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Laser fabrication of high aspect ratio thin holes on biodegradable polymer and its application to a microneedle

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Abstract

The present paper reports the fabrication of long thin holes with a high aspect ratio of 100 (diameter: 10 μm, depth: 1 mm) in biodegradable polymer material (polylactic acid, referred to herein as PLA) using a UV excimer laser. Holes having diameters of 10, 20 and 50 μm are fabricated from the side surface of a PLA sheet, and their fabricated shapes are observed using an optical microscope. These holes are compared with holes fabricated in other polymer sheets. It is proven that a long thin hole can be fabricated in PLA material, although at a lower fabrication rate compared that for epoxy material. This laser fabrication is applied to a PLA microneedle, which is fabricated by the micromolding technique. A hole is fabricated along the centerline of the newly developed microneedle, and it is confirmed experimentally that blood plasma is taken into this hole by capillary force.

Keywords: Polymer material; Polylactic acid (PLA); Excimer laser processing; High aspect ratio hole; PLA microneedle

1. Introduction

In recent years, significant research has been conducted in the field of polymer MEMS. A UV excimer laser beam is effective for fabricating polymer materials. This fabrication method has the advantage of readily coping with changes in design for a fabricated object, compared with a conventional batch process using photomasks followed by dry or wet chemical etching. Laser fabrication is performed individually for each object, which is time consuming. However, this fabrication method could be used for fabricating a mold into which a polymer material can be injected several times with a comparatively short cycle time. As polymer materials for the excimer laser fabrication, common industrial materials, such as PMMA [1,2], polyimide [2–5], SU-8 (epoxy based photoresist) [6], Parylene [7] and polycarbonate [8–10], are used, and their fabrication results have been reported. By contrast, biodegradable polymers, such as polylactic acid (PLA) or polyglicolide acid (PGA) have come to be used for several purposes, such as embedded devices in the human body in the regenerative medicine field and ecological disposable industrial products. In addition, in the MEMS field, microstructures, such as microneedles are fabricated using this material [11–13]. However, there appear to be no reports on the excimer laser fabrication of biodegradable polymer materials. In the present paper, excimer laser fabrication is applied to PLA material.

The abovementioned reports deal with comparatively large areas, such as through holes of over 100 μm in diameter [1,6], sacrificial layer areas of over 500 μm^2 [2], trenches for fluidic channels of over 40 μm in width [3,4], taper holes having entrance diameters of 50 μm [14] and 250 μm [5], line patterns of approximately 30 μm in width [7] and curved surface areas for aspheric lenses of over 1000 μm in diameter [8]. The aspect ratio of these features is usually less than 10. In these processes, the evacuation area of product gas during fabrication is secured. On the other hand, for the polymer microneedle application [11–18], it is necessary to fabricate a long thin hole along the centerline of the microneedle, the diameter of which should be less than several dozen microns and having an aspect ratio of up to 100. Excimer laser fabrication of such small features with high aspect

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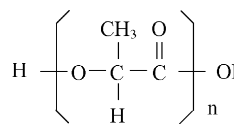
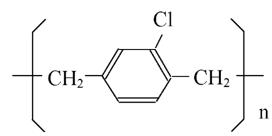
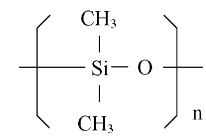
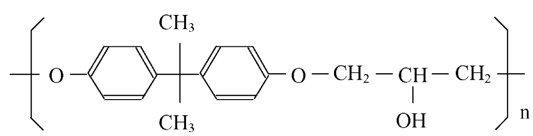
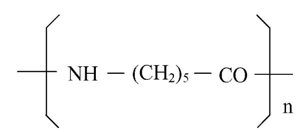
Table 1
Mechanical properties of polymer materials

	Polylactic acid	Parylene	PDMS	Epoxy	Nylon
Young's modulus (GPa)	3.4	3.2	0.003	10	0.7
Tensile strength (MPa)	64	69	7.1	68	61.8
Glass transition temp. (°C)	61	90	–	–	50
Melting point (°C)	173	290	–	–	215
Trade name	Lacty 5000	Parylene C	Sylpot 184 W/C	Epikote828	–
Chemical formula					

ratios has not been reported. In the present laser fabrication, product gas is difficult to evacuate because the machining depth becomes deep.

In the present paper, a long thin hole having a diameter of 10 μm and a depth of several hundreds of microns is fabricated in PLA material and the basic fabrication performance is investigated. This laser fabrication is then applied to a PLA microneedle fabricated by the micromolding technique. A hole is fabricated along the centerline of the microneedle. Finally, it is confirmed experimentally that blood plasma is taken up into the fabricated hole by capillary force.

2. Hole fabrication in polymer materials by excimer laser

2.1. Fabrication of thin holes in several types of polymer films

A laser-machine tool (MARUBUN Corp, OPTEL PRO) that emits a KrF laser beam having a wavelength of 248 nm is employed. The pulse length is 10 ns, and a computer program can be used to set the repetition rate up to 500 Hz, in 1-Hz intervals. The energy per pulse can be set up to 20 mJ, in 0.1-mJ intervals. The energy distribution of the beam is hat shaped (not Gaussian shaped, as in the case of the YAG laser, for example). Five mirrors and an aperture mask are placed in the traveling path of the beam. The aperture mask includes eight holes of different sizes that can be switched by a revolving mechanism. Finally, the beam is focused by a 1/20 reduction lens, which forms circular beams having diameters of 10, 20, 50, 75, 100, 150, 200 and 300 μm. The object sample is placed on a stage, which can travel up to 100 mm with resolution of 1 μm in both the *x* and *y* directions. This stage is moved by a stepping motor, which is controlled synchronously for laser firing by a computer program.

Polylactic acid (PLA), which is a biodegradable polymer, polydimethylsiloxane (PDMS), Parylene, epoxy and nylon are adopted as polymer materials. The chemical formulas, mechanical properties and thermal properties of these materials are shown in Table 1. Thin holes, 10 μm in diameter, are fabricated by a pulsed excimer laser beam on sheets of these materials at atmospheric pressure, i.e., in air. The conditions of laser machining are set as follows: the laser beam diameter is 10 μm, the repetition rate is 5 Hz, the energy per pulse is 10 mJ and the total pulse shot number is 500. To facilitate the observation of the shape of cross section, the experimental method is as follows: a hole is laser machined from the side surface of a transparent polymer sheet and is observed using an optical microscope from the top surface of the sheet. This method is shown schematically in Fig. 1. Generally, it is difficult to observe the cross section of a small hole, because cleaving a sample object accurately along the line passing through a fabricated hole is difficult. In addition, for experiments to examine deep hole fabrication, the preparation of a comparatively thick film of several hundred microns by

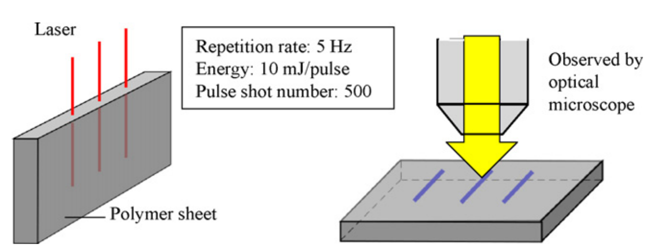


Fig. 1. Conditions of laser micromachining of holes in a polymer sheet and observation method.