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

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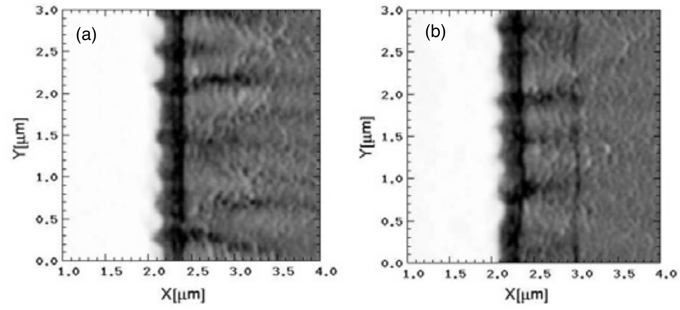

Fig. 1: Electron density distribution in the xy plane at irradiation time of $t = 250$ fs for (a) $0.6n_{cr}$ and (b)$0.9n_{cr}$.

On metals under irradiation of linear polarized femtosecond laser pulses, grating structures are self-formed[1)2)] and they are oriented perpendicular to the laser polarization direction.The nano-structured metal surface is used in chemical application[3)]. To investigate the mechanism of self-formation, we have measured the grating structure interspaces dependence on laser fluence for Cu[1)]and several metals[4)] such as Ti, Pt, Mo, and W. In the ranges of the laser fluence in which the grating structures are self-formed, the interspaces of the grating structures are shorter than the laser wavelength of 800 nm. The interspaces increase up to 680 nm as laser fluence increases. This dependence of the interspaces on laser fluence has been explained by the parametric decay model[5)]. This model, proposes the following hypothesis. Surface plasma waves are induced at the interface between free space (air) and either laser-produced plasma or metal plasma by parametric decay; in other words, the incident laser light decays into a surface plasma wave and a scattered electromagnetic wave. The plasma wave travels slowly at a speed of less than 10^{-2} times that of light, and an ion-enriched local areas appear in the laser pulse duration. The plasma wave is slow enough for the ions to experience a strong Coulomb repulsive force and can be exploded into a vacuum; that is, a Coulomb explosion[6)7)]occurs. Through this process, the periodic grating structures are formed. However, the surface plasma wave could not observe directly due to experimental difficulties. Thus the formation of periodic structures is not yet fully understood. In this paper, we tried to visualize the surface plasma wave with two-dimensional particle in cell (2D-PIC) simulation.

In order to confirm the surface plasma wave induced by femtosecond laser, the 2D-PIC simulation by using the code FISCOF[8)] has been demonstrated for initially pre-formed plasma on a target. For the simulation, the pre-formed plasma has the thickness of 2 μm in the x direction of the (x, y) simulation plane. The electron density of the pre-plasma is varied in the range of $0.2n_{cr}$ - $0.9n_{cr}$, where n_{cr} is the critical density for 800nm wavelength. The plasma is initially characterized by a Maxwellian distribution with electron temperature T_e=1 keV and ion temperature T_i=T_e. Hydrogen plasma m_i/m_e=1836 is used, where m_i and m_e are the ion and electron mass. The charge of the ions is Z=1. The target of $10n_{cr}$ is located behind the pre-plasma and its dimension of 10 μm thick and 8 μm wide. Intense laser (I=1.0×10^{18} W/cm^2, λ=800 nm, rise time =15 fs) is irradiated continuously onto the pre-formed plasma target at normal incidence. The laser is linearly polarized with the direction parallel to y axis. The irradiated laser intensity is set 4 order 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. Note that the nano grating structure was self-formed experimentally as a result of multi pulse irradiation in the range of 50 - 10,000 pulses. Thus 4 order higher intensity is acceptable to express as a cumulation effect for multi pulse irradiation. Figure 1[9)] shows the electron density distribution at the $t = 250$ fs for $0.6n_{cr}$ and $0.9n_{cr}$ of pre-plasma. The simulation results show that the surface wave is produced on the pre-plasma surface at x=2.0 μm. The period of the surface wave is analyzed by 1D-Fourier transform for the electron density distribution in y direction. Before the analyzation, the electron density is integrated along the x direction from 1.8 to 2.5μm. The period of surface wave is ∼500 nm at 0.9 n_{cr} and depend on the pre-plasma density in the range of $0.2n_{cr}$ - $0.9n_{cr}$. The obtained result by 2D-PIC simulation is helpful to discuss the dynamics of the surface plasma wave generation.

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