B.Tech. (ECE) VI Sem
Unit-3
VLSI Technology (BEC-35)

Etching Introduction and Its Classification

(Description in Bottom of Each PPTs)

PART-IV

March-April 2020

LEARNING OBJECTIVES

- **The learner will be able to Describe**
  - The purpose of Etch processes
  - Terms associated to describe etch processes
  - Differences between and uses of wet and dry etch methods
  - Dry etch types
  - The advantages of plasma enhancement
  - New etching methods for nanomanufacturing

NEED OF ETCH

- To remove material from areas identified by the lithography process
  - Areas of photoresist exposed to light
  - Developing leaves only these areas open
  - Etching removes substrate areas not masked
- To create structures for functional use
- To remove oxide layers below features to allow for motion

WHAT IS ETCHED AND WHY?

- Silicon
  - Pure silicon is highly reactive and forms SiO_2 from reaction with atmospheric oxygen
  - Patterning and removal of bulk structures
  - Sacrificial layer below moving features in MEMS
- Silicon Dioxide
  - A hard coating layer used as an insulator or a doping barrier
  - A critical layer in the construction of MOSFET devices

WHAT IS ETCHED AND WHY?

- Silicon Nitride
  - Hard, impervious protective layer
  - Remove areas for connections
- Aluminum
  - Conductor used for wiring
  - Removed for patterning wires
- Tungsten
  - Contact barrier/Interconnect/Via plug

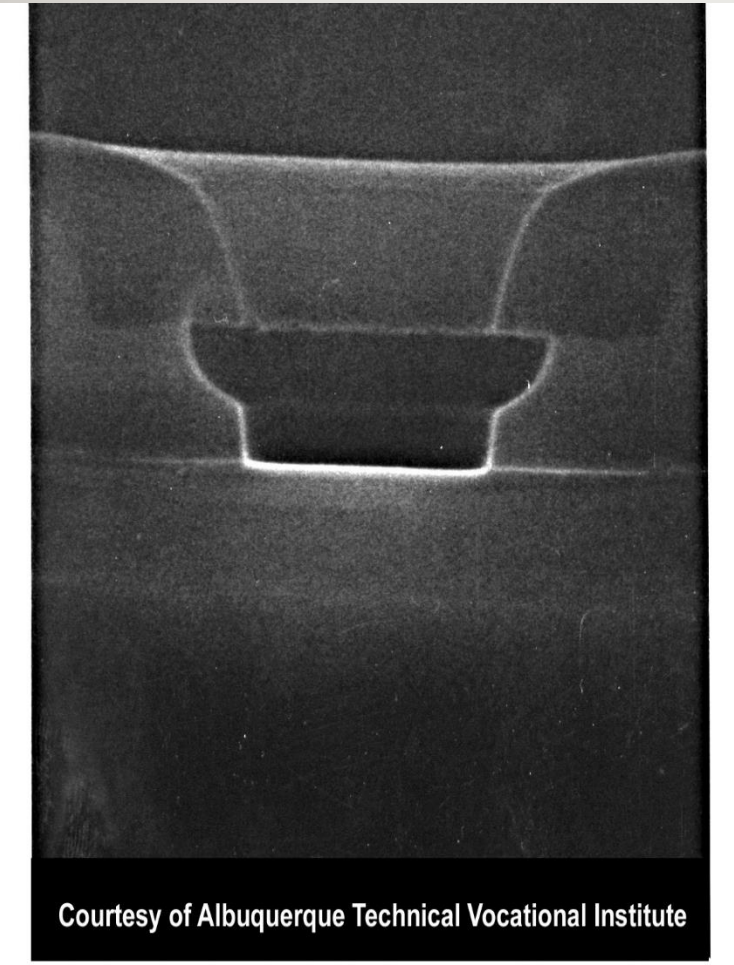
ETCH PROCESS PROPERTIES

- Any etch process is characterized by certain properties
  - **Etch Rate**
    - The amount of material removed from the wafer over a defined period of time
  - **Uniformity**
    - The evenness of the removal over the entire surface of the wafer

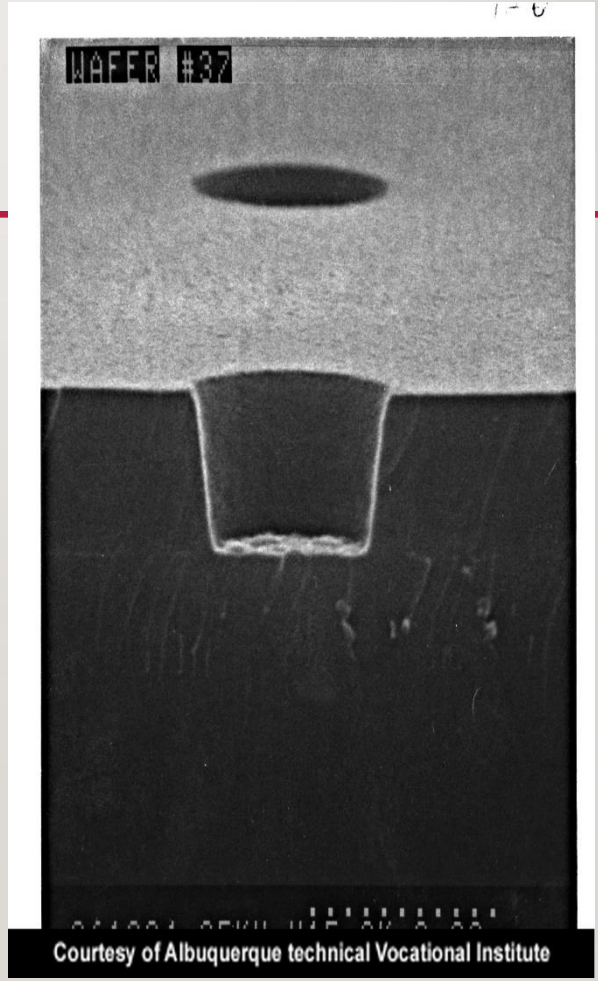
ETCH PROCESS PROPERTIES

- Any etch process is characterized by certain properties
  - **Profile**
    - **Isotropic** – Etching proceeds at equal rates in both horizontal and vertical direction
    - **Anisotropic** – Etching proceeds faster in one plane than in another
  - **Selectivity**
    - The ability of the etch process to distinguish between the layer to be etched and the material not to be etched

ETCH PROFILES



Isotropic Etch Profile



Anisotropic Etch Profile

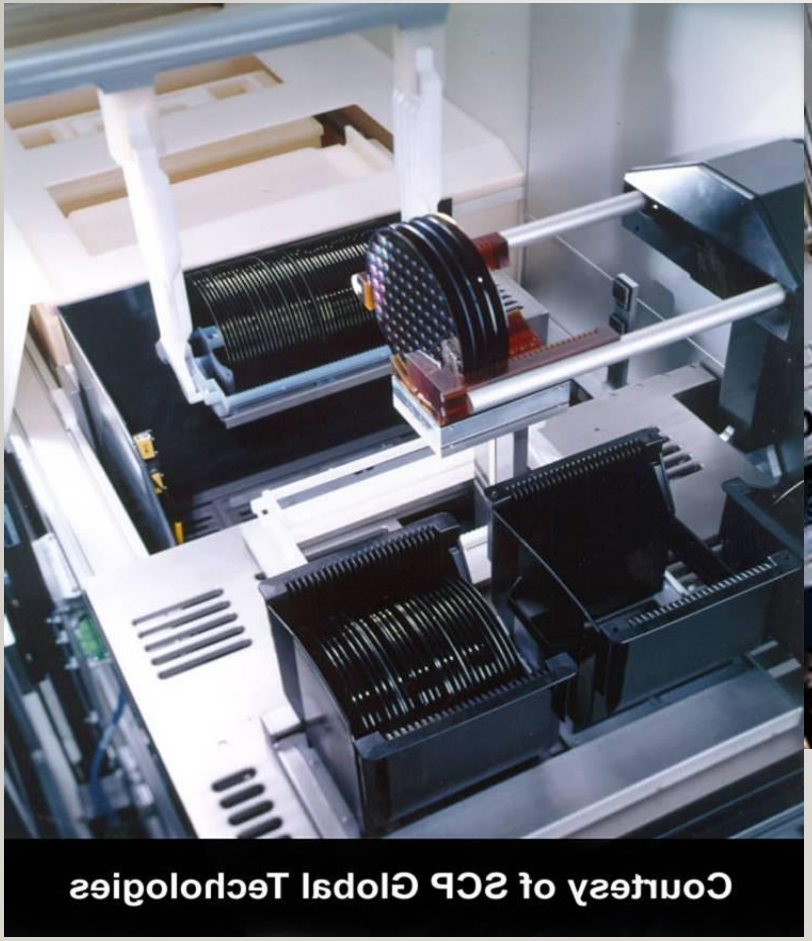
ETCHING – WET AND DRY

- Wet Etch is performed by immersing entire wafers in liquid etchant solutions.
  - Reaction is between surface layer exposed and etchant
  - Purely a chemical process
- Dry etching is performed by placing the wafer in a chamber and pumping in chemical vapors or using plasma
- Dry etching can be chemical, physical, or both in its etch.

WET ETCH

- Oxidation-reduction equations often define wet etch processes
  - Silicon etch with HNO_3 & HF
    - $Si + HNO_3 \text{ \& } HF \rightarrow H_2SiF_6 + HNO_2 + 2H_2O$
- Most Wet Etch Processes are Isotropic
  - Etch proceeds in both vertical and horizontal direction
  - Etch mixtures can change the etch rate or profile depending on silicon crystal orientation

WET ETCH PROCESS STEPS



Etch

Rinse

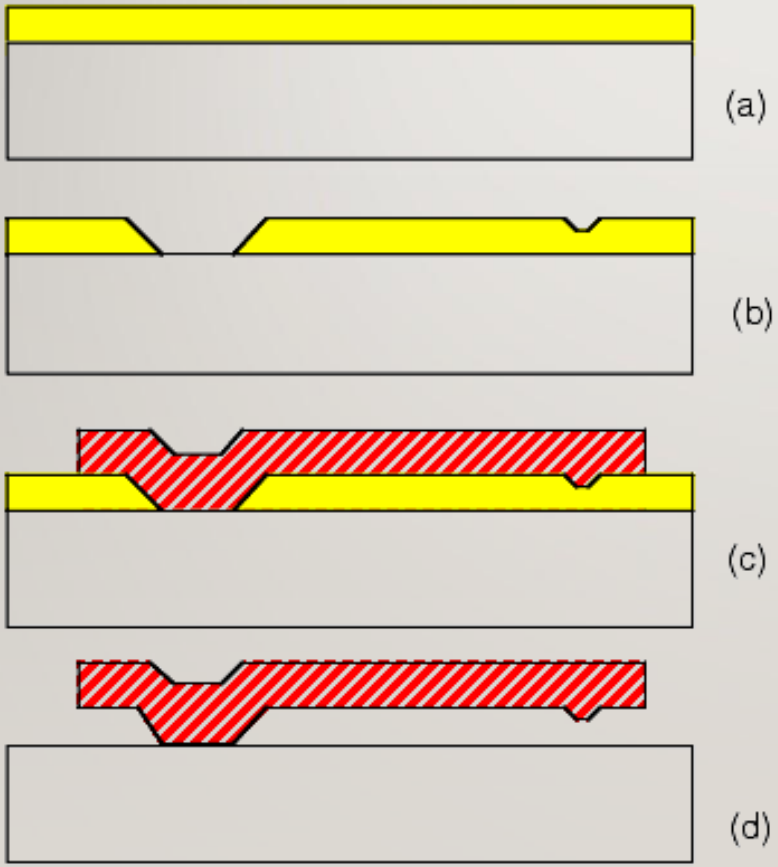
From MATEC Module 48

Dry

WET ETCH (2)

- Wet Etch processes can be batch processes where multiple wafers are etched at one time.
- Wet etch processes are limited to feature sizes of 3uM or larger, limiting their use in nanomanufacturing to bulk processes
- Wet etch can be used to remove sacrificial layers present in MEMS devices
- Wet etch is also used for resist stripping

CREATION AND ETCH OF SACRIFICIAL LAYER



- (a) Sacrificial Layer deposition
- (b) Patterning of layer
- (c) Metal Deposition
- (d) Etch of sacrificial layer to free feature

http://www.aero.org/publications/helvajian/helvajian-2.html

QUESTIONS FOR PRACTICE

Click once for each question.

1. What are the advantages of wet etch processes?

Low Cost, good throughput, good selectivity

2. What are disadvantages of wet etch processes?

Isotropic etch profiles, not usable for <3 uM features

3. What is an isotropic etch profile?

A profile where etching proceeds at equal amounts in all directions

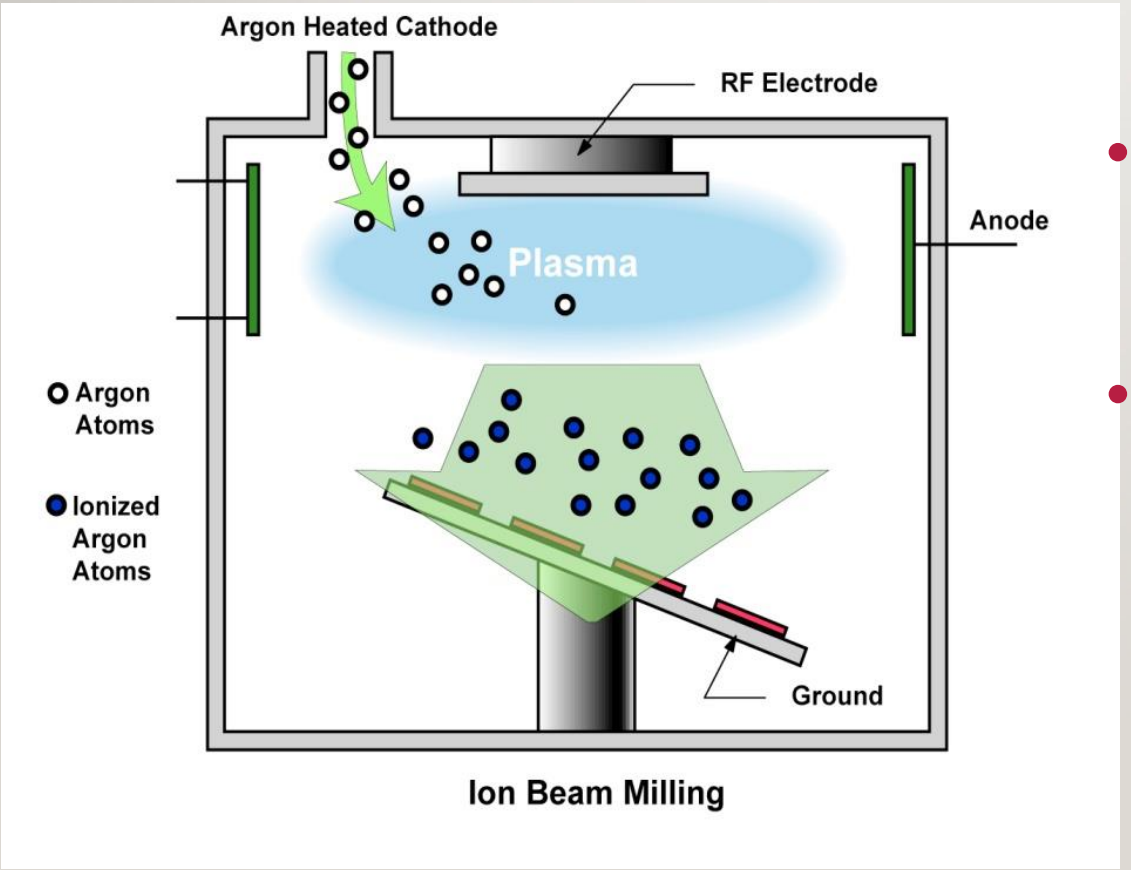
DRY ETCH METHODS

- Dry Etching can be a physical or chemical process (or both)
  - Ion Beam Etch - a physical etch process
  - Gaseous chemical etch
  - Plasma enhanced etch
  - Reactive Ion Etch
  - Deep Reactive Ion Etch

PHYSICAL DRY ETCH

- Sputtering (Ion Milling or Ion Beam Etch)
  - Reduced pressure environment (<50 mTorr)
    - Increases mean free path between molecules
      - Fewer collisions between molecules
  - Inert gas injected at low pressure is used as "milling" tool
  - RF Plasma in chamber
    - Energy transfer to gas molecules creates a plasma of equal numbers of ions and molecules
    - Positive ions bombard negatively charged target (wafer), removing molecules from the surface

ION MILLING (CONT'D)



- Plasma etch has low selectivity
- Plasma etch tends to be anisotropic
- High RF levels can cause damage to the wafer

DRY CHEMICAL ETCH

- Gaseous forms of chemicals are injected into a process chamber and the wafer is heated.
- Temperature is critical to etch rate.
- Reactivity between Fl with the surface occurs example: $Si + CF_4 \rightarrow SiF_3 + F$
- Generally isotropic in nature
- Although etching of the surface will occur, a much higher etch rate can result with plasma enhancement.

PRACTICE QUESTIONS

Click once for each question.

1. What are the advantages of dry etch processes?

Smaller features can be etched, anisotropic etch profiles are possible fewer liquid chemicals are required

2. What are disadvantages of dry etch processes?

Higher cost, more sophisticated equipment, etch rate

3. What is an anisotropic etch profile?

A profile where etching proceeds at a higher rate in a vertical direction than in the horizontal direction

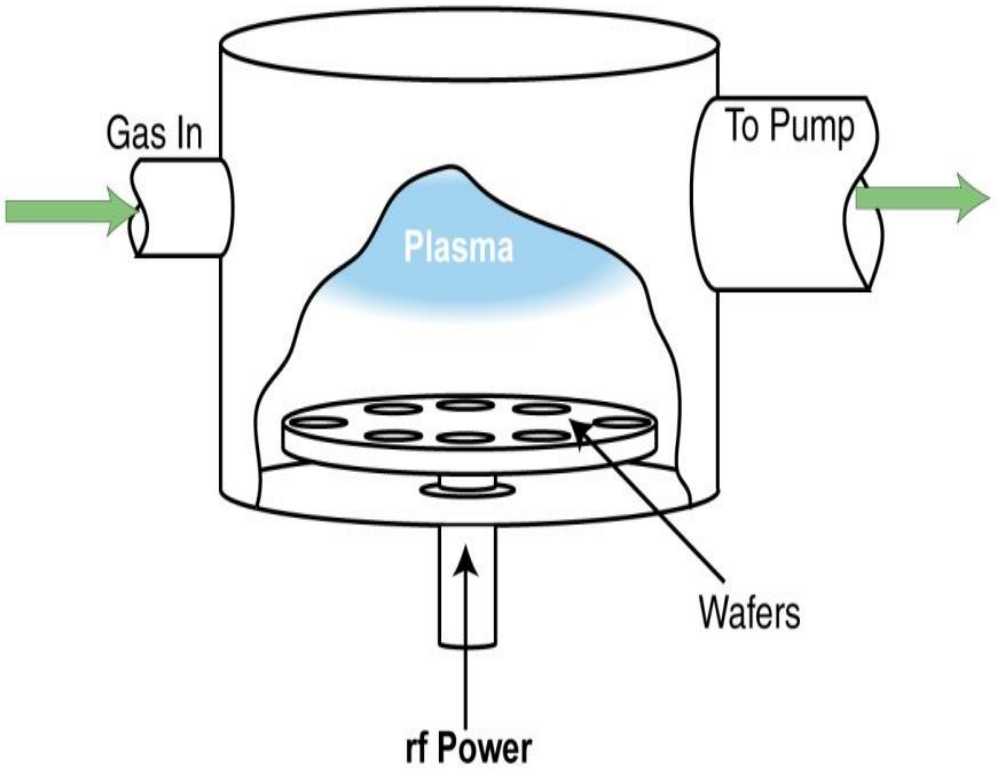
REMOTE PLASMA ETCH

- Gaseous species entering chamber pass by an externally generated RF Field.
- This causes the generation of free radicals that are highly reactive and speeds up the chemical etch process.
- No plasma in the chamber can avoid damage due to ion bombardment.

From MATEC Module 47

REACTIVE ION ETCH

- In RIE, a combination physical and chemical etching occurs.
- In this case, both Ar and the chemical gas are used
- Ar performs an ion milling physical etch and the chemical etch proceeds as well.



Reactive Ion Etcher

REACTIVE ION ETCH (2)

- RIE has the advantages of the physical ion milling etching and those of the dry chemical etch
- Anisotropic Profile
  - Higher Etch Rate than either process
  - Higher selectivity ratio than physical etch
  - Smaller feature sizes possible
- RIE has become the process of choice

PRACTICE QUESTIONS

Click once for each question.

1. What advantage does plasma provide in dry etch?

Plasma creates radicals and ions in the gas that more actively etch the wafer

2. What process does plasma etch use?

Sputtering, ion milling or physical etching

3. What type of process is Reactive Ion Etching?

A physical and chemical etch process

DEEP REACTIVE ION ETCH

- High Aspect ratio features (narrow, tall) require vertical sidewalls
- Bosch DRIE process uses alternative etch and passivation technique to etch vertically and protect sidewalls with passivation coating
- Cryrogenic process uses low temperatures and simultaneously passivates and etches

DRY ETCH PARAMETERS (1)

- **Factors Influencing Dry Etch Process**
- **Etch rate**
  - RF Power level
  - Gas formula
  - Etch Temperature
- **Pressure**

- Extremely high pressure results in an isotropic etc
- Low pressure with high energy can damage wafer

DRY ETCH CONCERNS

- **Factors Influencing Dry Etch Process**
- **Micro-loading**
  - Different etch rates across wafer surface
  - Ashing can occur
- **Post-etch corrosion**
  - Due to residual etchant left on wafer after final rinse
  - Using a non- chlorine based etchant such as fluorine Eliminates the problem.

Taken directly from MATEC Module 47

References

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