§22. Mechanism of Nanostructure Formation on Metal Surface Induced by Intense Short Pulse Laser

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Recently, the PIC simulation results have been reported [1), 2)] to discuss the dynamics of periodic nanostructuring on solid surface induced by surface plasma wave. However generation mechanism of surface plasma wave is still under investigation. To visualize the surface plasma wave induced by femtosecond laser, 2D PIC simulation by using the code FISCOF[3),4)] has been demonstrated for initially preformed plasma on a target. For the simulation, the surface of the preformed plasma was located at $z = 2$ μm (as shown as black dotted line in Fig. 1(a)) and its thickness of 2 μm in the z direction of the (z, y) simulation plane. And the laser beam was irradiated onto the surface from left hand side as shown in black arrow. The electron density of the pre-plasma was varied in the range of 0 - 1.0 n_{cr} by 0.1 n_{cr} step, where n_{cr} was the critical density for laser wavelength of 800nm. The plasma was initially characterized by a Maxwellian distribution with electron temperature T_e=1 keV and ion temperature T_i= 0.1T_e. Hydrogen plasma m_i/ m_e =1836/16 was used to speed up the simulation time, where m_i and m_e are the ion and electron mass. The charge of the ions was $Z = 1$. Even though the formation mechanism of the surface wave is essentially same for the plasma involving the heavy elements Z_{High}, the time to develop the surface wave is sifted to longer than that for light elements. However, we have used the electron-hydrogen plasma to reduce the calculation time. The target of 10 n_{cr} was located behind the pre-plasma and its dimension of 10 μm thick and 20 μm wide. Intense laser (I=1.0×10^{16} W/cm^2, λ_L=800 nm, rise time =15 fs) was irradiated continuously onto the preformed plasma target with normal incidence. The laser was linearly polarized with the direction parallel to y axis. Figure 1 shows the electron density distribution at the t = 650 fs for 0.7 n_{cr} of pre-plasma. 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 - 1.5 μm and y = -5 - 5 μm. The obtained FFT spectrum is shown in Fig. 1(b). The period of surface wave is 720 nm at 0.7 n_{cr} and depend on preformed plasma density n_{cr}. Figure 1(c) shows the interspace of the surface wave depend on preformed plasma density. Lower the preformed plasma density, interspace of the surface wave tends to be shorter. The obtained simulation result is helpful to discuss the dynamics of the surface plasma wave generation. However, the irradiated laser intensity is set three orders of magnitude higher than that obtained by the experiment since the multi pulse irradiation effect could not take it into account for this 2D-simulation in realistic calculation time. The periodic grating structure was self-organized experimentally as a result of multi pulse irradiation in the range of 25 - 1000 pulses[5),6)]. After several pulses irradiation, the surface of metal was not flat. Thus the structures with nanometer size have been distributed and reported in [7)]. The structures might be contributed to enhance the laser intensity locally through the near field effect. To reduce this discrepancy, we need further investigation to express as a cumulation effect for multi pulse irradiation.

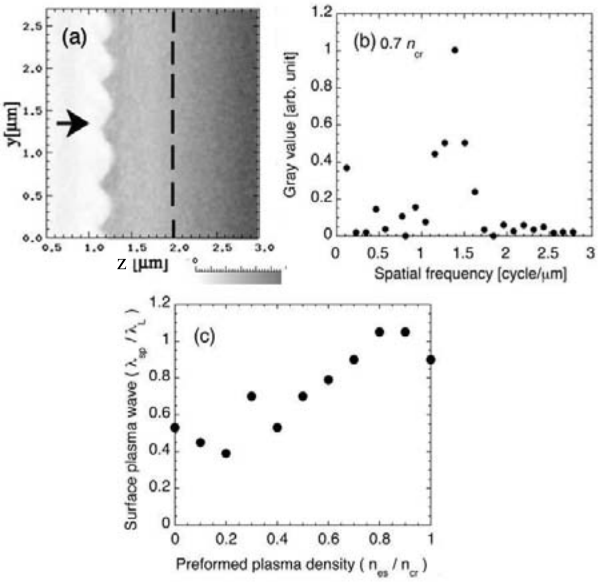

Fig. 1: (a) Electron density distribution in the z-y plane at irradiation time of t =650 fs for 0.7n_{cr}. (b) Fourier-transform spectrum for the surface electron density of (a) in the area of z = 1.0 - 1.5 μm and y = -5 - 5 μm. (c) Dependence of the normalized surface-wave on preformed plasma density.

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