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Review

Femtosecond laser ablation of polypropylene for breathable film

Ik-Bu Sohn [a], Young-Chul Noh [a,*], Sung-Chul Choi [a], Do-Kyeong Ko [a], Jongmin Lee [a], Young-Jin Choi [b]

[a] Precision Optics Lab., Advanced Photonics Research Institute, GIST, Oryong-dong 1, Buk-gu, Gwangju 500-712, Republic of Korea
[b] Daerung Packaging Industry, Sundong-ri 400, Chowol-eup, Gwangju city, Gyeonggi-do 464-864, Republic of Korea

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Abstract

A polypropylene (PP) film was ablated using a femtosecond laser with a center wavelength of 785 nm, a pulse width of 184 fs and a repetition rate of 1 kHz. Increments of both the pulse energy and the shot number of pulses lead to co-occurrence of photochemical and thermal effect, demonstrated by the spatial expansion of rim on the surface of PP. The shapes of the laser-ablated PP films were imaged by a scanning electron microscope (SEM) and measured by a 3D optical measurement system (NanoFocus). And, the gas and water vapor transmission rate, mechanical properties of PP film micropatterned by fs laser pulses was characterized. Our results demonstrate that a femtosecond pulsed laser is an efficient tool for breathable packaging films in modifying the flow of air and gas, where the micropatterns are specifically tailored in size, location and number of which is easily controlled by laser processing conditions.

Keywords: Laser materials processing; Femtosecond laser ablation; Polymers; Packaging; Microperforated film

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1. Introduction

Laser ablation with femtosecond lasers is sufficiently promising for microfabrication of materials. For instance, a thermal affected zone was not formed in the ablated area even for metals [1]. Also, the high peak power of fs lasers could induce a multiphoton absorption to ablate transparent materials [2]. Similar results were also obtained in the case of polymer [3–6]. With the advance of femtosecond laser technology and polymer science, femtosecond laser–polymer interaction has been attracting more and more attention, and has recently directed polymer applications to fabricating microelectronic components and optical devices, according to their specific thermal, electrical, mechanical and chemical properties [7]. It has also been demonstrated that transparent polymers can be processed with ultrashort laser pulses. This indicates that nonlinear absorption and/or incubation effects play an important role. The detailed ablation mechanism is still under discussion. It is also well known that femtosecond laser processing has great potential for ablation on polymers, two-photon polymerization, and direct writing [8–12].

Polypropylene (PP) has been widely used in the packaging industry because of its highly adaptable properties and good thermal stability, chemical resistance, physiological compatibility. And, the microperforated PP film relates to the field of packaging for respiring or biochemically active agricultural

* Corresponding author. Tel.: +82 62 970 3386; fax: +82 62 970 3359.
E-mail address: ycnoh@gist.ac.kr (Y.-C. Noh).

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products such as fresh fruits, fresh vegetables, fresh herbs, and flowers and more particularly for use in modifying the flow of oxygen and carbon dioxide into and/out of a fresh produce container. In this paper we will present ablation of PP films by a 785-nm femtosecond laser. We experimentally measured the ablation depths and widths for various pulse energies and pulse numbers. Finally, it is the first time, for our knowledge, we have demonstrated femtosecond laser micropatterned packaging films for breathable film.

2. Experimental

Femtosecond laser micromachining, materials processing and micro-structuring has become important in recent years for many fields including in micro-optics, micro-electronics, micro-biology and micro-chemistry. Laser ablation, because of its non-contact nature, allows the micromachining and surface patterning of materials with minimal mechanical and thermal deformation. These advantages lie in its ability to deposit energy into a material in a very short time period, before thermal diffusion can occur. As a result, the heat-affected zone, where melting and solidification can occur, is significantly reduced, leading to structured features that are smaller in size, have higher aspect ratios, and have greater spatial precision. In this paper, the femtosecond laser processing system with a pulse duration of 184 fs, a repetition rate of 1 kHz and a pulse energy of 1 mJ at $\lambda = 785$ nm was used for the ablation experiment in air. Fig. 1 shows the schematic of the femtosecond-pulsed laser system. The laser pulses were guided into a microscope and focused by an objective lens. The average power of the laser beam is controlled by motorized attenuator, which is consisted of halfwave plate and polarizer. The sample is translated by a computer-controlled three-dimensional stage at a resolution of 100 nm. The processes during the focused irradiation of femtosecond pulses were observed through a CCD camera mounted upon the microscope. For further investigation, the pulse number N was varied by using a synchronized pulse switching system, which is consisted of synchronizing device and Pockels-cell (Laser-metrics 5100EW 50 kHz).

3. Results and discussion

It was reported that when a pulsed UV laser irradiates on the surface of an organic polymer, depending upon the incident wavelength, pulse number and pulse energy, a range from several hundred nanometers to ten of micron on the surface of the material could be ablated away with a geometry that is defined by the incident laser beam. Oriented polypropylene (OPP) films with a thickness of 30 μm, which run well over a wide range of temperatures and have good clarity and printability, were prepared for ablation. Fig. 2 shows the SEM image of OPP film ablated by a femtosecond laser with the pulse energy of 1.9, 12.7 and 38 μJ. As can be seen in Fig. 2, OPP film was successfully ablated with a femtosecond laser pulse. The threshold fluence was determined to be 2.9 J/cm^2 for 785-nm and 185-fs laser pulses with the input beam diameter of 5.6 mm and the focal length of 20 mm. An ablation threshold is the minimum pulse energy per unit area needed to initiate the ablation process and is specific for each material. The threshold of OPP film was measured by patterning the surface with various pulse energies with a single pulse. An optical microscope was used to determine the ablation threshold, which was defined as the minimum pulse energy for an observable damage of the target surface. In Fig. 3, the ablation width and depth versus pulse energy are shown for OPP film. For the OPP film, the ablation width of the crater was increased with higher pulse energies but the depth was limited to near 23 μm above the pulse energy of 300 μJ. This means that it is not possible to drill through the polypropylene film with the thickness of 30 μm using a single pulse fs laser pulse. The morphologies of the laser-patterned polypropylene films were characterized using an optical microscope and optical measurement system (NanoFocus).

Fig. 4 shows the SEM image of the OPP film surface ablated with the wavelength of 785 nm and the pulse energy of 5.5 μJ. When the pulse number was 1, 2, and 5, the ablation width/depth were 5.5/1.5, 9.7/4.5, 11.6/13.9 μm, respectively. After the first pulse was deposited, the ablation depth was determined to follow a linear relationship with the successive pulses. We measured the ablation width and depth for various pulse

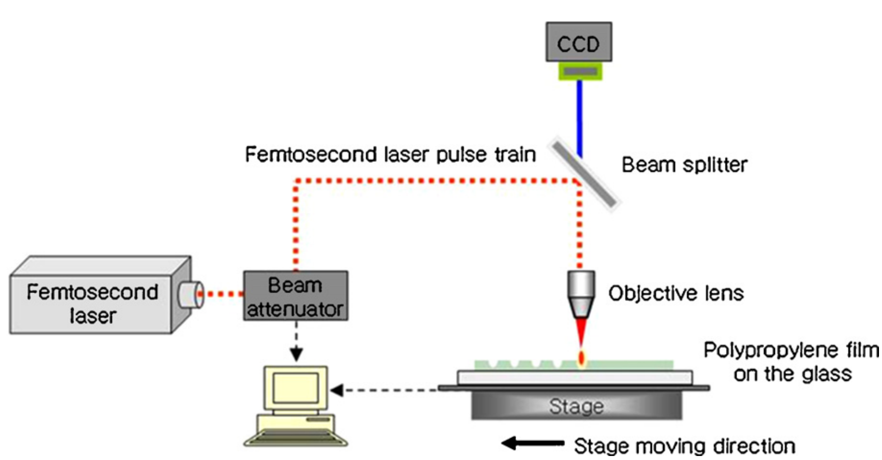

Fig. 1. Femtosecond laser pulse processing system.