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主 論 文 の 要 旨

論文題目 Plasma Simulation Analysis for Formation Mechanism of Periodic Nanograting Structures by Laser Pulses

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論 文 内 容 の 要 旨

This Ph. D. thesis can be considered as a simulation study for investigating the formation mechanism of periodic nanograting structures. Periodic nanograting structures are one of the contemporary science issues that gained much attention in the last 20 years due to their vast usage in industrial applications. Our thesis presents two studies that contribute to explaining the formation mechanism. The first study is for irradiating plasma with a relativistic laser beam of intensity 10^{18} W/cm^2-μm^2. The simulation results show that Weibel instability can explain the formation mechanism within the relativistic intensity regime of a laser beam. On the contrary, for the nonrelativistic laser beam, irradiating plasma with a laser intensity of 10^{16} W/cm^2-μm^2 shows that the surface plasma wave together with the oscillating two-stream instability acts as the formation mechanism in the second case.

Detail explanations of the first case in this thesis are as follows:
The Weibel instability has been introduced in this part as the related physics to this phenomenon. The laser beam of intensity 10^{18} W/cm^2-μm^2 and wavelength 800 nm is used to excite the periodic nanograting structure after irradiating the interface between ablated and target plasmas. The induced magnetic field, together with the electron current density and the electron density, has been calculated by the particle in cell code. 13 tips are formed as the periodic nanograting structure along y-axis from -3.0 to 3.0 μm at t = 250 fs, and averaged

interspace size of 0.6 μm is shorter than the laser wavelength. The periodic nanograting structures are observed at y = -0.8, -0.6, -0.2, 0.3, and 0.9 μm in the electron density profile where the positive x-component of the electron current density J_{xe} exists. Furthermore, the positive and the negative z-component of the magnetic field B_z are formed on both sides of above positions. For example of J_{xe} at y = 0.3 μm, positive B_z exists at y = 0.5 μm while the negative B_z exists at y = 0.1 μm. The above description shows consistency between the magnetic field and the electron current density which leads to producing periodic nanograting structure and confirms the existence of Weibel instability and its role in the formation mechanism.

For explaining the second case, we provide details on the formation mechanism of the periodic nanograting in the case of using the nonrelativistic laser beam. The laser beam of intensity 10^{16} W/cm^2-μm^2, wavelength 800 nm and spot size 10 μm is irradiated onto the plasma. The periodic nanograting structure has formed along the front of expanding plasma, which is diffused from the target plasma. Studying the electron density profile shows that the surface plasma wave (SPW) and the oscillating two-stream (OTS) instability are the reason for the structure formation. The mechanism of SPW generation is considered as the collective behavior of excited electrons in the y-direction due to the laser electric field. The bidirectional collective behavior of electrons in y-direction leads to SPW propagation near the surface, producing the so-called standing wave. The ponderomotive force of the standing wave plays a significant role in forming seeds or tips for the development of periodic nanograting structures. The OTS instability affects the formed tips and grows them up to form the periodic nanograting structures. The electron density profiles successfully show growth of tips over time. At t = 500 fs, averaged interspace size of periodic nanograting structures is measured as 0.5 μm, and it is found to agree with the theoretical interspace.