Engineering of Semiconductor

:Semiconductor Physics and Devices

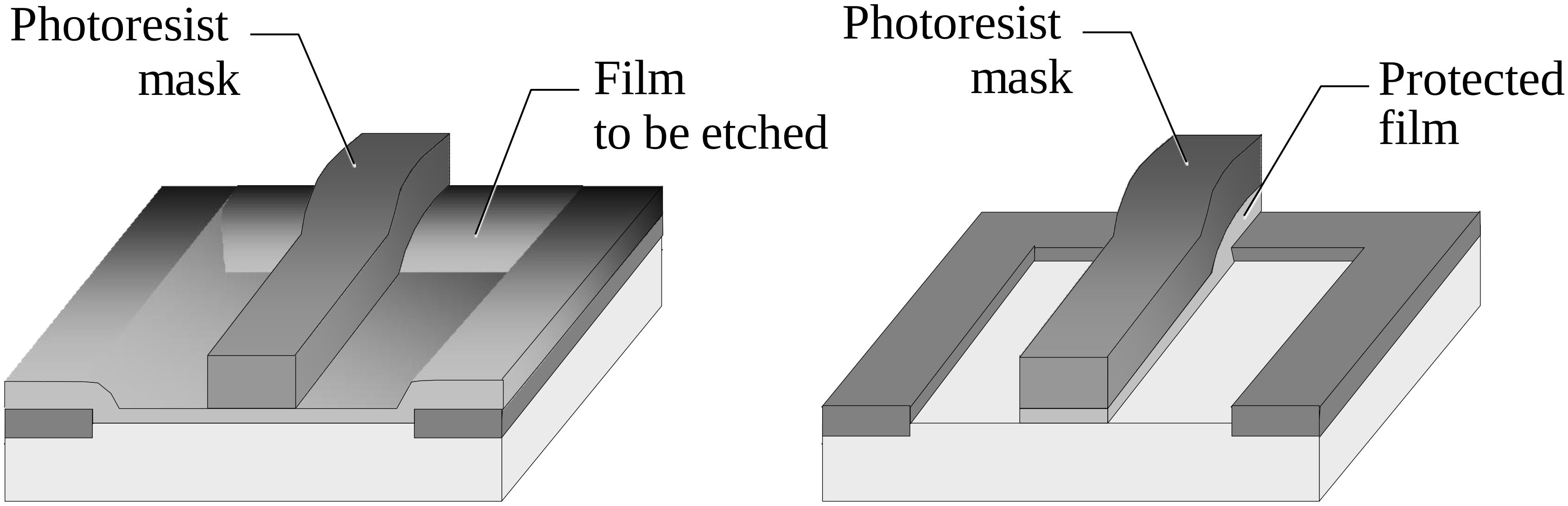
Chapter 2. Silicon Technology

Objectives

Overview of Silicon Technology

- Wafer preparation
- Lithography
- Oxidation
- Etching
- Doping
- Deposition
- Packaging

Applications for Wafer Etch in CMOS Technology



(a) Photoresist-patterned substrate

(b) Substrate after etch

Figure 16.1

Process Flow in a Wafer Fab

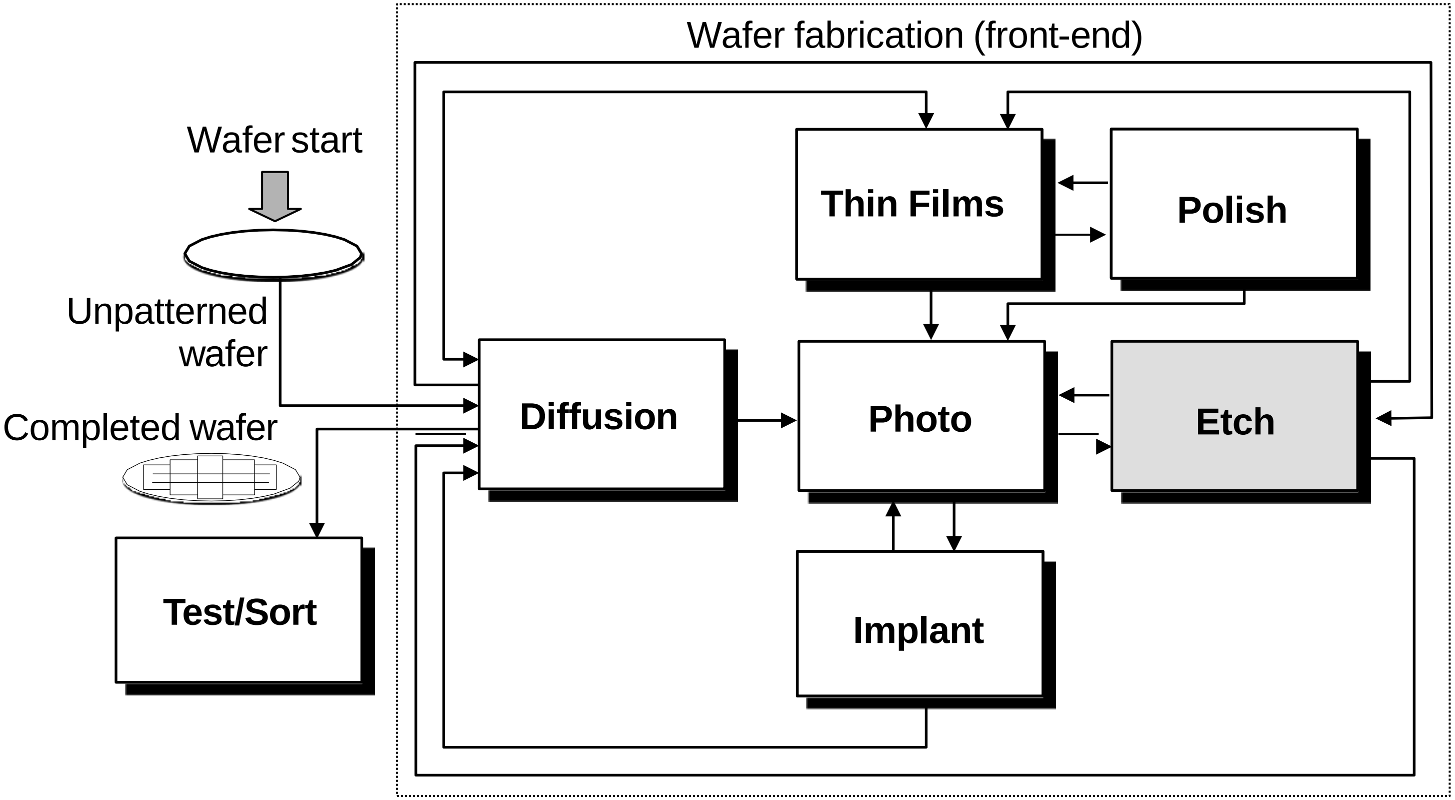


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Figure 16.2

Etch Process

Categories of Etch Processes

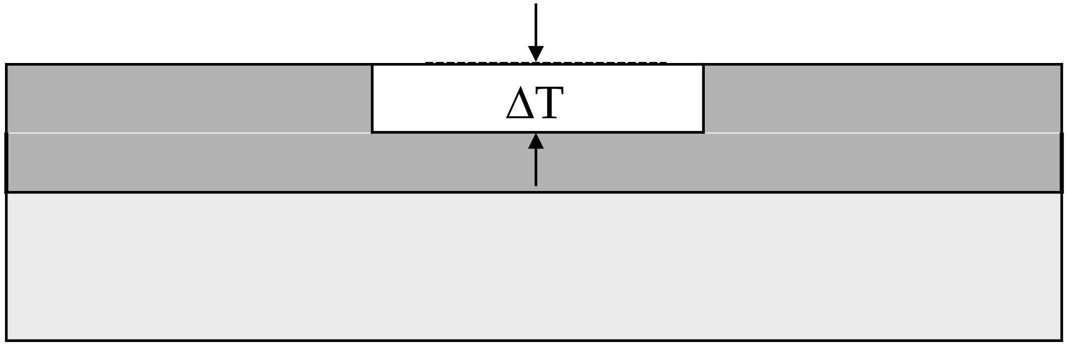
- Wet Etch
- Dry Etch
- Three Major Materials to be Etched
  - Silicon
  - Dielectric
  - Metal
- Patterned Etch Versus Unpatterned Etch

Etch Parameters

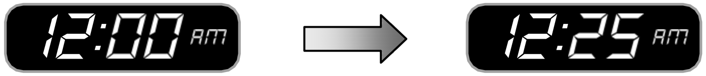
- Etch rate
- Etch profile
- Etch bias
- Selectivity
- Uniformity
- Residues
- Polymer formation
- Plasma-induced damage
- Particle contamination and defects

Etch Rate

ΔT = change in thickness



t = elapsed time during etch

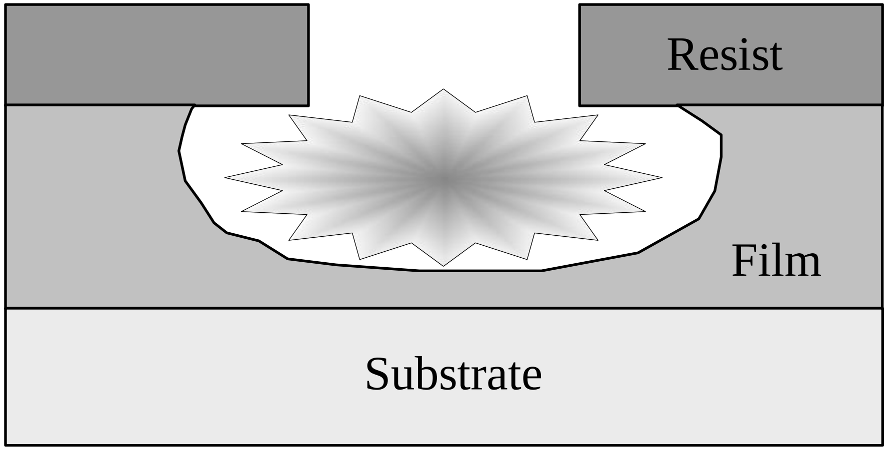


Start of etch

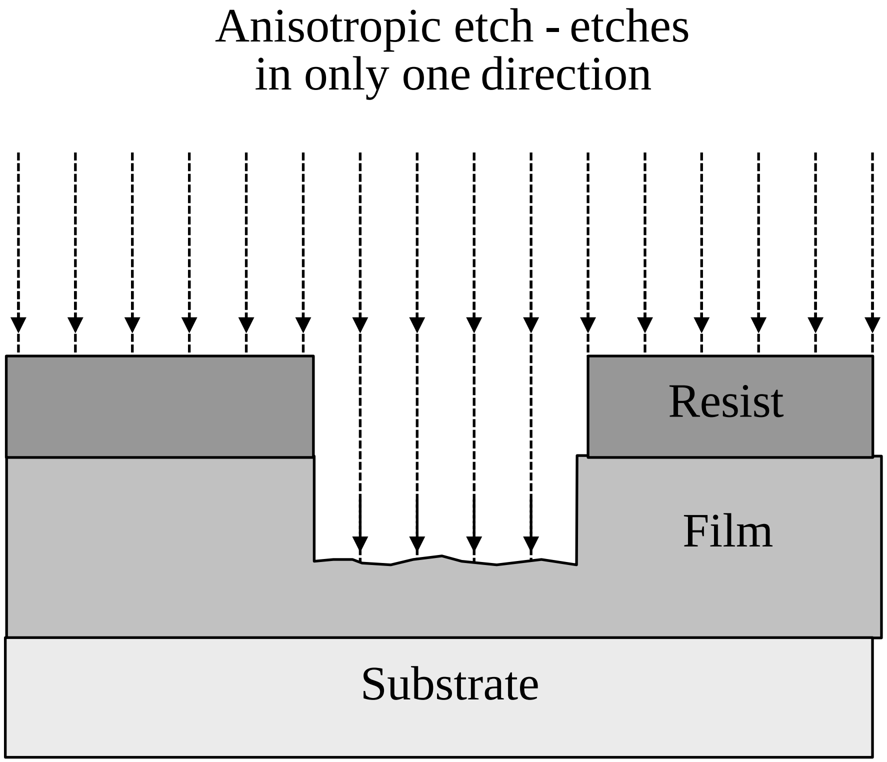
End of etch

Wet Chemical Isotropic Etch

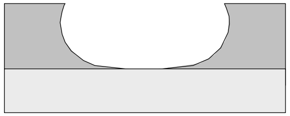
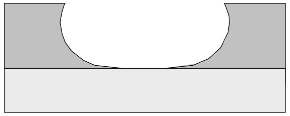
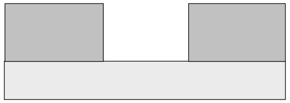
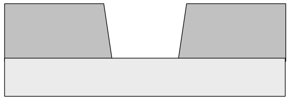
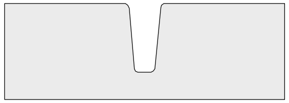
Isotropic etch - etches in all directions at the same rate



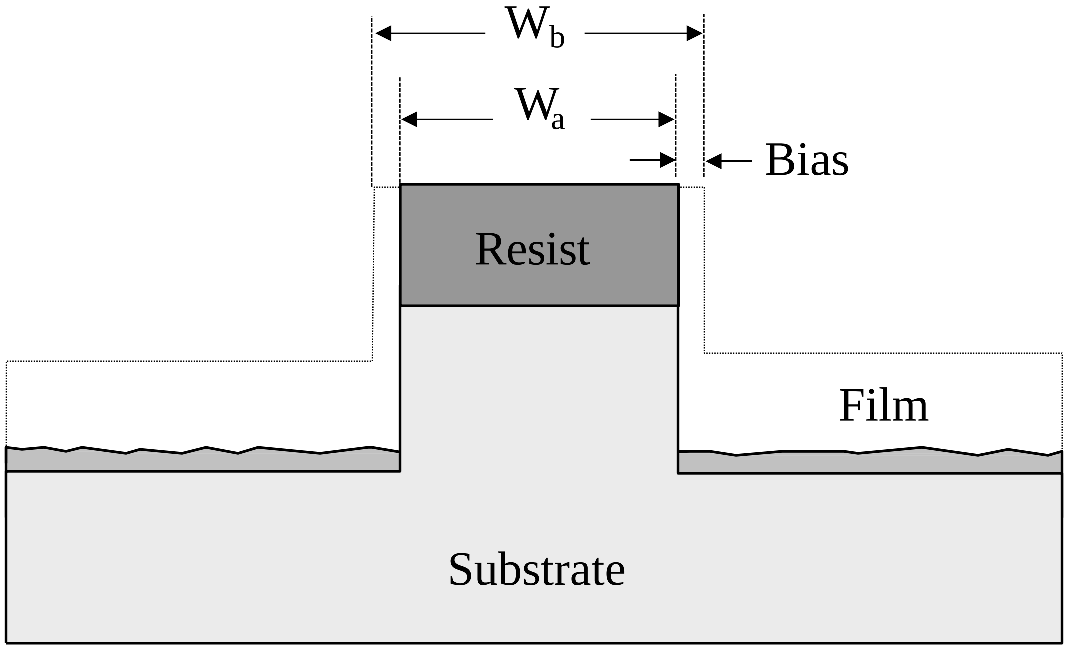
Anisotropic Etch with Vertical Etch Profile



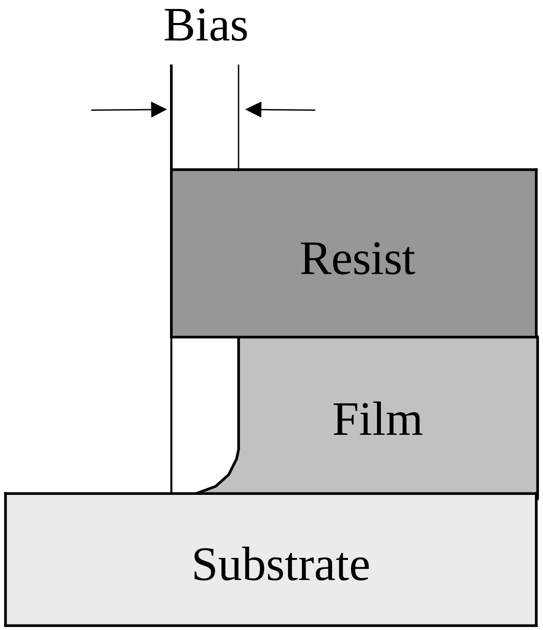
Sidewall Profiles for Wet Etch Versus Dry Etch

Type of Etch	Sidewall Profile	Diagram
Wet Etch	Isotropic	
Dry Etch	Isotropic (depending on equipment & parameters)	
	Anisotropic (depending on equipment & parameters)	
	Anisotropic – Taper	
	Silicon Trench	

Etch Bias

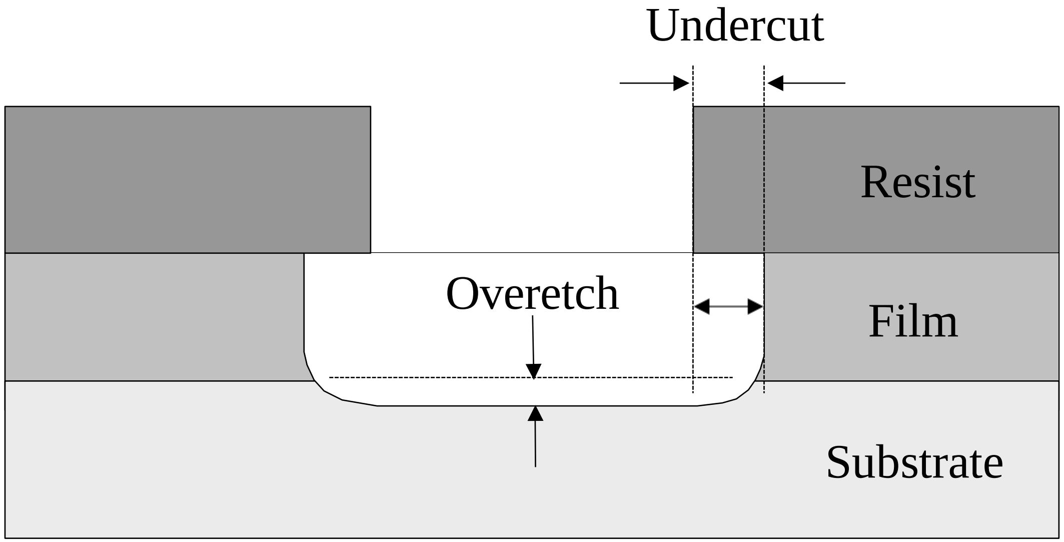

W_b
W_a
Bias
Resist
Film
Substrate

(a)


Bias
Resist
Film
Substrate

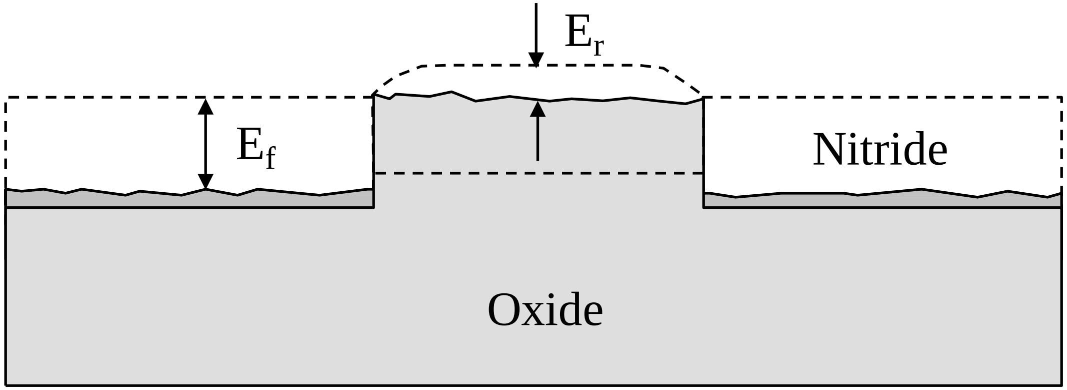
(b)

Etching Undercut and Slope



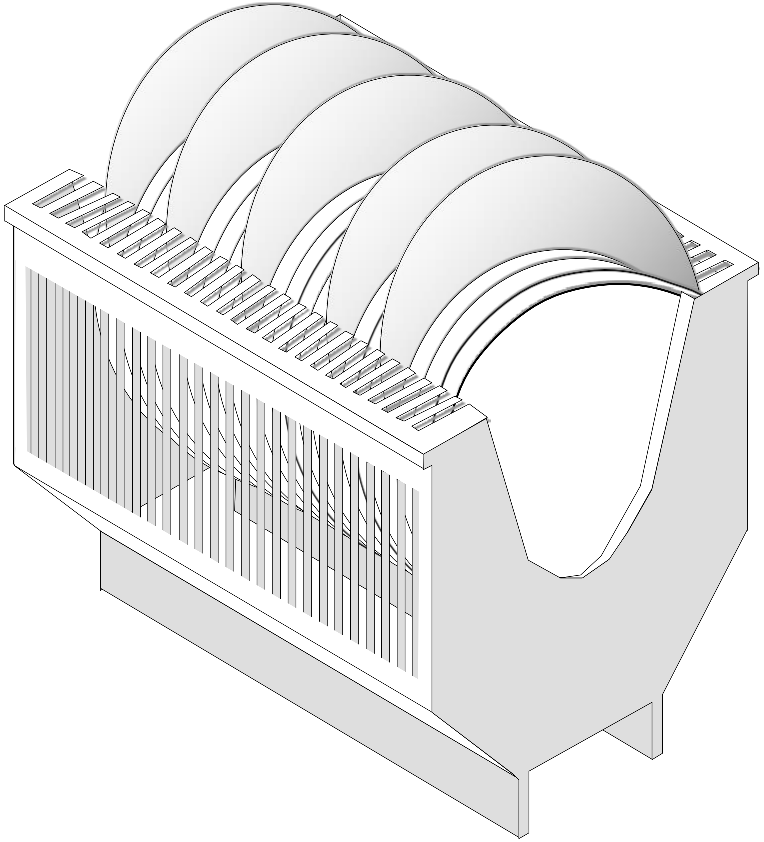
Etch Selectivity

$$S = \frac{E_f}{E_r}$$

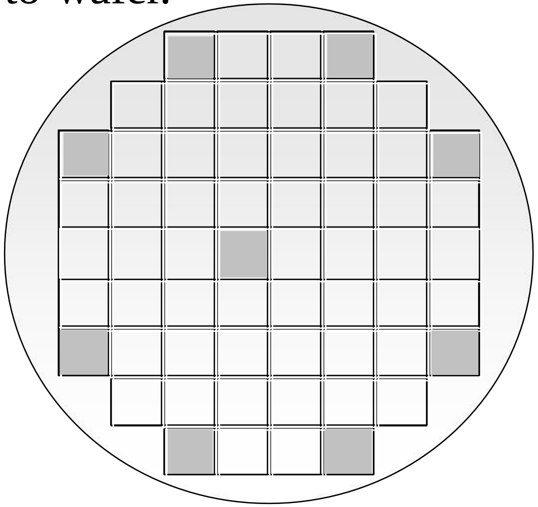


Etch Uniformity

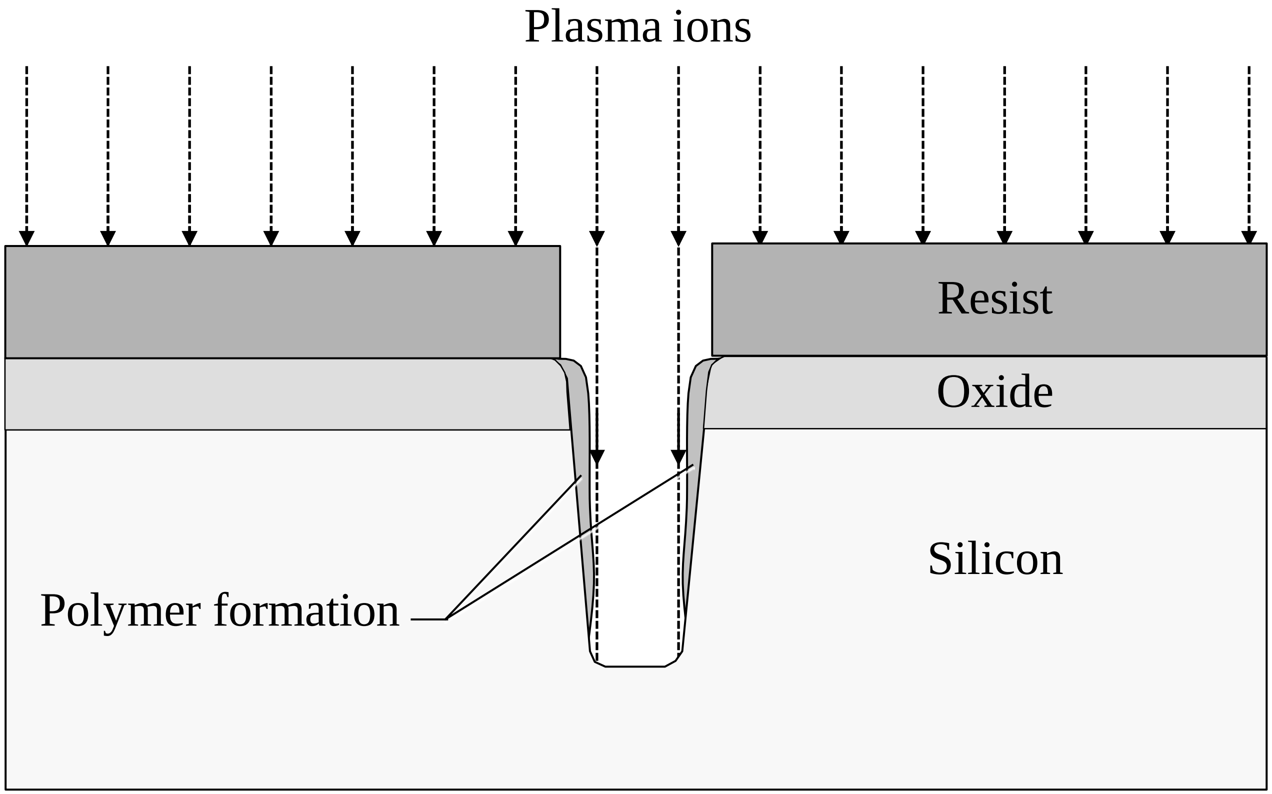
Randomly select 3 to 5 wafers in a lot



Measure etch rate at 5 to 9 locations on each wafer, then calculate etch uniformity for each wafer and compare wafer-to-wafer.



Polymer Sidewall Passivation for Increased Anisotropy



Dry Etch

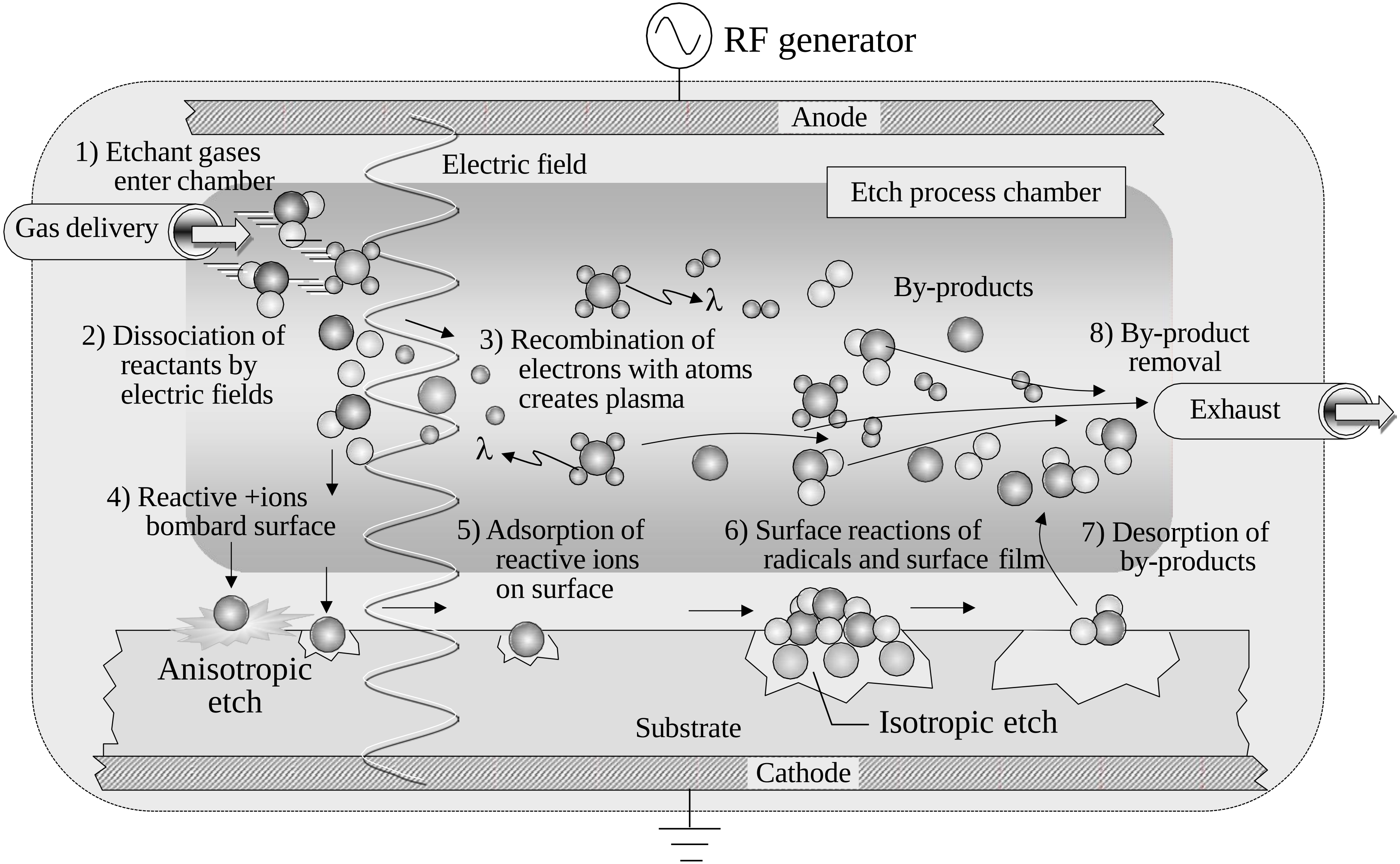
- Advantages of Dry Etch over Wet Etch
- Etching Action
- Potential Distribution

Advantages of Dry Etch over Wet Etch

1. Etch profile is anisotropic with excellent control of side wall profiles.
2. Good CD control.
3. Minimal resist lifting or adhesion problems.
4. Good etch uniformity within wafer, wafer-to-wafer and lot-to-lot.
5. Lower chemical costs for usage and disposal.

Table 16.2

Plasma Etch Process of a Silicon Wafer



RF generator

Anode

Electric field

Etch process chamber

1) Etchant gases enter chamber

Gas delivery

2) Dissociation of reactants by electric fields

3) Recombination of electrons with atoms creates plasma

By-products

8) By-product removal

Exhaust

4) Reactive +ions bombard surface

5) Adsorption of reactive ions on surface

6) Surface reactions of radicals and surface film

7) Desorption of by-products

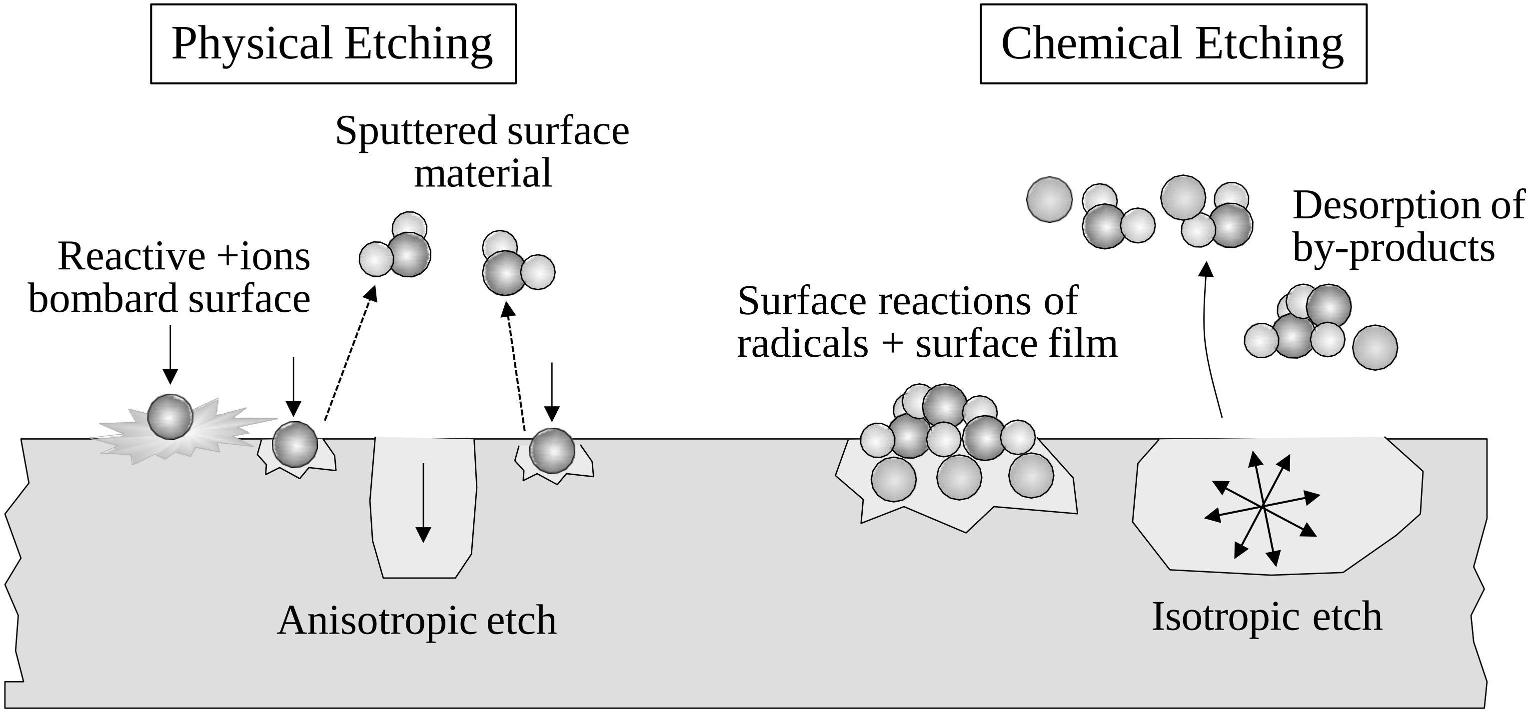
Anisotropic etch

Substrate

Isotropic etch

Cathode

Chemical and Physical Dry Etch Mechanisms



Chemical Versus Physical Dry Plasma Etching

Etch Parameter	Physical Etch (RF field perpendicular to wafer surface)	Physical Etch (RF field parallel to wafer surface)	Chemical Etch	Combined Physical and Chemical
Etch Mechanism	Physical ion sputtering	Radicals in plasma reacting with wafer surface*	Radicals in liquid reacting with wafer surface	In dry etch, etching includes ion sputtering and radicals reacting with wafer surface
Sidewall Profile	Anisotropic	Isotropic	Isotropic	Isotropic to Anisotropic
Selectivity	Poor/difficult to increase (1:1)	Fair/good (5:1 to 100:1)	Good/excellent (up to 500:1)	Fair/good (5:1 to 100:1)
Etch Rate	High	Moderate	Low	Moderate
CD Control	Fair/good	Poor	Poor to non-existent	Good/excellent

* Used primarily for stripping and etchback operations.

Plasma Etch Reactors

- Barrel plasma etcher
- Parallel plate (planar) reactor
- Downstream etch systems
- Triode planar reactor
- Ion beam milling
- Reactive ion etch (RIE)
- High-density plasma etchers

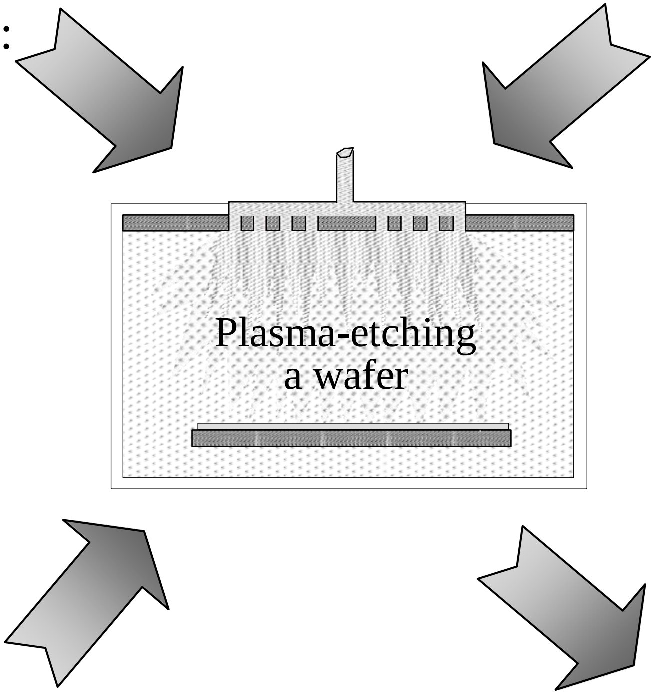
Dry Etch Applications

- Dielectric Dry Etch
  - Oxide
  - Silicon Nitride
- Silicon Dry Etch
  - Polysilicon
  - Single-Crystal Silicon
- Metal Dry Etch
  - Aluminum and Metal Stacks
  - Tungsten Etchback
  - Contact Metal Etch

Requirements for Successful Dry Etch

1. High selectivity to avoid etching materials that are not to be etched (primarily photoresist and underlying materials).
2. Fast etch rate to achieve an acceptable throughput of wafers.
3. Good sidewall profile control.
4. Good etch uniformity across the wafer.
5. Low device damage.
6. Wide process latitude for manufacturing.

Dry Etch Critical Parameters



Equipment Parameters:

- Equipment design
- Source power
- Source frequency
- Pressure
- Temperature
- Gas-flow rate
- Vacuum conditions
- Process recipe

Process Parameters:

- Plasma-surface interaction:
  - Surface material
  - Material stack of different layers
  - Surface temperature
  - Surface charge
  - Surface topography
- Chemical and physical requirements
- Time

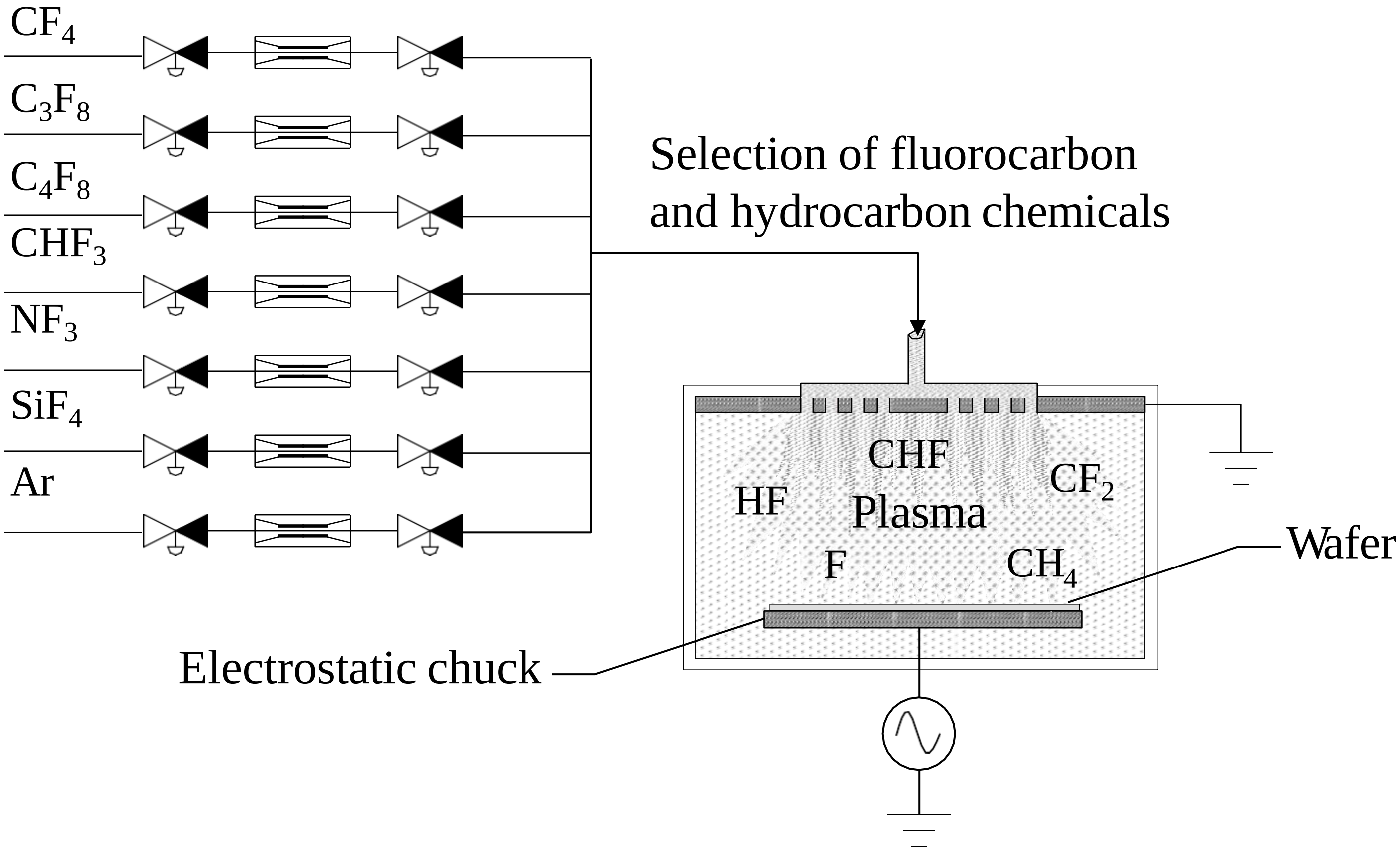
Other Contributing Factors:

- Cleanroom protocol
- Operating procedures
- Maintenance procedures
- Preventive maintenance schedule

Quality Measures:

- Etch rate
- Selectivity
- Uniformity
- Feature profile
- Critical dimensions
- Residue

Oxide Etch Reactor



Selection of fluorocarbon and hydrocarbon chemicals

Electrostatic chuck

Wet Etch

- Wet Etch Parameters
- Types of Wet Etch
  - Wet Oxide Etch
  - Wet Chemical Strips

Wet Etch Parameters

Parameter	Explanation	Difficulty to Control
Concentration	Solution concentration (e.g., ratio of NH4F:HF for etch an oxide).	Most difficult parameter to control because the bath concentration is continually changing.
Time	Time of wafer immersion in the wet chemical bath.	Relatively easy to control.
Temperature	Temperature of wet chemical bath.	Relatively easy to control.
Agitation	Agitation of the solution bath.	Moderate difficulty to properly control.

Table 16.7

Approximate Oxide Etch Rates in BHF Solution at 25° C

Table 16.8[1] Approximate Oxide Etch Rates in BHF Solution at 25°C[a]

Type of Oxide	**Density (g/cm^3)**	**Etch Rate (nm/s)**
Dry grown	2.24 – 2.27	1
Wet grown	2.18 – 2.21	1.5
CVD deposited	< 2.00	1.5[b] – 5[c]
Sputtered	< 2.00	10 – 20

a) 10 parts of 454 g NH_4F in 680 ml H_2O and one part 48% HF
b) Annealed at approximately 1000°C for 10 minutes
c) Not annealed

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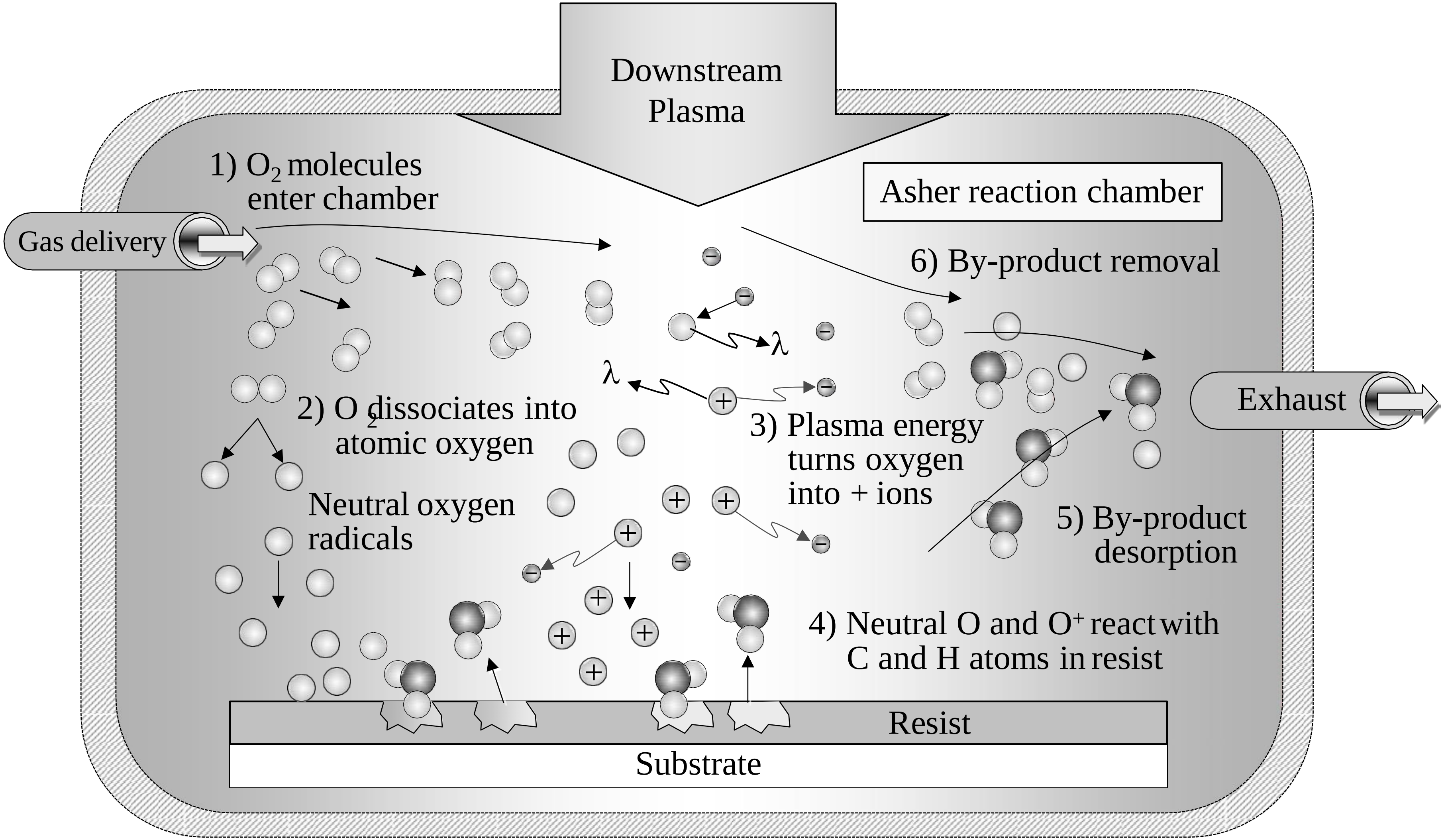
[1] B. El-Kareh, ibid, p. 277.

Photoresist Removal

Plasma Ashing

- Asher Overview
- Plasma Damage
- Residue Removal

Atomic Oxygen Reaction with Resist in Asher



1) O_2 molecules enter chamber

2) O_2 dissociates into atomic oxygen

Neutral oxygen radicals

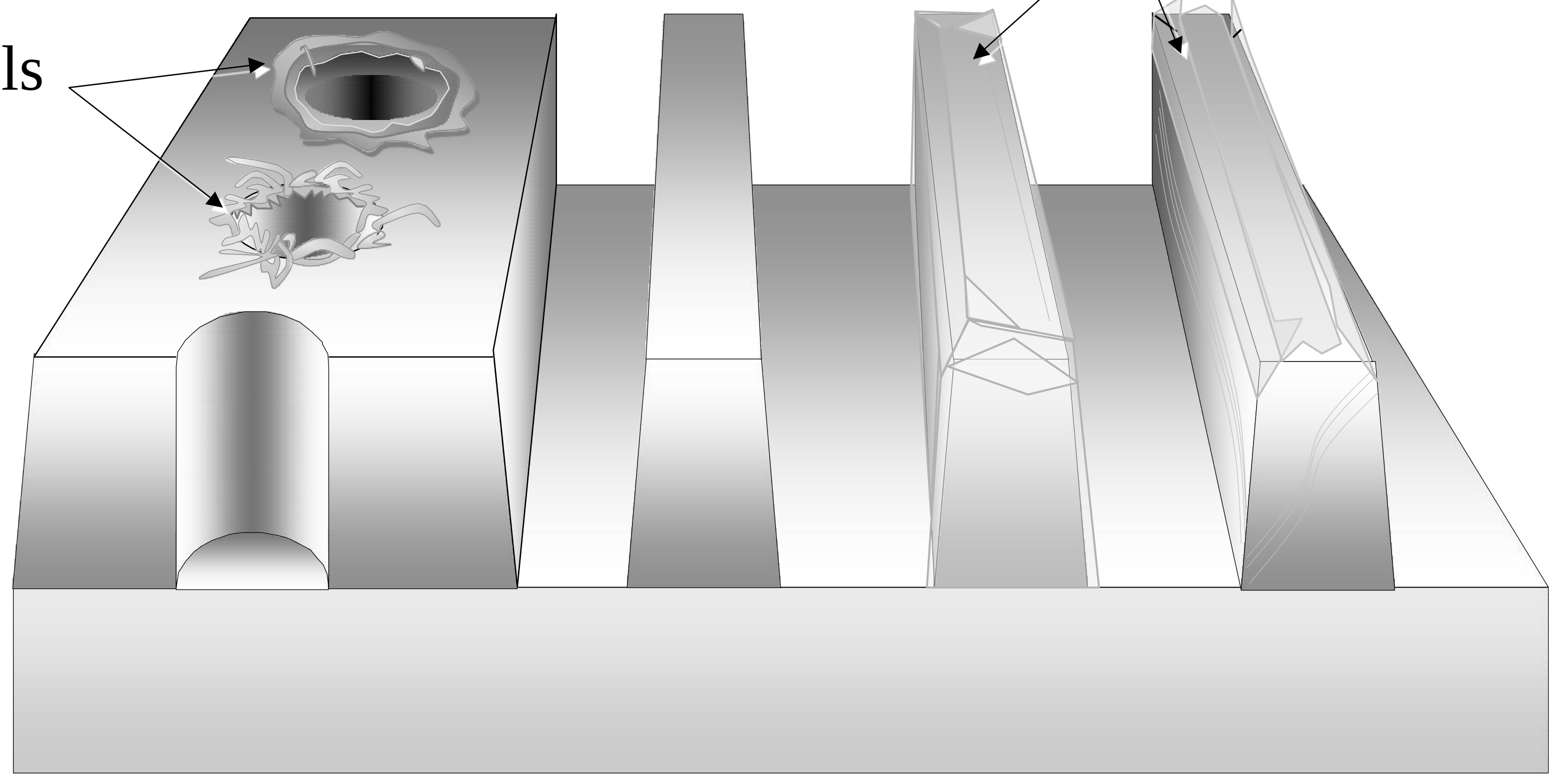
3) Plasma energy turns oxygen into + ions

4) Neutral O and O^+ react with C and H atoms in resist

5) By-product desorption

6) By-product removal

Post Etch Via Veil Residue



Polymer residue

Via veils

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