Mechanism of uniform LIPSS formation by two-color double femtosecond laser pulse irradiation on biomaterials

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A titanium (Ti) is used as a biomaterial widely. Ti has features such as weather resistance, impact resistance, rigidity, and are applied to artificial bone. The surface topography of a material determines its biocompatibility. The osseointegration of the material is induced by cell adhesion, proliferation, and differentiation and may be improved by certain topographical modifications. Adding a new function to the Ti as one method, the spread direction of cells was controlled by forming periodic nanostructures on the Ti surface. Periodic nanostructures were self-organized on the Ti and titanium dioxide surface by femtosecond laser irradiation [1]. It is called Laser Induced Periodic Surface Structure (LIPSS). With two-color double pulse irradiation method, it was found that the uniform LIPSS was formed. In our previous study, to evaluate the uniformity of LIPSS, The Perpendicular Period and Phase Scanning (P^3S) method was invented. P^3S assesses the uniformity of LIPSS using the standard deviation of the peak period and the average of the phase difference in the direction perpendicular to LIPSS. However, the mechanism of uniform LIPSS formation was not understood. In this study, the purpose is to experimentally clarify the uniformity due to the combination of the polarization directions of the double pulses, and to elucidate the mechanism of the formation of uniformity LIPSS by comparing the results with a 3-D electromagnetic particle-in-cell simulation.

A femtosecond Ti: sapphire laser (IFRIT; Cyber Laser, Japan) with a wavelength of 800 nm, a repetition rate of 1 kHz, and a pulse width of 160 fs was used. A beam splitter separated a single laser pulse into two pulses. One pulse was converted into a 400 nm wavelength using a barium borate crystal (BBO), which generated a second-harmonic wave. Then the two pulses with wavelengths of 800 nm (ω) and 400 nm (2ω) were aligned coaxially to produce two-color double-pulse femtosecond laser irradiation. The two-color double-pulse beam was focused on a Ti plate. The spatial profiles were Gaussian in shape, and their diameters were adjusted to 25 μm for both pulses. The ω and 2ω polarizations were controlled to be parallel and orthogonal using a λ/2 plate, and the surface of the Ti plate was ablated by irradiation with the two-color double-pulse laser beam. LIPSS was observed using a scanning electron microscope (SEM).

When the polarization directions of ω and 2ω were orthogonal, a uniform LIPPS was formed compared to the LIPSS formed by single-pulse irradiation, but when the polarization directions of ω and 2ω were parallel, the uniform LIPSS was not formed. The results suggest that when the polarization directions of ω and 2ω are parallel, the polarization of 2ω acted to decrease uniformity on the LIPSS formed by ω, and when the polarizations of ω and 2ω are orthogonal, the polarization of 2ω acted to increase uniformity on the LIPSS formed by ω. From previous studies, it is known that LIPSS is formed perpendicular to the polarization, which is thought to be due to the excitation of surface plasmons perpendicular to the polarization. The results of this study suggest that LIPSS was formed perpendicular to the polarization of ω, and that the polarization of 2ω affected the shape of LIPSS in the direction parallel to the polarization of 2ω. The results of this study also suggest that the LIPSS shape was not changed by the surface plasmon of 2ω, whose direction is perpendicular to the polarization of 2ω, and the simulation results will be discussed in the presentation.

[1] T. Shinonaga, et al., "Cell spreading on titanium dioxide film formed and modified with aerosol beam and femtosecond laser" Applied Surface Science 288 649–653 (2014)
[2] M. Tsukamoto, et al., "Cell spreading on titanium periodic nanostructures with periods of 200, 300 and 600 nm produced by femtosecond laser irradiation" Applied Physics A 122 184 (2016)