EE669

Thin Film Deposition

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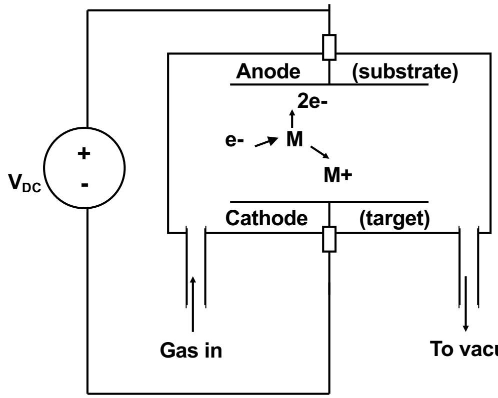
Basics of DC Plasma

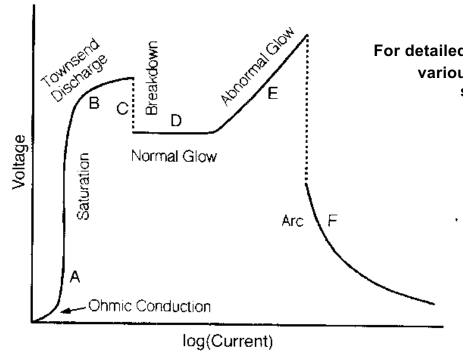


Pressure ~ 1 torr
Mean free path,
λ ~ 50 µm

2

Basics of DC Plasma (2)

Current – Voltage characteristics

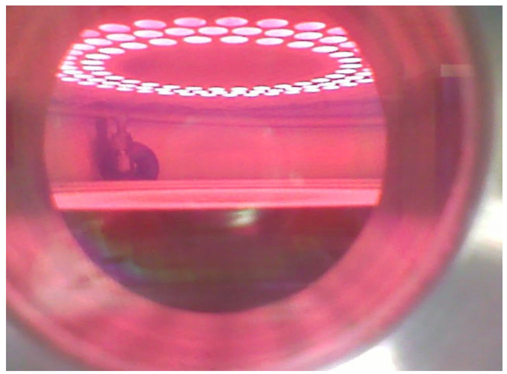


For detailed description of various regimes, see supplementary.

John E. Mahan, "Physical Vapor Deposition of Thin Films", John Wiley and Sons, 2000

3

Glow Discharge



S. Paluri, IITB-NF

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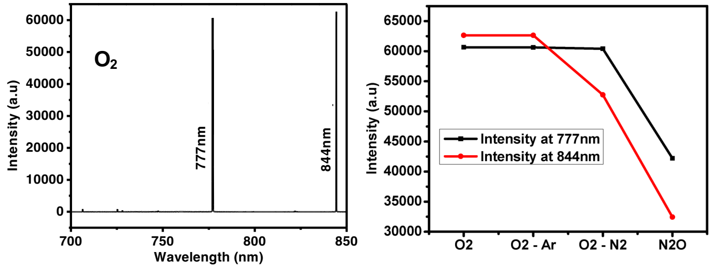
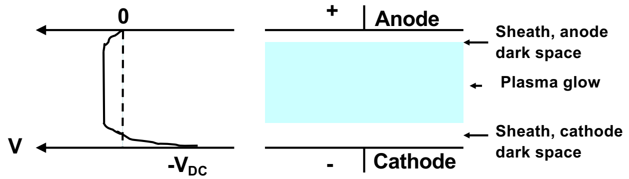
Use of Optical Emission Spectroscopy (OES) to analyze plasmas.



Sandeep S. S., Anil K., IEEE PVSC conference 2012, EUPV 2013, IEEE EDL 2013

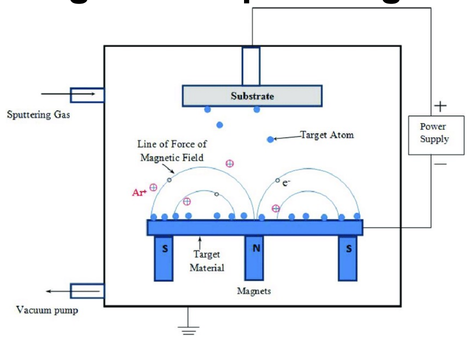
Another tool to investigate plasmas is a Langmuir Probe.

Basics of DC Plasma (3)



- Breakdown and glow regimes
  - Spatial rearrangement in the discharge
  - Ions are heavier than electrons => Ar^+ is ~10^6 heavier than an electron => leads to formation of sheaths
  - Plasma is highly conducting, no electric field in the plasma
  - Plasma is sustained by the following process
    - Ions are accelerated towards the cathode, impinge on the cathode causing secondary electron emission
    - The SE's get accelerated towards the plasma, cause impact ionization
  - Glow due to radiative relaxation of excited neutral species

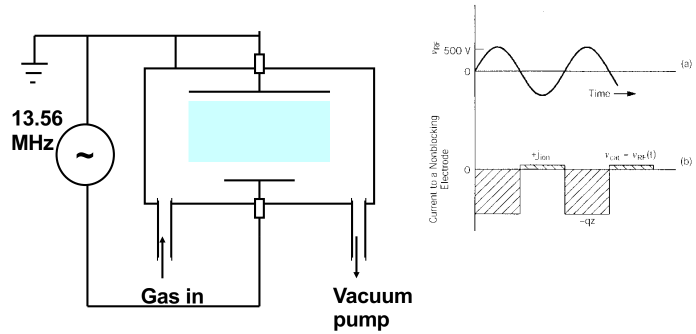
Magnetron Sputtering Principle



- Improves the sputtering efficiency and hence faster deposition
- Almost all sputtering systems (DC/RF/pulsed DC) use magnetrons
- Less effective for sputtering magnetic materials like Ni, Fe, Co

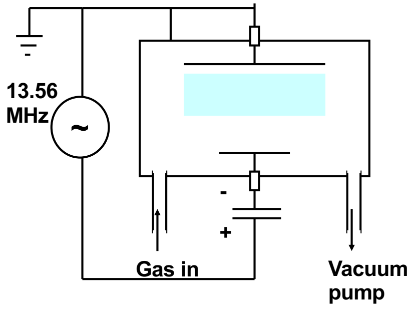
Jain et al., Metal Deposition: Plasma-Based Processes. 10.1081/E-EPLT-120053919, 2016

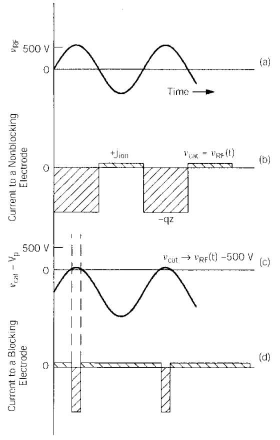
Basics of RF Plasma



John E. Mahan, "Physical Vapor Deposition of Thin Films", John Wiley and Sons, 2000

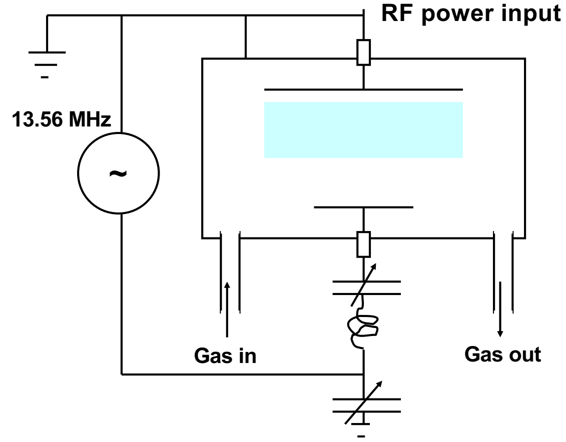
Basics of RF Plasma





A self bias would be developed across the capacitor.

Basics of RF Plasma (3)



Typical DC or RF plasma

- 1 torr (133 Pa) of Ar gas

$$PV = nRT$$

$$\frac{n}{V} = \frac{P}{RT}$$

- P – pressure in Pascals
- R ideal gas constant = 8.314472 $J.K^{-1}.mol^{-1}$
- T – Temperature in Kelvin
- V is the volume and "n" the number of moles of the gas
- Density of gas molecules at 300K, 0.8 mTorr ~ 3 x 10^{16} cm^{-3}
- Typical ion and electron density in the plasma = 10^{10} cm^{-3}
- Neutral species temperature = 300K, Positive ion temperature ~ 500K, electron temperature ~ 23000 K

John E. Mahan, "Physical Vapor Deposition of Thin Films", John Wiley and Sons, 2000

Basics of Plasma

Electron – impact reactions in the plasma

Excitation

$$e + X_2 \Rightarrow X_2^* + e$$

Dissociation

$$e + X_2 \Rightarrow 2X + e$$

Ionization

$$e + X_2 \Rightarrow X_2^+ + 2e$$

Dissociative ionization

$$e + X_2 \Rightarrow X^+ + X + 2e$$

Result: free radicals, ions and electrons

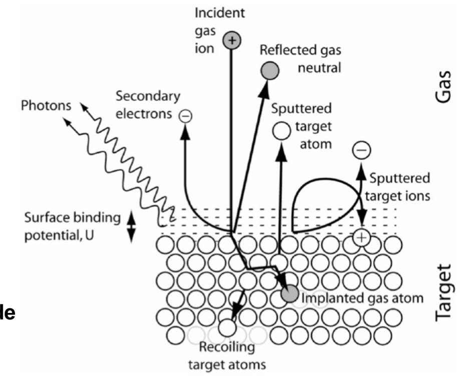
Hess and Graves, Chapter 7 in Chemical Vapor Deposition Principles and Applications, edited by Hitchman and Jensen, Academic Press, 1993

Processes of Interest in PVD

- Ions accelerated towards the cathode => sputtering
- Transport of the sputtered material through the plasma
  - Reactions, if any reactive species is available. For example, the deposition of TiN and TaN from Ti or Ta target in Ar + N_2
- Fast moving particles impinging the substrate from the plasma
  - Target ions or neutral species => deposition
  - Electrons
  - Ions of the sputtering gas (Ar, Xe,……)

$\left.\begin{matrix}\text{Electrons} \\ \text{Ions of the sputtering gas (Ar, Xe,……)}\end{matrix}\right\}$ Modification of deposited film

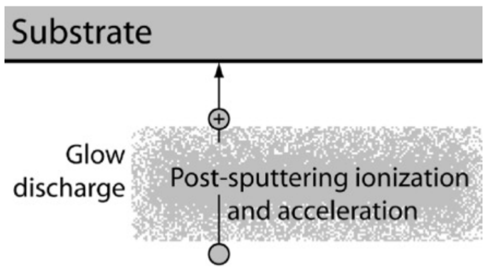
Sputtering Process



Cathode

Angus Rockett, “Material Science of Semiconductors”, Springer Verlag, 2008

Energetic particles impinging on the substrate



Anode

Angus Rockett, “Material Science of Semiconductors”, Springer Verlag, 2008