

# Plasma Processing Technology

Final(100min, close book)

Jan. 8, 2013

- (a) Calculate the distance in cm between the electrodes at the minimum breakdown potential ( $V_b$ ) for an Ar discharge ( $C_2=2.5$ ) at  $P=0.02$  torr.

(b) Discuss (i) the requirements for the formation of negative ions, and (ii) the effect of negative ions on the stability of a specific plasma.

(c) (i) Give the plasma chemistry of the Penning ionization using argon to illustrate your point, and (ii) what are the necessary conditions for the Penning ionization to take place?
- (a) Give the electrical circuitry of a single Langmuir probe for extracting a result of current density ( $J$ ) at the applied potential ( $V$ ) in a plasma, using an X-Y recorder.

(b) A pair of  $J$  and  $V$  has been taken from the linear portion of the  $J$ - $V$  curve; they are (0.001A; 2V) and (0.003A; 12V), and the probe has a dimension of  $L=4\text{mm}$  and  $D=1\text{mm}$ . Calculate the value of the electron temperature ( $T_e$ ) of this plasma.

(c) This  $J$ - $V$  curve also shows a saturated electron current at 0.0042A. Give a way to achieve the plasma potential  $V_p$ ?
- (a) An ECR plasma (2.45 GHz) of Ne gives the following data:  $T_i=300\text{K}$ ,  $T_e=50000\text{K}$  and  $n_e=10^{18}\text{m}^{-3}$ , where  $\text{Ne}^+$  possessing 5eV. Calculate (i) The Larmor radius of the  $\text{Ne}^+$  in the bulk plasma. (ii) Critical velocity and (iii) its potential for the  $\text{Ne}^+$  entering the plasma sheath. (iv) The ion current in the plasma sheath.

(b) What are the benefits of a remote plasma reactor in case of fabricating  $\text{SiO}_2$ ,  $\text{Si}_3\text{N}_4$ , etc.?

(c) Prove the necessary condition for the maximum work.

(d) What type of material damage can be induced when a silicon wafer exposed to the  $\text{CF}_4+40\%\text{H}_2$  plasma for RIE?

$e^- = 1.6 \times 10^{-19}\text{ C}$   
 $k = 1.38 \times 10^{-23}\text{ J/K}$   
 $c = 3 \times 10^8\text{ m/s}$   
 $m_e = 9.1 \times 10^{-31}\text{ kg}$   
 $\epsilon_0 = 8.854 \times 10^{-12}\text{ F/m}$   
 $\text{Ar}^* = 11.5\text{ V}$   
 $\text{Ne}^* = 16.6\text{ V}$   
 $\text{Ar}^+ = 15.7\text{ V}$   
 $\text{Ne}^+ = 21.6\text{ V}$   
 $\text{Ar atom weight} = 39.9\text{ g}$   
 $\text{Ne atom weight} = 20.2\text{ g}$   
 $N_A = 6.02 \times 10^{23}\text{ molecules/mol}$

Parschen's law:

$$V_b = \frac{C_1(pd)}{C_2 + \ln(pd)}$$

$$\text{Debye length: } \lambda_D = \left( \frac{\epsilon_0 k T_e}{n_e e^2} \right)^{1/2}$$

$$\text{Plasma frequency: } \omega_p = \left( \frac{n_e e^2}{m_e \epsilon_0} \right)^{1/2}$$

$$\text{Larmor radius: } r_L = \frac{m v_{\perp}}{eB}$$

$$\text{Electron cyclotron frequency: } \omega_c = \frac{eB}{m_e}$$

$$\text{Critical ion velocity: } v(x=0) = \left( \frac{kT_e}{m_i} \right)^{1/2}$$

$$\text{Saturated electron current density: } \frac{1}{4} n_e v_e$$

$$\text{For } V \ll V_p, J_e = \frac{en_e v_e}{4} \exp \frac{-e(V_p - V)}{kT_e}$$