CHAPTER 2

PRINCIPLE OF ION BEAM NEUTRALIZATION

2.1 Physics of Ion Beam

Ion beam is a group of charged particles, which are forced to move in a specific direction. The beam usually travels inside a low pressure environment. Charged particles are created by many methods, for example, plasma and metal vapor vacuum arc (MEVVA). Then they are accelerated to acquire some energy and directed towards the target. The beam current is usually limited by space-charge effect. This effect occurs between the accelerating electrodes, where only positive or negative charged particles are present. The limited current density for an extraction potential V_a and electrode spacing a is given by (Forrester, 1988)

$$J = (4\varepsilon_0/9)\sqrt{2e/m}\frac{V_a^{3/2}}{a^2}. \tag{2.1}$$

An ion beam Perveance is a quantity that describe the space charge effect and is defined as

$$P = \frac{I}{V^{3/2}}. \tag{2.2}$$

It is used as a measure of electrode capability and is a function of the electrode geometry. Poissance is defined as a ratio of the beam current, I, to the Child current, I_0, and is defined as

$$\Pi = \frac{I}{I_0} = \frac{I}{\chi V^{3/2}}, \tag{2.3}$$

where χ is defined as

$$\chi = \frac{4\epsilon_0}{9}\sqrt{\frac{2e}{m}}, \tag{2.4}$$

Beam current is defined in the same way as the current in conventional circuit, i.e. charged particle travelling through a unit area per unit time. It can be measured by using a Faraday cup, which is simply a cylindrical metal tube with one end closed and the other end opened to let the particles come in. Next to the open end there are two ring electrodes. One is biased at negative potential and the other one, facing the ion beam, is connected to ground. These two electrodes are used to prevent secondary electrons from escaping the cup which may lead to an unwanted additional measured current. It is challenging to create ion beam at high current. The current of the beam is usually limited by many factors, for instance, plasma density, accelerating potential, electrode geometry.

2.2 Ion Beam Neutralization

An ion beam with Poissance larger than unity is considered as a high current ion beam. Without space-charge neutralization such a beam could not propagate to its target. Beam stall might occur as the kinetic energy of the beam particles are converted to the electric potential energy (Forrester, 1988). The space-charge fields created by the beam repel the beam particles transversely. Consequently, beam blow up occurs. Fortunately, the beam particles interact with the ambient gas and create low energy electron-ion pairs which partially neutralize the beam. However, for low energy ion beams this is not effective.

Magnetic fields created by the moving charged particles could generate an attractive force to the escaping particles (Tauschwitz, 2001). For high energy ion beams this can compensate the repulsive electric fields. But again, this is not efficient for low energy ion beams.

Another effect happens when the charged particles arrive a floating or a non-conducting target. Charged particles accumulate on the target and a potential is created on the surface (Kobayashi et al, 1994). For a non-uniform ion beam this effect is even worse. The potential on the target varies spatially and can reach several hundred volts. The target may be damaged due to the surface discharge created by such a high potential difference (Korzec et al, 2000). Usually, this is not the case, because as ions bombard on the target they create secondary electrons, which will be trapped in the beam and partially neutralize the beam. However, for a high current ion beam, the number of electrons is not enough. In order to neutralize the beam an electron source is needed to provide additional electrons to the beam. Those electrons cancel the space-charge fields of the beam which reduces beam blow-up.

Ion beam neutralization does not mean that all charged particles are neutralized, but it refers to a combination of neutral particles, positive and negative charged particles in the beam volume. The electrons are unlikely to combine with the ions in the beam, because it needs three-body collision to recombine an ion with an electron. In our case the pressure is too low to have three-body collision in the beam. The only possible third body is the target. The recombination occurs at the surface of the target. Therefore, the surface discharge of the target is suppressed.

In order to integrate the electron source to the ion beam line, there must be no high positive potential electrode facing the electron source. Otherwise, electrons would be drawn to it. For our system, which is comprised of an Einzel lens whose center electrode must be biased with a high positive voltage, an electron suppressor is required. In order to make sure that electrons are kept in the beam, low energy electrons are usually required for ion beam neutralization.

Charge neutralization is achieved when an ion beam contains the same number density of ions and electrons. No matter if the electrons are moving or not. This usually be obtained easily by providing additional electrons into the beam. Beam potential would draw electrons and trap them in the beam. Some high energy electrons are lost to the wall. In most cases, beam potential are kept at several volts to ensure the electron trap. Low energy electrons are essential to be kept in the beam.

Current neutralization is obtained when the flux of ion and electron entering the target are the same. This can be achieved by accelerating electrons along the beam (Humphries, 2002). To help accelerate the electrons to move with ions a negative potential is usually biased to the electron source.

2.3 Neutralization methods

- **Immersed wire neutralizer:** (Forrester, 1988) The easiest way to neutralize an ion beam is to put an electron-emitting wire cross the beam. The wire emits electrons by means of current heating. Number of electrons can be controlled by changing the wire current. A major disadvantage is that the wire must be replaced periodically due to sputtering of the ion beam. Sputtering of the filament also creates contamination.

- **Hollow-cathode neutralizer:** (Forrester, 1988) This method was intended to use in space application. The thruster of the space ship ejects massive ions from it, leaving the ship negatively charged. Electrons of the same flux as ion were needed to be ejected from the ship. This was done by feeding Cs gas through a very hot tube creating plasma inside the tube. The flow of gas pushes the plasma out of the orifice and a plasma bridge is formed between the ion beam and the electron source.

- **Filament plasma bridge neutralizer:** (Cacciato et al, 1999; Ito et al, 1995; Kikuchi et al, 1993) This method seems to be very popular. The principle of operation is quite similar to the previous method. A hot filament is used to produce electrons and they are accelerated to a high energy which is enough to ionize atoms and plasma is formed. The plasma source is placed near the ion beam so that the plasma can flow out from the source through an orifice. A plasma bridge is formed between the ion beam and the plasma source.

- **Plasma cathode electron gun:** Fusellier et al (1998) developed a microwave plasma cathode electron gun which accelerates electrons from a microwave plasma generated by an antenna. The diagram of such a system is shown in figure 2.1.

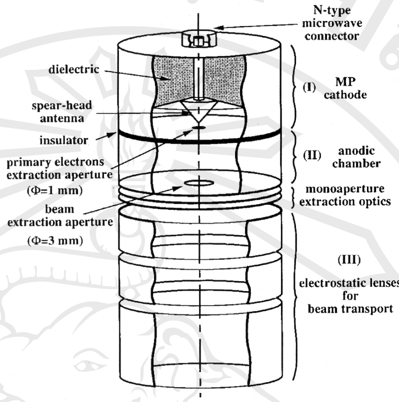

Figure 2.1. Schematic diagram of the microwave plasma cathode electron gun (Fusellier et al, 1998)

- **Secondary electron flood:** Reece et al (1997) used a secondary electron flood system to reduce charging effect on the wafer during high current ion implantation, see figure 2.2. For this method the control of electron energy and transport of the electrons to the target was a major difficulties.

- **Bipolar extraction system:** Korzec et al (1991) used an alternating electron and ion extraction via the same optic, but at different extraction voltage, i.e. 200-800 V for ion extraction and -50 – -200 V for electron extraction. This allows the non-conducting target to be charged and discharged periodically, possibly resulting in a zero target bias. However, switching the capacitor at high voltage is difficult. Therefore, it is not useful in this context. The set up diagram of such a system is shown in figure 2.3.

- **Ring plasma neutralizer:** Kobayashi et al (1994) have constructed a microwave ring discharge to neutralize the surface of an insulator undergoing implantation. A solenoid coil and permanent magnets were used to enhance plasma confinement. The discharge ring was made as a perimeter of the target as shown in figure 2.4. The electron current collected by the target biased at 10 V was more than 60 mA.

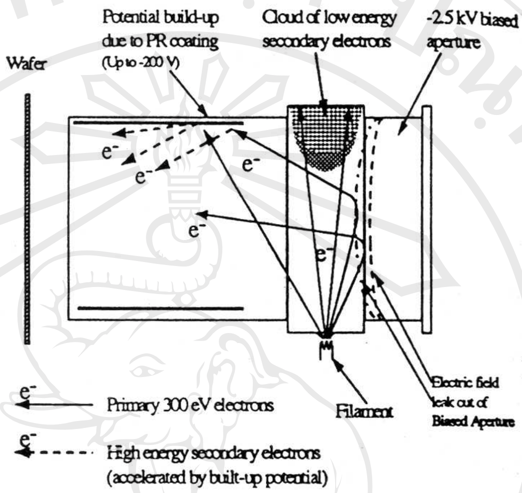

Figure 2.2. Proposed mechanism for transport of high energy electron in a secondary electron flood design (Reece et al, 1997)

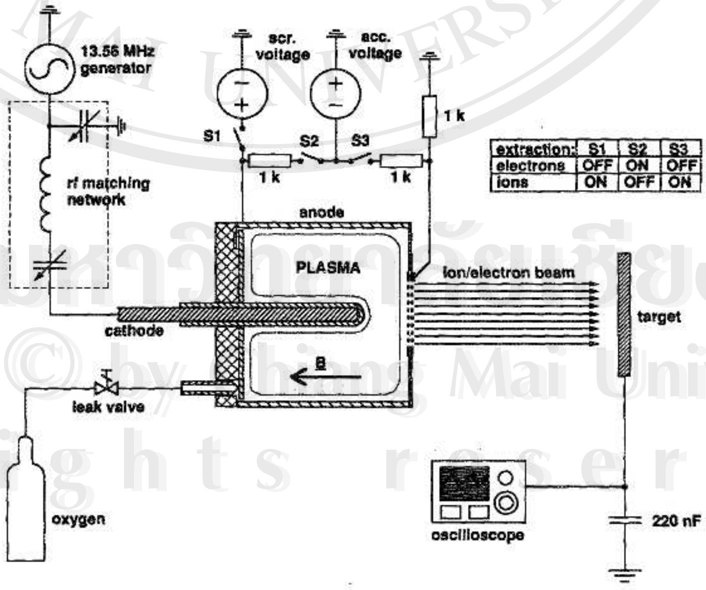

Figure 2.3. Set up diagram of the bipolar extraction system (Korzec et al, 1991)

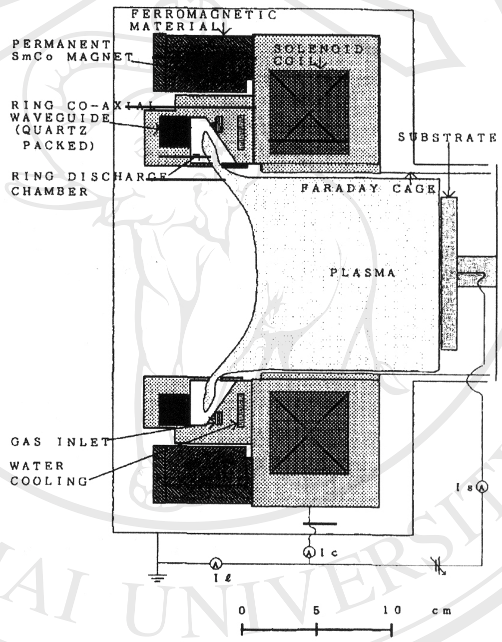

Figure 2.4. Schemetic side view of the ring plasma neutralizer (Kobayashi et al, 1994)