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Ion dynamics in plasma sheath under the effect of E×B and collisional forces

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ABSTRACT

Using the fluid model, we investigated the velocity, kinetic energy and the density distribution of the ions in collisional and collisionless magnetized plasma sheath. Considering an external magnetic field, the ion movement under the effect of magnetic, electric and collisional forces has been analyzed numerically. The nonexistence of fluctuations in ions kinetic energy in collisionless strong magnetized plasma sheath and increasing the ions velocity in depth direction due to the collisions in some positions in the sheath are shown. The fluctuations of ion velocity in weak magnetized plasma sheath are shown too when ions enter the sheath with oblique incident angle.

1. Introduction

Ion implantation, as a standard technical skill, has been applied to modify and achieve better surface properties of electrically insulating materials. To prevail over the limitation of conventional ion implantation and enlarge the range of the targets which can be modified by this technique, the plasma source ion implantation (PSII) has been developed in the last decades as a very promising and efficient technique for surface treatment and modification of materials [1,2].

During PSII treatments, a target object is immersed in plasma and a large negative bias is applied to it. As the plasma is in contact with the negatively biased target, a strong localized electric field appears between the plasma and the target. In this ion rich boundary layer, which is called *sheath* [3], the ions are accelerated and gain energy over kilovolts and transported to the target. These energetic ions are implanted into the target thereby modifying its surface characteristics. As the sheath conformably surrounds the target, the entire object can be implanted without manipulation and at the same time [4].

Since the main ion acceleration occurs in the sheath, the energy that ions gain as they fall through the sheath regulates the physical and chemical processes that occur at the surface of target. So the sheath dynamics are extremely important in PSII related processes, and the information about the ion dynamics is needed to optimize the PSII process.

In the past decade, several experimental and numerical studies have been worked out to analyze the complex behavior of the plasma sheath during PSII [5–9]. Among these works, some authors has been investigated the problem of collisional sheath [9–12]. The collisions between ions and neutrals are very important in PSII since the ion collisions in the sheath can significantly reduce the ion kinetic energy and change the characteristics of the ions. It may be obvious that the collisional force decreases the kinetic energy of ions. However, we try to investigate the effects of collisions in the presence of an external magnetic field. In recent years, a great deal of interest has been arisen in the possibility of using magnetic field for controlling the PSII process [7,12–14]. Therefore including both the negative voltage and the external magnetic field, we try to understand some properties of sheath in the crossed $\mathbf{E} \times \mathbf{B}$ which are very important for PSII process.

2. Model and basic equations

Following some recent works [14–17], we consider a steady state plasma sheath in contact with a planar wall (Fig. 1) and assume that the physical parameters which characterize the sheath change along the depth direction. It means that the sheath has one-dimensional coordinate space and three-dimensional speed space. As illustrated in Fig. 1, the magnetic field which is spatially uniform and constant in time, embedded in the x–z plane and makes an angle θ with z-axis which is considered as the direction normal to the wall (if the ions enter the sheath vertically, $\theta = 0$ is equivalent with non magnetized plasma sheath since normal magnetic field does not affect the ion dynamics).

The numerical simulation for finding the ion dynamics in the plasma sheath is done by using fluid equations for the ions. These equations are coupled with the Boltzmann relation for the electrons and Poisson's equations. The basic equations are as follows:

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