Applied Surface Science 257 (2011) 2432–2435

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Femtosecond laser machining of electrospun membranes

Yiquan Wu[a,*], A.Y. Vorobyev[b], Robert L. Clark[a], Chunlei Guo[b]

[a] Department of Mechanical Engineering, University of Rochester, Rochester, NY 14627, USA
[b] The Institute of Optics, University of Rochester, Rochester, NY 14627, USA

ARTICLE INFO

Article history:
Received 1 June 2010
Accepted 29 September 2010
Available online 27 October 2010

Keywords:
Laser machining
Electrospinning
Membranes

ABSTRACT

We demonstrate that a femtosecond laser can be used to machine arbitrary patterns and pattern arrays into free-standing electrospun polycaprolactone (PCL) membranes. We also examine the influence of various laser irradiation settings on the final microstructure of electrospun membranes. A beam fluence of 0.6 J/cm^2 is used to ablate holes in 100 μm thick PCL membranes. The machined holes have an average diameter of 436 μm and a center-to-center spacing of 1000 μm. Based on these results, the femtosecond ablation of electrospun membranes shows great potential for fabricating a variety of functional tissue scaffolds. This technique will advance scaffold design by providing the ability to rapidly tailor surface morphology, while minimizing and controlling the deformation of the electrospun fibers.

1. Introduction

Electrospinning is a unique and versatile approach for controlled one-dimensional microfabrication with fiber diameters typically ranging from nanometers to micrometers [1–4]. Due to its comparatively low cost, relatively high production rate, and simplicity of infrastructure and processing, electrospinning is being investigated extensively for various applications in materials processing and nanotechnology [5–9]. A typical electrospinning process involves the use of a high voltage bias to charge the surface of liquid droplets. When an applied electric field is sufficiently strong, charges built up on the surface of the droplets will overcome surface tension inducing the formation of a liquid jet that accelerates toward a grounded collector. As an electrospun jet approaches a collector, the jet experiences a fluid instability stage that leads to thinning of the jet and solidification of the fibers [10,11]. Because the effect of fluid instability limits the ability to weave the electrospun fibers, random-assembled membranes are generally obtained. Layer-by-layer electrospinning has been shown to produce fibrous porous membranes in several materials including metals, polymers, ceramics, and composites. Porous membranes have multiple applications and are actively used in energy storage, healthcare, biotechnology, and environmental engineering [5,7–9].

Femtosecond laser machining currently shows much promise as a versatile tool for the precise processing of materials with micro- and nano-scale features [12–14]. The unique characteristics of ultra-short laser pulses enable precise processing and minimize sample damage caused by stress waves, thermal conduction, and melting [15]. Researchers have utilized the femtosecond laser machining of ceramics, polymers, alloys, metals, semiconductors, and glass [16–22] to construct a wide range of devices in the biomedical, photonic, microelectronic, and microfluidic fields. In this paper, we demonstrate the ability of a high-intensity femtosecond laser to machine holes and slots in electrospun polycaprolactone (PCL) membranes. The laser system configuration allows for on-demand machining of arbitrary macro- and micropatterns into electrospun membranes, providing design flexibility that could be utilized to assess the structure, function, and application of electrospun membranes.

2. Experimental setup

For fabrication of electrospun PCL membranes, a precursor solution of 10 (w/v%) was prepared by dissolving polycaprolactone (PCL, Aldrich, MW 80,000) in a solvent mixture of dichloromethane (Aldrich) and methanol (Aldrich) in a ratio of 8:2 by volume. The solution was loaded in a 10 ml plastic syringe (BD company) equipped with a 25 gauge nozzle (McMaster), and was pumped through the nozzle, using a syringe pump (Cole–Parmer), at a constant flow rate of 2.0 ml/h. A high-voltage power supply (Acopian) was used to provide a potential voltage of 18 kV to the stainless steel nozzle. Electrospun membranes were collected on grounded aluminum foil or carbon sheets.

To create structures in electrospun PCL membranes, we used an amplified Ti:sapphire femtosecond laser system that consists of a mode-locked oscillator and a two-stage amplifier. The laser system generated 65-fs pulses containing 1.5 mJ per pulse at a

* Corresponding author at: Materials Science Program, Department of Mechanical Engineering, University of Rochester, 215 Hopeman Building, Rochester, NY 14627, USA. Tel.: +1 585 275 4844; fax: +1 585 256 2509.
E-mail address: wuyiquan@me.rochester.edu (Y. Wu).

0169-4332/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.apsusc.2010.09.111

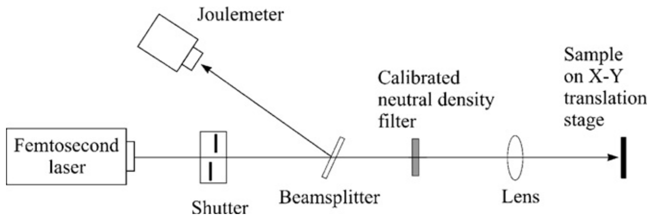

Fig. 1. Experimental setup for machining of electrospun PCL membranes.

maximum repetition rate of 1 kHz and central wavelength of 800 nm. The experimental setup is shown in Fig. 1. The laser beam was horizontally polarized and focused by a thin lens onto a sample mounted on a motorized *X*–*Y* translation stage. The number of laser pulses incident on the sample was controlled by a fast electromechanical shutter. A beam splitter directed a fraction of the incident beam into a joulemeter so that the energy of the femtosecond pulses could be monitored. A neutral density filter was used to adjust the beam intensity incident on the sample plane. A desired pattern can be produced by opening the shutter and laterally translating the sample using the *X*-*Y* mechanized stage. The microstructure of the electrospun membranes before and after laser machining were characterized using a field-emission scanning electron microscope (FE-SEM, Zeiss-Leo DSM982 model) operated at an accelerating voltage of 5 kV. The samples were sputter coated with a thin film of gold prior to imaging.

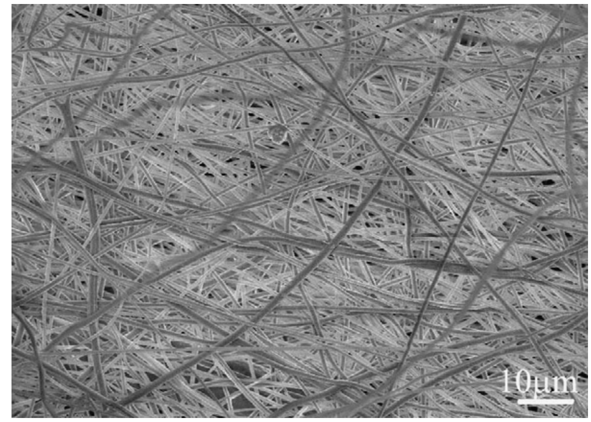

Fig. 2. SEM micrograph of electrospun PCL membrane before femtosecond laser machining.

3. Results and discussion

Fig. 2 shows a scanning electron microscope (SEM) image of a 100 μm thick electrospun membrane. The diameters of the electrospun fibers range from 0.4 μm to 0.9 μm, with an average diameter of 0.5 μm. The as-prepared membranes were observed to contain randomly distributed electrospun fibers. A series of experiments were conducted to assess the effect of laser fluence on structure fabrication in the electrospun PCL membranes. As shown in Fig. 3(a), using femtosecond laser pulses with a fluence

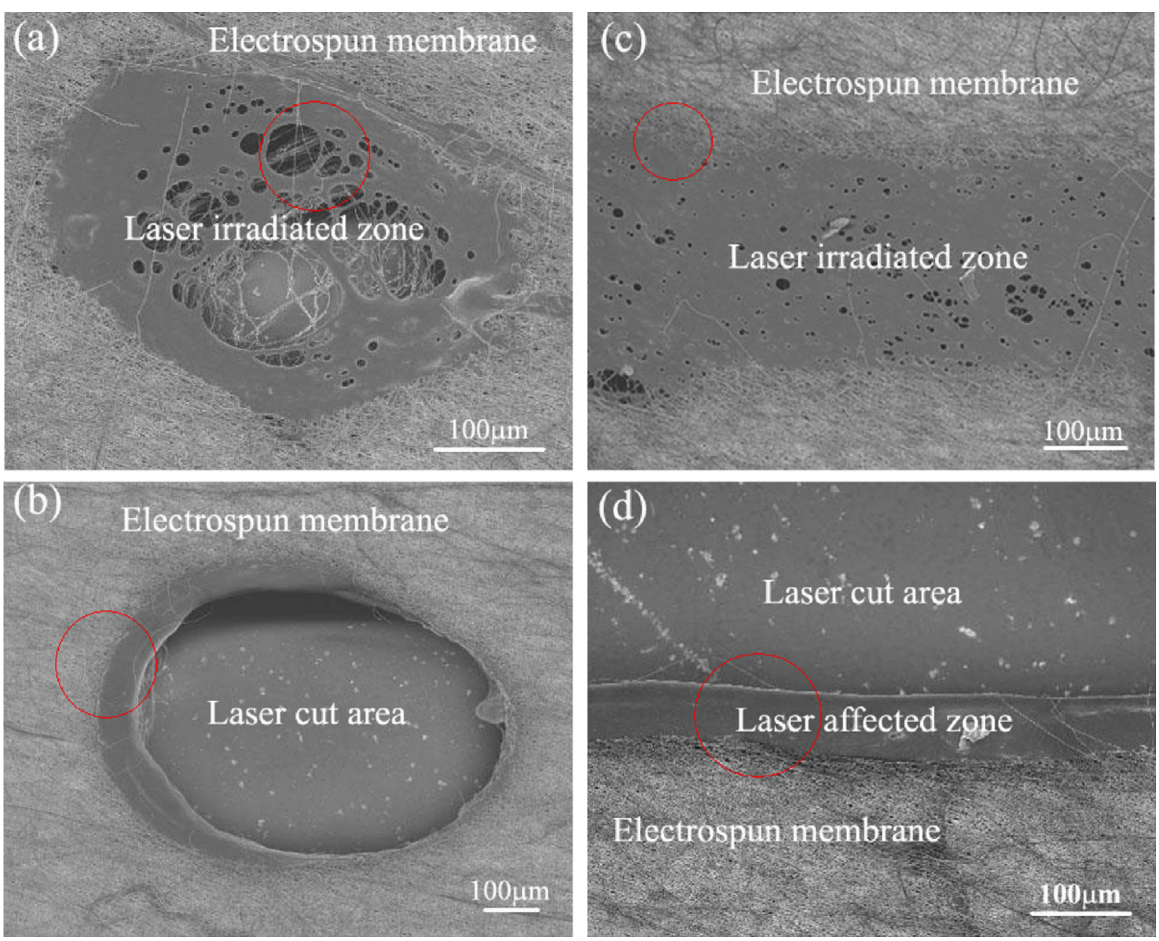

Fig. 3. SEM micrographs of electrospun membranes irradiated by femtosecond laser at different processing conditions: (a) $F = 0.17\,J/cm^2$, (b) $F = 0.75\,J/cm^2$, (c) $F = 0.17\,J/cm^2$ at a scanning speed of 1 mm/s, and (d) $F = 0.75\,J/cm^2$ at a scanning speed of 1 mm/s.