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

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On metals and semiconductors under irradiation of linear polarized femtosecond laser pulses, laser induced periodic surface structures (LIPSS) were self-organized [1)2)] and they were oriented perpendicular to the laser polarization direction. Laser produced LIPSS had an interspace of 0.5 λ_L - 0.85 λ_L which was shorter than the laser wavelength λ_L and its interspaces depended on laser fluence. This dependence was well explained by the parametric decay model [3)4)]. An assumption in the model is that, as a consequence of the ultrafast interaction with the laser beam, the solid surface is initially covered by a pre-formed surface plasma with a density much lower than that of the solid. Surface plasma waves are then induced at the interface between free space and the laser-produced surface plasma by parametric decay process. Then, the LIPSS are self-organized. In this study, the double pulse irradiation experiment has been carried out to discuss the relation between the preformed plasma density and the grating interspaces self-organized on the metal surface. Additionally we have tried to visualize the surface plasma wave with two-dimensional particle in cell simulation[5)6)].

In the experiments, the T^6-laser system (λ_L=805 nm, τ =40 fs, 10 Hz) was used. The double pulse beam with a time delay of 160 fs was composed of a first pulse, responsible for the surface plasma formation, and a delayed pulse, responsible for the periodic grating structures formation. The first pulse fluence F_{PP} was varied and always kept below the formation threshold F_{TH} =60mJ/cm^2 of the periodic grating structure on Ti. The delayed pulse fluence F_{LP} was kept constant above F_{TH}. The double pulses were collimated and focused to a spot size of 45 μm on the Ti target surface with a lens f= 10 cm, at normal incidence in air. The polarization direction of the first pulse was set to be parallel to that of the delayed pulse. The double pulsed beam was shaped to be spatially flat. The target of titanium was mechanically polished. The roughness, Ra, was less than 2nm for sample. The laser fluence in the flat top region was varied in the ranges of F_{PP} =10 - 50 mJ/cm^2 for plasma formation and F_{LP}=60, 100, 150 mJ/cm^2 for periodic grating structures formation. The number of irradiated double pulse beam was N=1, 25 in all experiments. Laser-produced grating structures were examined by scanning electron microscopy (SEM; JSM-5560, JEOL). In Fig. 1(c), the dependence of periodic structure interspaces on laser fluence of first pulse F_{PP} for the delayed pulse fluence of F_{LP}=60 mJ/cm^2. The interspaces of periodic grating structures were in range of 0.5 λ_L - 0.85 λ_L expected by the parametric decay model and were decreasing as the F_{PP} decreased.This tendency suggests that variation of the surface plasma density characterized by first pulse fluence led to a variation of the grating interspaces. Figure 1(a) shows the electron density distribution at the t = 650 fs for 0.7 n_{cr} of pre-plasma obtained by PIC simulation. The simulation results show that the surface wave is produced on the surface of expanding preformed plasma at z = 1.2 μm. The period of the surface wave was analyzed by Fourier transform for the electron density distribution in the area of z = 1.0 - 1.5μm and y = -5 - 5 μm. The period of surface wave is 720 nm at 0.7 n_{cr} and depend on preformed plasma density n_{cr}. Figure 1(b) shows the interspace of the surface wave de-pend on preformed plasma density. Lower the preformed plasma density, interspace of the surface wave tends to be shorter. The simulation results suggest that the initial preformed plasma density led to a variation of the grating interspaces.

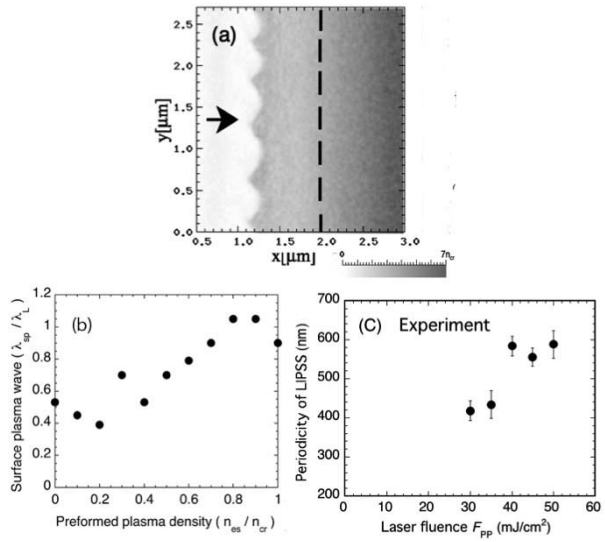

Fig. 1: (a) Electron density distribution in the z-y plane at irradiation time of t =650 fs for 0.7n_{cr}. (b) Dependence of the normalized surface-wave on pre-formed plasma density obtained by PIC simulation(c) Dependence of periodicity of LIPSS on the laser fluence obtained by experimentally .

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