§9. Study on Intense Laser Interaction with Surface Plasma on Solid Materials

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Ablation threshold of metals have been investigated experimentally and theoretically since the 1990s with respect to the mechanism of femtosecond laser ablation. Three ablation thresholds have been identified for metals irradiated with a laser pulse of $\leq$400 fs at a wavelength of 800 nm [1)2)]. Two of the thresholds are characterized by the electronic thermal conduction length ($l \sim 80$ nm) and optical penetration length ($d \sim 10$ nm), respectively. The ablation rates at these thresholds are well expressed by the two-temperature thermal diffusion model. However, the third (low) ablation threshold can not be characterized by this model because the ablation rate is 0.01 nm/pulse (less than one atomic layer) and the threshold is strongly dependent on laser pulse duration. The ablation rates are well explained by the assumption of multi-photon absorption[2)]. We defined this region in which characterized by the low ablation threshold as nano-ablation. As a result of the nano-ablation, high energy singly charged ions were emitted from metal surface and laser induced periodic surface structures (LIPSS) were self-organized on metal surface [3)4)5)]. They were oriented perpendicular to the laser polarization direction. For laser fluence levels near the ablation threshold, LIPSS have an interspace of $\sim$ 0.5 λ_L - $\sim 0.9\lambda_L$ which was shorter than the laser wavelength λ_L and its interspaces depended on laser fluence. This dependence has been explained by some models, such as the parametric decay [6)7)], bi-direcrtional surface plasma wave, plasmon polariton excitation, second harmonic generation and Weibel instability. However, the mechanism of the periodic structures is still debated. We need further investigations. In this study, we have tried to visualize the surface plasma wave with two-dimensional particle in cell simulation[8)9)] and have discussed the possible mechanism of LIPSS formation[10)11)].

LIPSS self-organized with an intensity 10^{16}W/cm^2-μm^2

A two-dimensional particle in cell code demonstrated the study of the formation mechanism for the periodic nano-grating structure (LIPSS) in the hydrogen plasma by using 500 fs pulses of the ultra-fast laser with wavelength 800 nm, incidence angle 0 degree, linearly-polarized, and intensity 10^{16} W/cm^2-μm^2. LIPSS has been clearly self-organized at the boundary between preformed plasma and dense plasma at $t = 650$ fs. The bidirectional surface plasma wave plays a significant role together with the oscillating two-stream instability in order to produce LIPSS[10)]. The interspace of LIPSS λ_{SPP} can be expressed as

$$\lambda_{SPP} = \sqrt{\frac{2 - \frac{n_{es}}{n_{cr}}}{1 - \frac{n_{es}}{n_{cr}}}}, (1)$$

where, n_{cr} is the critical density for a laser wavelength of 800 nm, n_{es} is the initially preformed plasma on a target.

LIPSS self-organized with an intensity 10^{18}W/cm^2-μm^2

The formation mechanism of LIPSS was studied by the 2D PIC code using an ultrafast laser pulse with a high intensity 10^{18}W/cm^2-μm^2, wavelength 800 nm, incidence angle 0 degree, and linearly-polarized. LIPSS has been clearly self-organized at the boundary between the pre-formed plasma and the dense plasma at t = 250 fs. It is found that the relation between the magnetic field and the current density affect on the electron distribution in the dense plasma to form the LIPSS. The Weibel instability has explained the enhancements of the magnetic field with time and its role in forming the LIPSS[11)]. The Weibel instability might have contributed to form the LIPSS in the case of laser intensity 10^{18} W/cm^2-μm^2. 2D PIC code FISCOF2 has played a significant role in analyzing the formation mechanism of the periodic nano-grating structures.

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