom of the cavity is a {100} plane (see Miller indices), and the sides are {111} planes. The blue material is an etch mask, and the green material is silicon.

Some wet etchants etch crystalline materials at very different rates depending upon which crystal face is exposed. In single-crystal materials (e.g. silicon wafers), this effect can allow very high anisotropy, as shown in the figure. The term "crystallographic etching" is synonymous with "anisotropic etching along crystal planes".

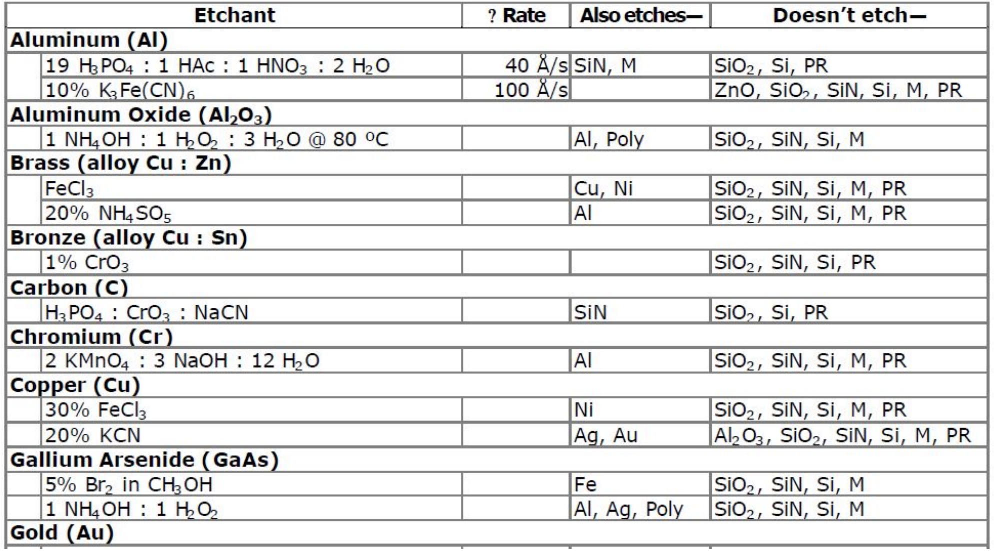
Etching is consisted of 3 processes:

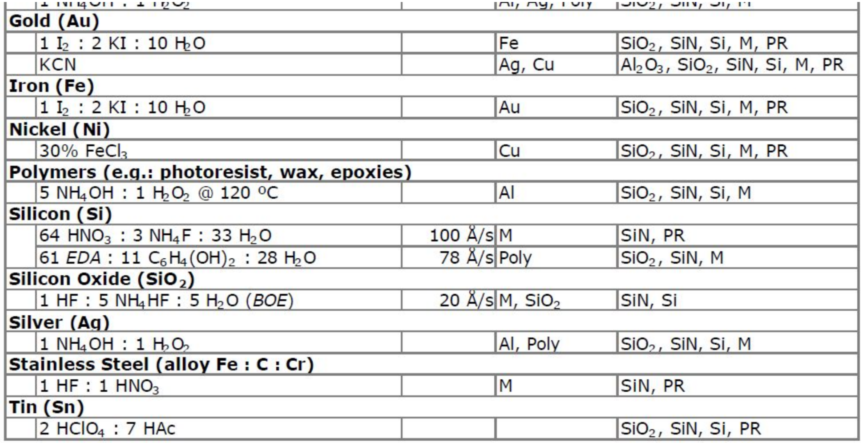
- Mass transport of reactants (through a boundary layer) to the surface to be etched
- Reaction between reactants and the film to be etched at the surface
- Mass transport of reaction products from the surface through the surface boundary layer



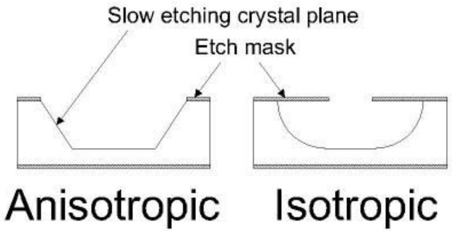
Acetic Acid (H_3COOH): GaAs; Pb; Ti
Hydrochloric Acid (HCl): Al; Cr; Cu; Fe_2O_3; Ga; GaAs; GaN; In; Fe; Pb; Ni; NiO, Ni_2O_3; Sn; SnO_2; Ti; Zn
Hydrofluoric Acid (HF): GaAs; Ni; SiO_2; Ti
Nitric Acid (HNO_3): C; Cu; GaAs; In; Fe; Pb; Ni; Ag; Pd; Pt; Sn; Ti; Zn; ZnO
Phosphoric Acid (H_3PO_4): Al; Cu; GaAs; GaN; Fe; Ni; SiN; ZnO
Potassium Hydroxide (KOH): Al; C; Cu; Ag; GaAs; Si; Ti
Sodium Hydroxide (NaOH): Al; Cu; Ag; Ti; GaAs; GaN
Sulfuric Acid (H_2SO_4): C; Cu; GaAs; Fe; Pb; Ni; Ti

Aqua Regia **(3 HCl : 1 HNO_3)** etches all metals

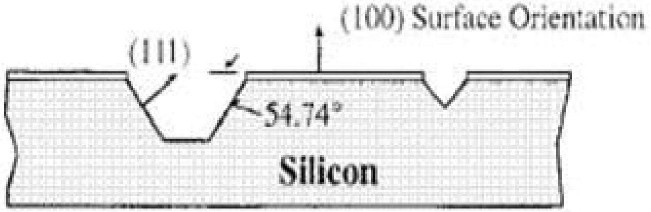




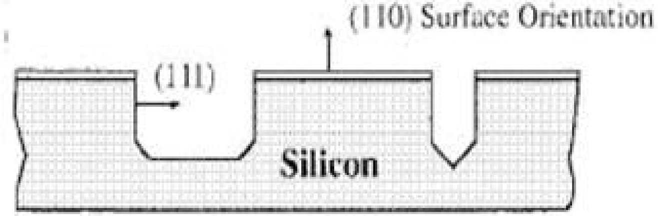
Etchant	? Rate	Also etches—	Doesn't etch—
Aluminum (Al)			
19 H_3PO_4 : 1 HAc : 1 HNO_3 : 2 H_2O	40 Å/s	SiN, M	SiO_2, Si, PR
10% $K_3Fe(CN)_6$	100 Å/s		ZnO, SiO_2, SiN, Si, M, PR
Aluminum Oxide (Al_2O_3)			
1 NH_4OH : 1 H_2O_2 : 3 H_2O @ 80 $^{\circ}$C		Al, Poly	SiO_2, SiN, Si, M
Brass (alloy Cu : Zn)			
$FeCl_3$		Cu, Ni	SiO_2, SiN, Si, M, PR
20% NH_4SO_5		Al	SiO_2, SiN, Si, M, PR
Bronze (alloy Cu : Sn)			
1% CrO_3			SiO_2, SiN, Si, PR
Carbon (C)			
H_3PO_4 : CrO_3 : NaCN		SiN	SiO_2, Si, PR
Chromium (Cr)			
2 $KMnO_4$: 3 NaOH : 12 H_2O		Al	SiO_2, SiN, Si, M, PR
Copper (Cu)			
30% $FeCl_3$		Ni	SiO_2, SiN, Si, M, PR
20% KCN		Ag, Au	Al_2O_3, SiO_2, SiN, Si, M, PR
Gallium Arsenide (GaAs)			
5% Br_2 in CH_3OH		Fe	SiO_2, SiN, Si, M
1 NH_4OH : 1 H_2O_2		Al, Ag, Poly	SiO_2, SiN, Si, M
Gold (Au)			
1 I_2 : 2 KI : 10 H_2O		Fe	SiO_2, SiN, Si, M, PR
KCN		Ag, Cu	Al_2O_3, SiO_2, SiN, Si, M, PR
Iron (Fe)			
1 I_2 : 2 KI : 10 H_2O		Au	SiO_2, SiN, Si, M, PR
Nickel (Ni)			
30% $FeCl_3$		Cu	SiO_2, SiN, Si, M, PR
Polymers (e.g.: photoresist, wax, epoxies)			
5 NH_4OH : 1 H_2O_2 @ 120 $^{\circ}$C		Al	SiO_2, SiN, Si, M
Silicon (Si)			
64 HNO_3 : 3 NH_4F : 33 H_2O	100 Å/s	M	SiN, PR
61 *EDA* : 11 $C_6H_4(OH)_2$: 28 H_2O	78 Å/s	Poly	SiO_2, SiN, M
Silicon Oxide (SiO_2)			
1 HF : 5 NH_4HF : 5 H_2O (*BOE*)	20 Å/s	M, SiO_2	SiN, Si
Silver (Ag)			
1 NH_4OH : 1 H_2O_2		Al, Poly	SiO_2, SiN, Si, M
Stainless Steel (alloy Fe : C : Cr)			
1 HF : 1 HNO_3		M	SiN, PR
Tin (Sn)			
2 $HClO_4$: 7 HAc			SiO_2, SiN, Si, PR



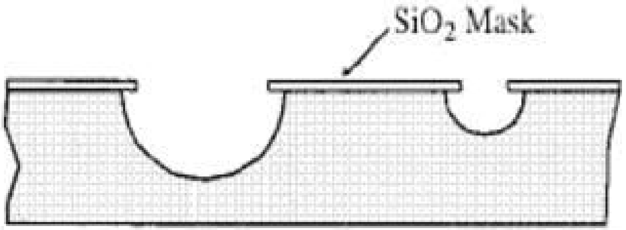
Anisotropic wet etching: (100)



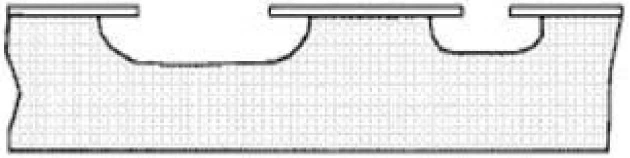
Anisotropic wet etching: (110)



Isotropic wet etching: Agitation



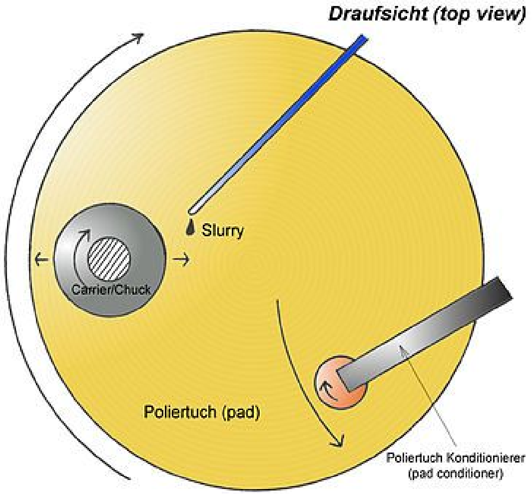
Isotropic wet etching: No Agitation

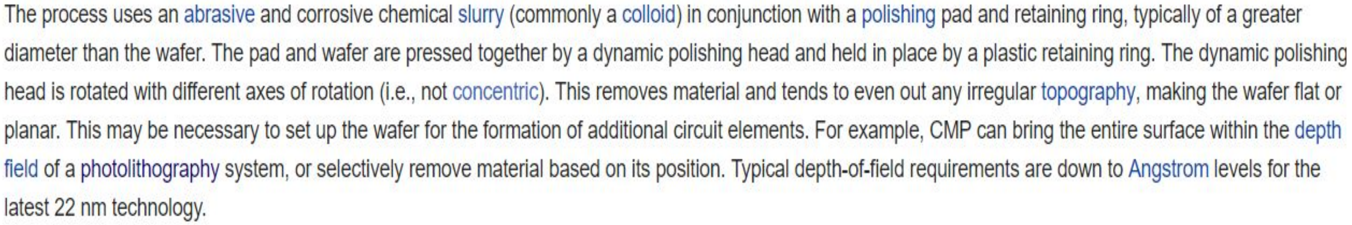


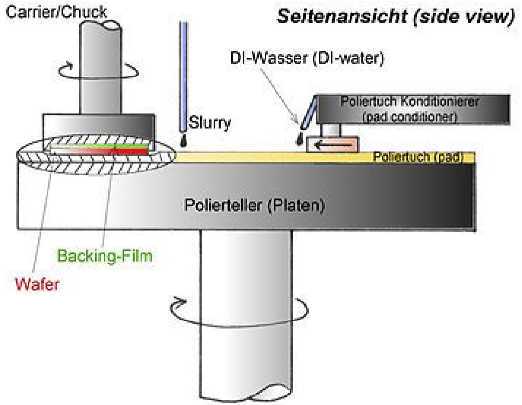

#1

CMP - Chemical Mechanical Polishing

Chemical mechanical polishing/planarization is a process of smoothing surfaces with the combination of chemical and mechanical forces. It can be thought of as a hybrid of chemical etching and free abrasive polishing.




The process uses an abrasive and corrosive chemical slurry (commonly a colloid) in conjunction with a polishing pad and retaining ring, typically of a greater diameter than the wafer. The pad and wafer are pressed together by a dynamic polishing head and held in place by a plastic retaining ring. The dynamic polishing head is rotated with different axes of rotation (i.e., not concentric). This removes material and tends to even out any irregular topography, making the wafer flat or planar. This may be necessary to set up the wafer for the formation of additional circuit elements. For example, CMP can bring the entire surface within the depth field of a photolithography system, or selectively remove material based on its position. Typical depth-of-field requirements are down to Angstrom levels for the latest 22 nm technology.



Limitations of CMP

There are currently several limitations of CMP that appear during the polishing process requiring optimization of a new technology.

In particular, an improvement in wafer metrology is required. In addition, it was discovered that the CMP process has several potential defects including stress cracking, delaminating at weak interfaces, and corrosive attacks from slurry chemicals.

The oxide polishing process, which is the oldest and most used in today's industry, has one problem: a lack of end points requires blind polishing, making it hard to determine when the desired amount of material has been removed or the desired degree of planarization has been obtained.

Bonus Videos/Animations

Recap the Week and All Steps

Who Remembers what?