Building College-University
Partnerships for Nanotechnology
Workforce Development

Plasmas and Materials

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Outline

- Introduction
- Models to understand the plasma process
- Chemistry
- Analyzing recipe parameters, and the resultant etch profiles
- Endpoint

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Introduction

- Reactive Ion Etching (RIE): An etch process where a substrate is placed on an RF-powered electrode to achieve a chemical and physical etch
- Aspect Ratio: The ratio of the depth to width for a small gap, tech, or hole
- DC Bias: A DC volt that develops across a plasma process chamber when an RF voltage is applied to the chamber's electrodes
- Mean Free Path: The average distance an atom or molecule travels before striking another atom or molecule
- Radicals: Molecules or fragments that contain unsatisfied bonds (unpaired electrons). They are extremely reactive

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Introduction

- <u>Ions:</u> Are atoms, molecules or pieces of molecules that have gained or lost electrons. They can be negatively (anions) or positively charged (cations)
- <u>Etch Rate</u>: The speed at which a material is removed from a substrate during etching
- <u>Residence Time</u>: The average time gas (etch chemistry, byproducts) is present in a vacuum chamber
- <u>Dark Sheath</u>: Area adjacent to plasma generating electrodes that appears darker than the rest of the plasma (glow region). The dark sheath (or ion sheath) is a result of a lack of electrons and has a stronger electric field as well as less resistance compared to the glow region
- <u>Sheath Potential</u>: The potential difference between the glow region of the plasma and the cathode in a dry etch system

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Limits of Wet Etch Illustrates the Need for Plasma Processing

- Wet etching is limited to ~ 2-3 μm pattern features due to liquid trapping / surface tension (dependent upon materials)
- Wet etching tends to undercut and produce sloped sidewalls
- Wet etching needs rinse and dry steps
- Wet chemicals can be hazardous, toxic and expensive (environmental concerns)
- Wet processes present material contamination issues

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Plasma Etching

- Plasma etching is a balance between:
  - Selective removal (what is intended vs. what is protected) of material through chemical reactions
  - Nonselective removal of material through ion bombardment (pressure and power related)
  - Deposition of sidewall polymers for passivation
  - Varying these parameters determines the etch profile

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Plasma

- Within a plasma, there are a number of species
  - Radicals
  - Ions
  - Neutrals
  - Electrons
  - Film formers
    - if desired, for sidewall passivation in etch processes
  - Diluents

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Contents of a Plasma

- A dry plasma etch may contain:
  - Radicals that chemically react with the substrate and **selectively** remove material
  - Ions that remove material through **physical bombardment** (no selectivity) and provide uniformity
  - Neutrals
  - Electrons aid in sustaining the plasma
  - Film formers that provide sidewall passivation (optional)
  - **Diluents**- an inert gas introduced into the reaction chamber along with the process gasses to maintain the desired reaction rate (optional)

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Selective Etching

- Etching that is done so that certain material is removed, but other materials or areas of the materials are ideally not affected
- Selective etching is difficult to achieve when chemically different layers form similar etch products
  - Example: SiO_2, Si, and Si_3N_4 each form SiF_4 during the etching process (↓ selectivity)

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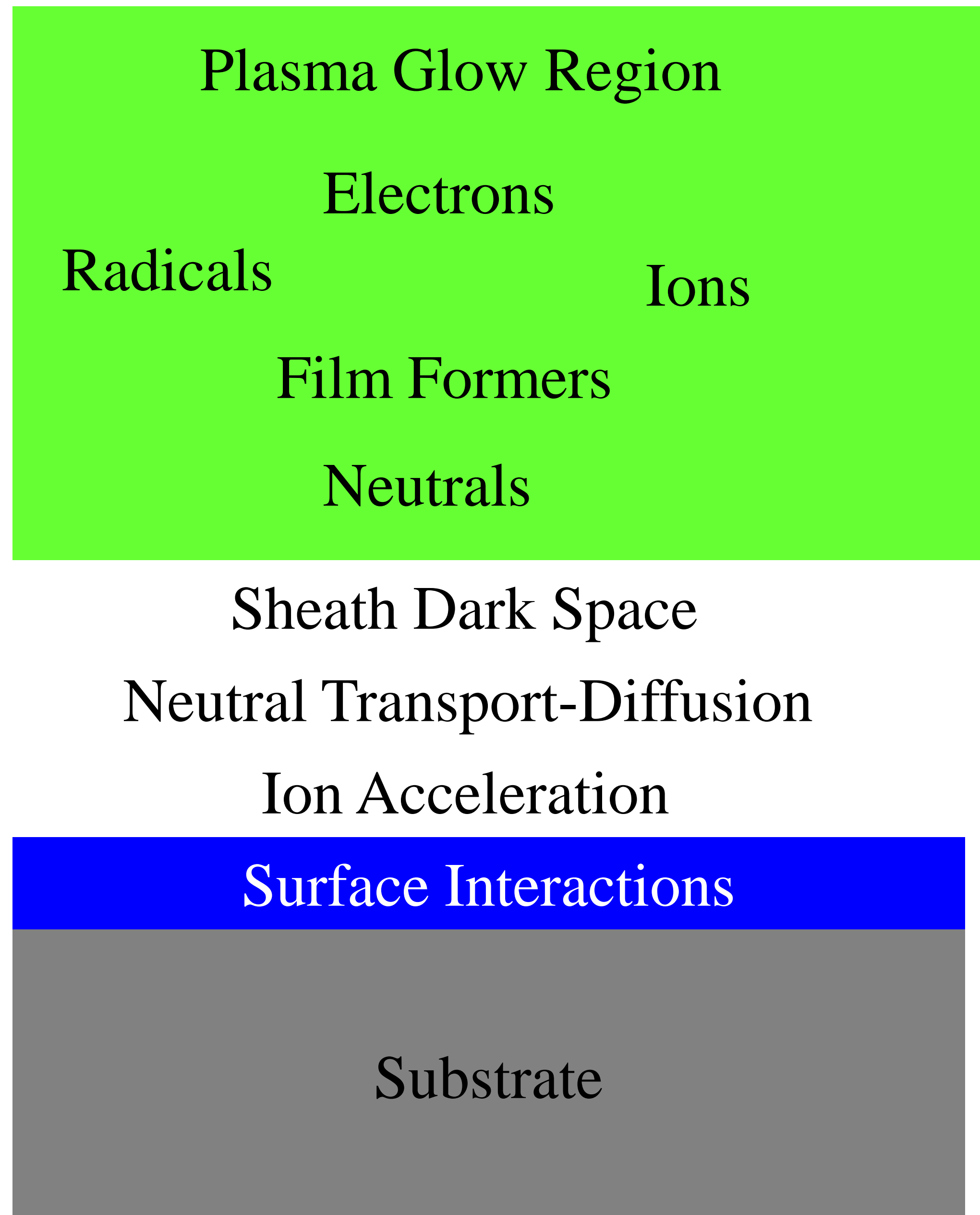
Simplified Plasma Model



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Ions vs. Radicals in a Plasma

- Radicals are molecules or pieces of molecules that contain unsatisfied bonds (unpaired electrons)
- Ions are molecules or pieces of molecules that are negatively or positively charged. We generally are concerned with the positive ions for focused bombardment, because they can be easily drawn to the cathode which holds the sample

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Plasma in Terms of Temperature, Chemistry, and Bombardment

- Chemistry = Selectivity
  - Radicals react with surface to form volatile etch products that are pumped away
  - Selectivity, properly tuned chemistry can result in some materials being etched more than others
- Bombardment = Uniformity
  - Ions accelerated by the voltage difference between the plasma and the surface being etched strike the substrate and remove material by kinetic energy. Bombardment energy also aids surface chemical reactions. Bombardment is a power and pressure regulated process
- Temperature = Rate
  - Average plasma temperature (for a low density plasma) is about 100°C plus room temperature, low enough for virtually any process, including photoresist
- Etch profile is a result of the energies at the substrate. C*B+T

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Pressure

- Pressure has the largest impact on plasma etching. It is the “big control knob”
- Pressure affects:
  - Mean free path (MFP)
  - Collisions at the material interface (substrate)
  - Etch profile: isotropic or anisotropic
  - Residence time
  - Microloading

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Pressure

- Pressure affects the MFP, which controls, among other things, the degree of ionization and thus the number of ions available for physical bombardment
- MFP (bombardment) gets larger as pressure is reduced, naturally the amount of chemistry (etching gas, etch byproducts) is reduced when the pressure is decreased
- A low pressure will increase bombardment, and uniformity, but decrease selectivity
- A high pressure will decrease bombardment, and decrease uniformity, but will generally increase selectivity

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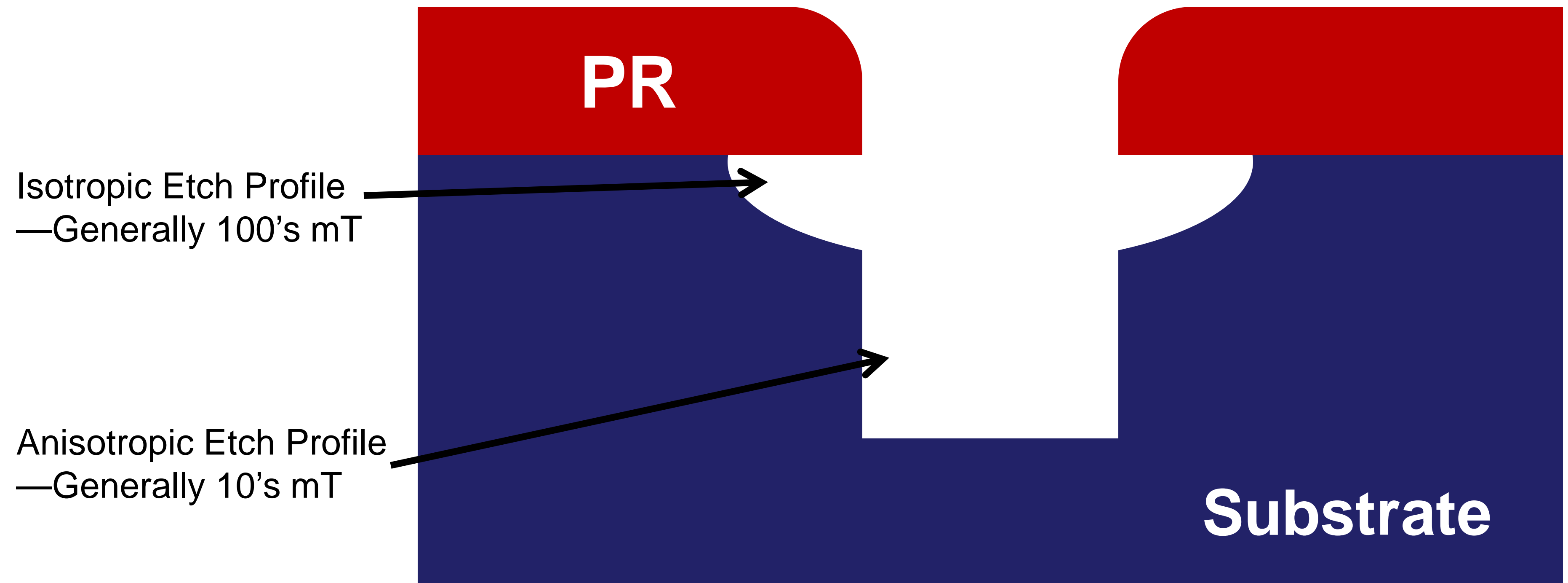
The “Wine Glass” Etch Profile (RIE)



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Power

- Power also affects ionization
- As power increases, ionization increases
- Power and pressure are inter-related: the effect of power depends on the operating pressure.

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Minimum Energy Required to Ionize a Particle

Particle	Energy(eV)	Particle	Energy(eV)
H	13.5	H_2	15.4
He	24.5	N_2	15.5
N	14.5	O_2	12.2
O	13.5	Cl_2	12
F	17.4	Br_2	11
Cl	13	BCl_3	11
Ar	15.7		

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The Six Steps of Plasma Etching

1. Reactive etching species are generated by electron/molecule collisions
2. Etchant species diffuse through stagnant region to the surface of the film to be etched
3. Etchant species adsorb onto surface (ion bombardment can help provide energy to drive chemical reactions)
4. Reaction takes place at the surface
5. Etched product desorbs from the surface (ion bombardment can help provide energy for desorption)
6. Etch products diffuse back into bulk gas and are removed by vacuum

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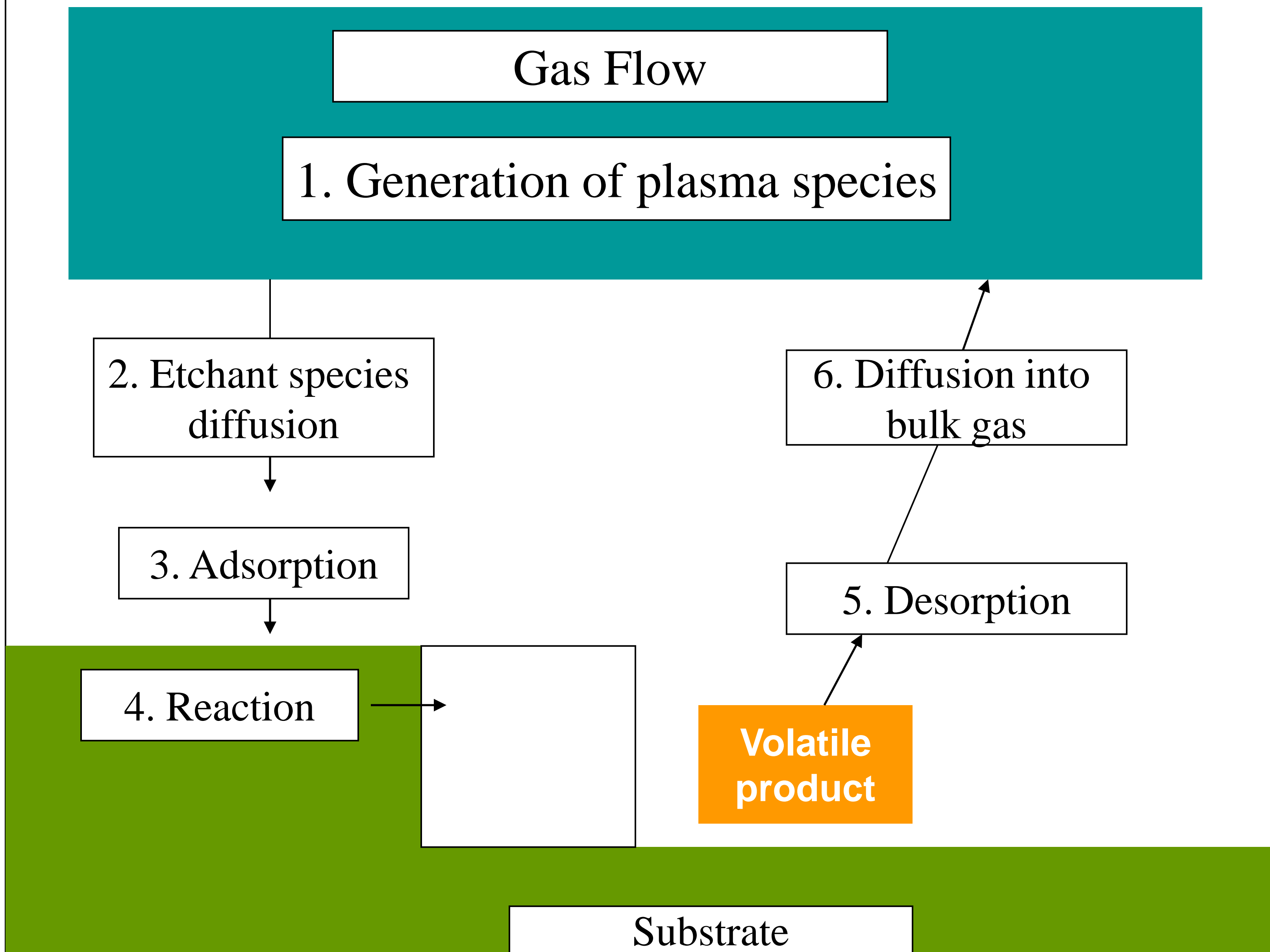

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