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Low Temperature Plasmas I)

- Irving Langmuir → Birth of plasma science, worked @ university initially, went to GE (Edisons company)
  - Realized noble gases last longer than others, coined the term plasma.
    - ⇒ Specifically started studying low temp plasma.

How to make them)

- Vacuum chamber, gas inside, applied electric field.

- Plasmas are collisional and radiative processes.
  - Can look @ many different collision scenarios (e^- + Molecule, etc.)
    - → The collisions yield many different results (ionization, etc), and get a result based on products from neutral collision.

- Low Temp Plas → Non-equilibrium (Non-Thermal)
  - ⇒ $T_e >> T_i, T_n$ w/ $T_i \approx T_n$
  - Temps range from 350 K → 2,500 K

Langmuir Probe → Measure current, electron density.

PPPL has a remote glow discharge Experiment

Low-temp plasmas are used to etch holes, etc into silicon for use in semiconductors
- Can be expensive, electron beam lithography is expensive, why we wanted to do colloidal stuff w/ Dr. Pfeil.

LTP are easily generated @ low pressure, but its expensive.
- Push now for LTP formation @ atmosphere pressure, but they're unstable
  - → Alternative is to decrease seperation to μm's ~~the~~ btwn anode/cathode.

Werner Siemens was studying plasmas. Huh! Ended up making O_3 generators using

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Low Temperature Plasma I

- Generated O_3 can be used as bubble filters for water treatment applications.

- Atmospheric pressure plasma jets can interact w/ organic material!

- Microplasmas can be used as antibacterial! They rupture the cell walls/membrane and kill microbes!

- Plasma medicine ⇒ Used to treat cancer (in naked mice)
- Can also treat teeth enamel for ~~wter~~ brightness.
- Plasma treatment to basil seeds dramatically increases growth.
  - Changes the biochemistry!
- Treatment w/ APPJ on living tissue is a viable option for wound healing in pigs. Super Crazy!!

8/11) Low Temp Plasma II)

- Low temp plasma industries, multiple multibillion dollar industries.
  - Semiconducting silicon chips → \$20B/year industry.
  - Thin films,
  - Electric propulsion ⇒ moving satellites in orbits → Plasma Thrusters
  - Nanomaterial synthesis ⇒ nanotubes, etc.
  - Plasma manufacturing (welding, cutting)
  - Plasma physics for electric grids + pulsed power (breakers and stuff)

- Semiconductor industry incentivized companies to open in USA and stay in USA
  - CHIPS for America Act.
  - American Companies invested \$40B in 2019.
  - Trying to stay competitive w/ China, Taiwan, etc.

⟹

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Low Temperature Plasmas II)

- Plasma Sources for semiconductor manufacturing
  - Capacitively - coupled plasmas CCP.
  - Inductively - coupled discharges ICP.
  - Electron and Ion beams → Generated by plasma processing system.

- Plasma needs to be considered using kinetic theory.
  - Need to recall that LTP are NOT in thermal equilibrium ($T_e >> T_i$)
  - Electron ion, photon energy distribution functions are all NON Maxwellian

CCP + ICP Typical Parameters

- Density $n = 10^9 - 10^{13}$ $1/cm^3$
- Gas pressure = few mTorr
- Small degree of ionization

Global Model ⇒ Particle balance determines T_e

- We can model electron temperature as a function of gas pressure.

Discharge modeling needs to be kinetic b/c e^- energy distrib. fxn is non maxwellian

EEDF ⇒ Electron energy distribution function.

- e^-, e^- collisions make the electron energy a Maxwellian.
  - ↳ Maybe b/c collisions is a kinetic process.

Semiconductors → Atomic Layer Deposition

→ Hard to control process, 

ALD lets you deposit one monolayer at a time, very smooth, very controllable.

Non maxwellian DF's in LTP's Let us select the amount of cold electrons, hot electrons; gives us more control over the process.

Low Temperature III)

Optical Diagnostics to Characterize Plasma

- Ultrafast femtosecond lasers:
  - TALIF, REMPI, FLEET, CARS, E-FISH

↳ Send photon in, gets absorbed, look @ emitted photon to characterize the molecule involved.