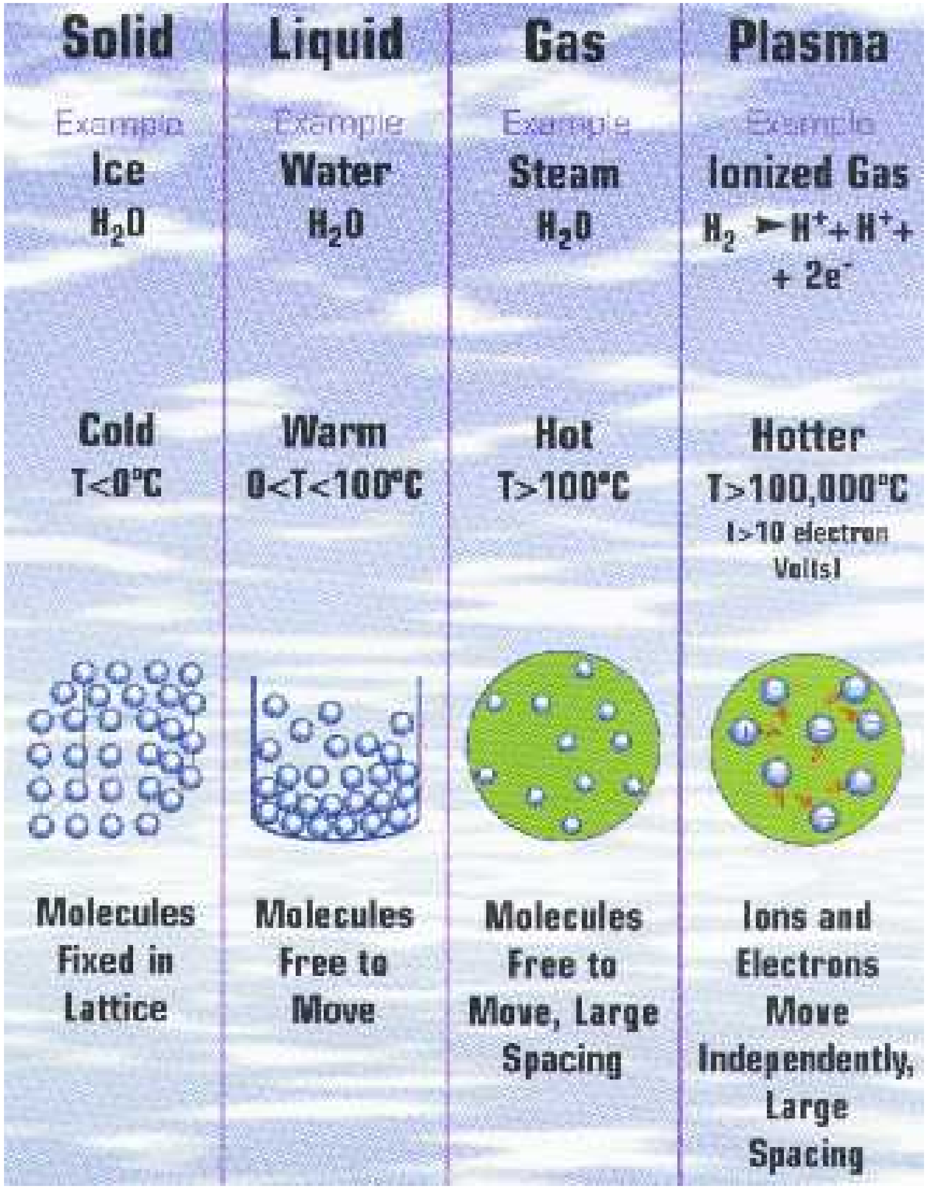
# Formation of Plasma at laboratory, Plasma diagnostics and Application of Plasma in Semiconductor Industry

# Plasma - The "Fourth State" of the Matter



**Where plasma is available?**

- **In Nature – The most part of our atmosphere is in plasma state**
- **In Laboratory / Industry – Plasma can be produced to apply them for different purposes**

**Why formation Plasma in laboratory/industry is important?**

**There is a wide range of applications from Semiconductor/Electronics industry to Biomedical Applications**

# CONDUCTION AND BREAKDOWN IN GASES

Gases consist of neutral molecules, and are, therefore, good insulators. Yet under certain conditions, a breakdown of the insulating property occurs, and current can pass through the gas. Several phenomena are associated with the electric discharge in gases; among them are spark, dark (Townsend) discharge, glow, corona, arc etc.

In order to conduct electricity, two conditions are required. First, the normally neutral gas must create charges or accept them from external sources, or both. Second, an electric field should exist to produce the directional motion of the charges.

Various phenomena occur in gaseous dielectrics when a voltage is applied.

-When low voltage is applied, small current flow between the electrodes and the insulation retains its electrical properties.

-If the applied voltage is large, the current flowing through the insulation increases very sharply and an electrical breakdown occur. A strongly conducting spark formed during breakdown, practically produces a short circuit between the electrodes. The maximum voltage applied to the insulation at the moment of breakdown is called the breakdown voltage.

In order to understand the breakdown phenomenon in gases, the electrical properties of gases should be studied. The processes by which high currents are produced in gases is essential. The electrical discharges in gases are of two types;

i) non-sustaining discharges

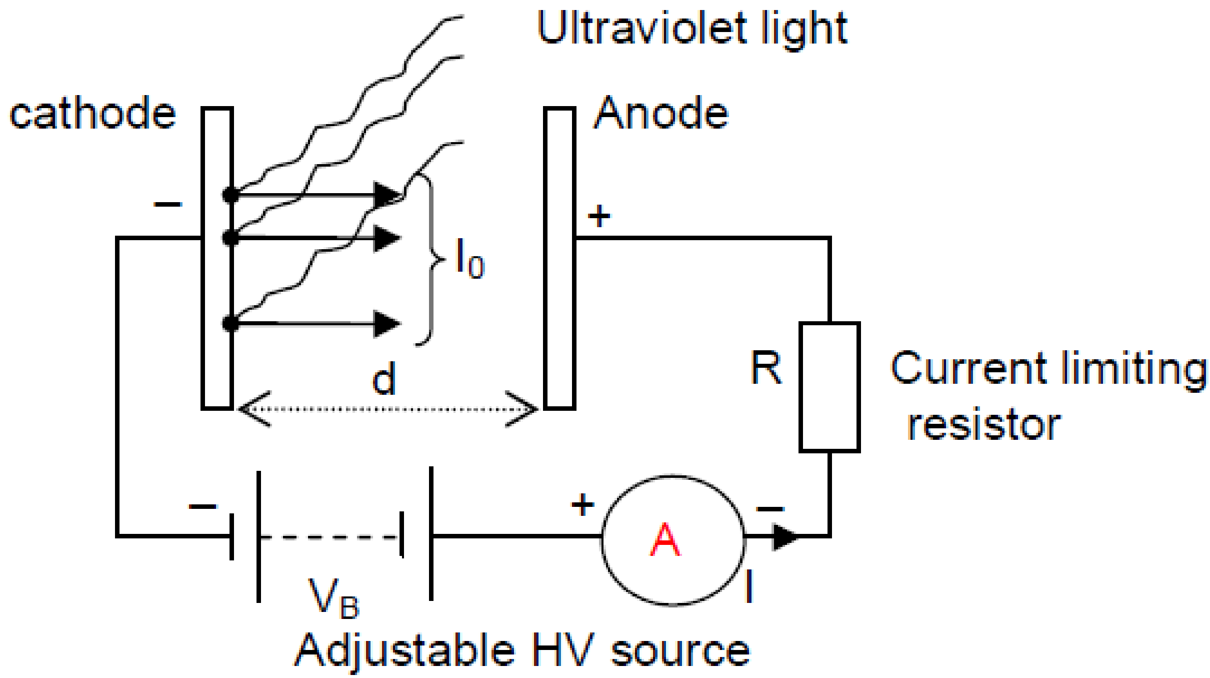
ii) self-sustaining types.

The breakdown in a gas (spark breakdown) is the transition of a non-sustaining discharges into a self-sustaining discharge. The build up of high currents in a breakdown is due to the ionization in which electrons and ions are created from neutral atoms or molecules, and their migration to the anode and cathode respectively leads to high currents.

# Ionization Process

The Townsend discharge is named after John Sealy Edward Townsend, a mathematical physicist of Oxford University. He has discovered the fundamental ionization mechanism.

Townsend theory and Streamer theory are the present two types of theories which explain the mechanism of breakdown under different conditions as pressure, temperature, electrode field configuration, nature of electrode surfaces and availability of initial conducting particles.




Consider a simple electrode arrangement as shown in the Fig., having two parallel plate electrodes (representing uniform field geometry) separated by a distance d and immersed in a gas at pressure *p*. A uniform electric field *E* is applied between two electrodes. Due to any external radiation (ultra violet illumination) free electrons are liberated at the cathode.

When an electron, *e* is placed in an *E*, it will be accelerated with a force *eE* (coulomb force) towards the anode. This electron collides with the other gas molecules while it is traveling towards the anode. If the energy of the electron is sufficiently large (about 12.2 eV for $N_2$ or 15.5 eV for $O_2$), on collision it will cause a break-up of the atom or molecule into positive ion and electron, so the new electrons and positive ions are created. Thus created electrons form a group or an avalanche and reach the anode. This is the electric current and if it is

sufficiently large it results in the formation of a conducting path between the electrodes resulting in the breakdown of the gap.

## Townsend's Current Growth Equation

Assuming $n_0$ electrons are emitted from the cathode and when one electron collides with a neutral particle, a positive atom and electron formed. This is called an ionization collision.

Let $\alpha$ be the average number of ionizing collisions made by an electron per centimeter travel in the direction of the field where it depends on gas pressure $p$ and $E/p$, and is called the **Townsend's first ionization coefficient or primary ionization coefficient**. At any distance $x$ from the cathode (cathode is at x=0) when the number of electrons, $n_x$ , travel a distance of $dx$ they give rise to ($dn_x = \alpha n_x dx$ ) electrons.

$$\frac{dn_x}{dx} = \alpha n_x \text{ or } \quad n_x = n_0 e^{\alpha x}$$

and

$$n_d = n_0 e^{\alpha d} \text{ at } x=d.$$

Where $n_d$ is the number of electrons reaching the anode at $x=d$.

The number of new electrons created, on the average, by each electron is

$$\frac{n_d - n_0}{n_0} = e^{\alpha d} - 1 :$$

Therefore the average current in the gap, which is equal to the number of electrons traveling per second will be

$$I = I_0 \, e^{\alpha d}$$

where $I_0$ is the initial current at the cathode.

This current being dependent on $I_0$ does not represent self sustaining discharge

# Current Growth Equation in the Presence of Secondary Processes

When the initial set of electrons reaches the anode, the single avalanche process is completed. Since the amplification of electrons $e^{\alpha d}$ is occurring in the field, the probability of additional new electrons being liberated by other mechanisms increases, and created further avalanches and are called as secondary electrons.

The other mechanisms resulting in secondary processes are:

i) The positive ions created in the gap due to ionization shall drift towards cathode and may have sufficient energy to cause liberation of electrons from the cathode (emission) when they impinge on it. (less efficient)

ii) The exited atoms or molecules in avalanches may emit photons, and this will lead to the emission of electrons due to photo-emission.

iii) The metastable particles (like mercury, and rare gases) may diffuse back causing electron emission.

Defining the Townsend's secondary ionization coefficient $\gamma$ in the same way as $\alpha$, then the net number of secondary electrons produced per incident positive ion, photon, excited particle or metastable particle and the total value of $\gamma$ due to the three different processes is $\gamma = \gamma_1 + \gamma_2 + \gamma_3$ and is function of gas pressure $p$ and $E/p$.

Following Townsend's procedure for current growth, let us assume

$n_0'$ = number of secondary electrons produced due to secondary $\gamma$ processes.

Let $n_0''$ = total number of electrons leaving the cathode.

Then $n_0'' = n_0 + n_0'$

So the total number of electrons n reaching the anode becomes,

$$n = n_0'' e^{\alpha d} = (n_0 + n_0')e^{\alpha d} \text{ and } n_0' = \gamma[n - (n_0 + n_0')]$$

$$\text{Eliminating } n_0', \quad n = \frac{n_0 e^{\alpha d}}{1 - \gamma(e^{\alpha d} - 1)} \text{ or } I = \frac{I_0 e^{\alpha d}}{1 - \gamma(e^{\alpha d} - 1)}$$

## Townsend's Criterion for Breakdown

The denominator of the above equation (2nd Term) is less than unity. So as $\alpha$ increases due to more gradient or d is increased, the denominator becomes smaller and current larger.

As the distance between the electrodes $d$ is increased, the denominator of equation tend to zero and at some critical distance $d=d_s$,

$$1 - \gamma\,(e^{\alpha d} - 1) = 0$$

$$\text{or}\ \ \gamma\,(e^{\alpha d} - 1) = 1$$

This condition is called **Townsend's Breakdown Criterion**