Femtosecond laser-based subtractive and additive processing for bioapplications

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1. Introduction

Femtosecond laser has great advantages in the processing of soft materials due to its extremely short pulse duration and high peak intensity with modest average power, which realizes the fabrication of precise structure without significant thermal modification. Since a number of soft materials including polymers show high transmittance for visible to near-infrared wavelength, three dimensional structures can easily be fabricated via intense nonlinear absorption. In this presentation, we will describe our study on ultrafast laser processing of biomaterials, in terms of both subtractive and additive techniques, toward the biocompatible devices.

2. Laser processing of biodegradable polymers

Biodegradable polymers have been receiving increasing attention in wide field of applications including optical devices as well as scaffolding in tissue engineering. Among various methods for processing biodegradable polymers, laser-based methods have advantages in dry processing without using toxic chemicals and in ease of 3D manufacturing of complex-shaped surfaces or structures.

Enhancement of cell adhesiveness is one of the key factors for successful scaffold fabrication in tissue engineering. We investigated the "subtractive" laser processing for the formation of periodic nanostructure on poly-L-lactic acid (PLLA) by using femtosecond laser [1], since surface nano- and microstructures play important role to control the cell adhesiveness. Experimental study revealed that high-spatial frequency LIPSS can be formed perpendicular to the laser polarization. In addition, we found that the biodegradation rate of biodegradable polymers shows significant change following irradiation with femtosecond laser pulses. The biodegradation behavior is a key factor for tissue scaffolding or implants because it can provide suitable space for cell growth as well as tailored sustainability depending on their role. We demonstrated the change in the biodegradation rate of a poly(lactic-co-glycolic acid) (PLGA) by femtosecond laser pulses, which was dependent on the laser wavelength [2]. Significant acceleration of the degradation rate was observed upon 400 nm-laser irradiation, whereas 800 nm-laser irradiation did not induce a comparable degree of change. The X-ray photoelectron spectroscopy analysis indicated that laser pulse at the shorter wavelength dissociated the chemical bonds effectively, resulting in a higher degradation rate. The result shows the potential to control the degradation and sustainability of devices.

3. Fabrication of metal structure in biomaterial

In contrast to the femtosecond laser-based subtractive processing, which focuses on the removal of a material for fabricating biocompatible structures, we have recently investigating "additive" processing toward functionalizing biocompatible devices. We fabricated metal microstructures inside a synthetic polymer-based hydrogel by femtosecond laser direct writing by means of photoreduction [3]. We took advantage of the hydrogel's permeability to fluids, which enabled us to add silver ions by simply immersing the hydrogel into the silver nitrate solution after photo-crosslinking. Femtosecond laser pulses were focused into the hydrogels containing the silver ion. The silver structure is observed and confirmed by scanning electron microscopy (SEM) and elemental analysis using energy-dispersive X-ray spectroscopy (EDX). We also observed the stretchability of the fabricated structure. Interestingly, the hydrogel shrank in size while maintaining the silver structure inside. The shrinkage capability of the structure has the potential to be implemented not only for tunable devices, but also for fabricating highly dense structures to realize optical devices.

4. Conclusions

We have demonstrated the formation of periodic nanostructures on the biodegradable polymer as well as the change in biodegradation rate followed by femtosecond laser irradiation. These results will expand application area of laser-manufactured structure in tissue engineering. The fabrication of metal structures embedded in a hydrogel is a promising technique to realize active biocompatible devices. Our recent progress in both laser-based subtractive and additive processing will also be presented.

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