

Femtosecond Laser Processing for Biomedical Device Fabrication

The femtosecond laser has been used to fabricate biomedical devices. Laser ablation using pulses with a duration on the sub-picosecond or femtosecond time scales can remove materials with lower residual thermal effects, and the accuracy and quality of the device can be superior to conventional long pulse lasers. The process has been developed in a non-cleanroom environment, which can reduce the cost of the final product or affordable device fabrication. Also, it provides a convenient, economical and flexible way to fabricate three-dimensional patterns by varying the beam-scanning speed during ablation while clean room lithography requires a highly controlled environment and has limited capability for 3-D features. We demonstrated the femtosecond laser process for track-etched membrane drilling, hot embossing mold fabrication for micromolecular separation, microfluidic channels on dielectric materials, tissue engineering or PCL ablation and apertureless focusing for nanoscale channels.

Track-Etched Membrane Drilling

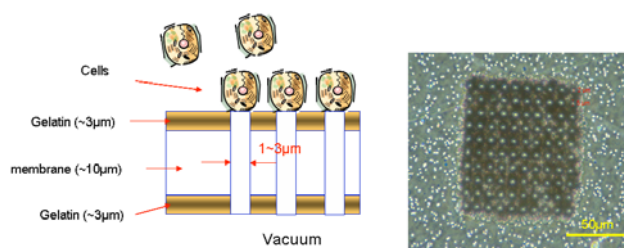


Figure 1. Schematic of cell capturing (left) and microscale hole array drilled by femtosecond laser (right) – Experiment condition: 1 µJ/pulse, 30 pulses/hole

Femtosecond laser machining was used to drill micron hole arrays on Track Etched Polycarbonate Membrane. Both sides of the 10 µm thick membrane were coated with gelatin (~3 µm on each side) to modify the bio-affinity. Process parameters of laser power, focus location and number of pulses were optimized for the best quality of drilling. Laser power was varied between 1 mW and 4 mW, and the shapes and dimensions of the holes were characterized by measuring the front and backside of the drill holes. Typical drilling diameters of complete holes were measured to be 1 µm ~ 4 µm. As shown in Figure 1, the drilling location as well as the diameter of the holes could be varied by adjusting the process parameters.

The shapes of the holes were found to be either conical or straight, depending on laser power. This fabrication is collaborative work between the Nanomanufacturing core technology group and Gene Delivery testbed group. The Gene Delivery testbed group will use the fabricated membrane cell-trapping applications.

Apertureless focusing for nanoscale machining

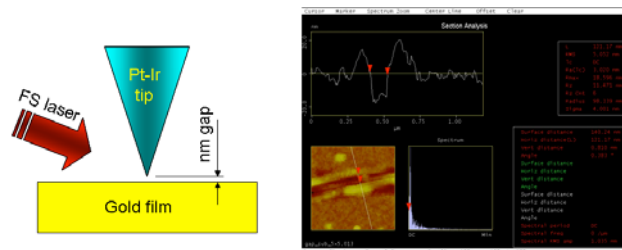


Figure 2. The concept of apertureless focusing with STM + FS laser (left) and 120nm wide and 20nm deep nanochannel fabricated on gold film

A femtosecond laser beam was applied on the apex of an STM tip made of Pt-Ir. Laser energy was concentrated at the nanoscale apex of the STM tip and transferred to an underlying gold surface to fabricate nanoscale channels needed for biomedical applications, such as DNA stretching. The dimension of fabricated channels in the 150 nm-thick gold film was measured to be 120 nm wide and 20 nm deep (Fig. 2).

Affordable microfluidic channel fabrication using hot embossing process

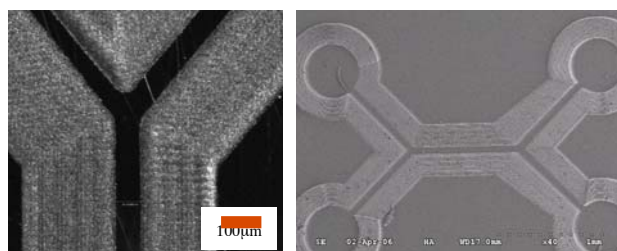


Figure 3. Magnetic particle separation channel mold on stainless steel (left) and replica of mold on PMMA (right)

Femtosecond laser micromachining was used to create microfluidic channel patterns on an AISI 304L stainless steel tool (Fig. 3 – left) to fabricate mold patterns in thermoplastic polymers by hot embossing. To characterize the machining process, measurements of single pulse ablation spots with pulse energies from 13 nJ to 500 nJ were used to determine the ablation threshold as 0.19 J/cm². The volume of material removed per pulse increased steadily with pulse energy, but the ablation efficiency relative to the evaporation enthalpy of removed material had its maximum value of 2% at 65 nJ. A pulse energy of 250 nJ, 75% focus spot overlap and 1.8 mm/s scan speed were selected as parameters that provided an acceptable compromise between machining rate and surface finish. Molds with fluid channel features 12 µm deep and as narrow as 8 µm wide could be machined using

laser ablation. A mold with channels 75 μm wide and 10 μm deep was machined and used to emboss a microfluidic micro-molecular magnetic separator pattern in poly-methyl macryolate (PMMA) polymer. This is collaborative work between the Nanomanufacturing core technology group and Biosensor test bed group. The Biosensor test bed group will use the fabricated device for magnetic particle separation applications.

Fabrication of microfluidic channel on dielectric material and surface roughness improvement by HEMA coating

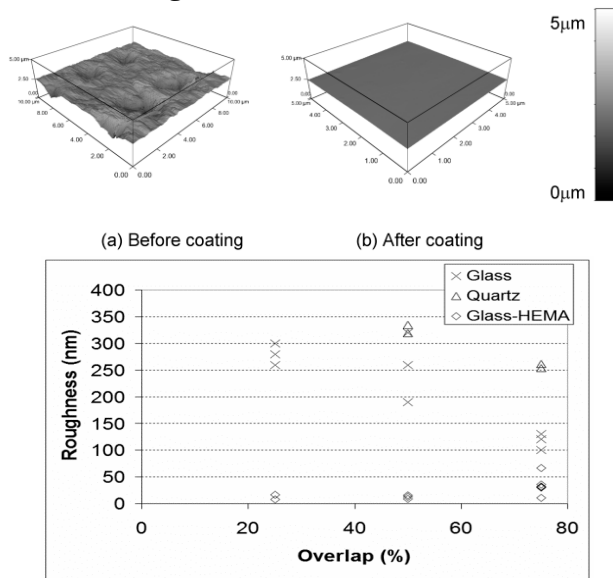


Figure 4. AFM scanning result of channel fabricated on glass, before coating (a) and after coating (b). The roughness of surface is summarized on the graph (bottom)

Techniques for microfluidic channel fabrication were tested in soda-lime glass and fused quartz using femtosecond laser ablation and ablation in conjunction with polymer coating for surface roughness improvement. Systematic experiments were done to characterize how process variables (laser fluence, scanning speed, and focus spot overlap, and material properties) affect machining feature size and quality. Laser fluence and focus spot overlap showed the strongest influence on channel depth and roughness. At high fluence, the surface roughness was measured to be between 395nm-731nm RMS. At low fluence, roughness decreased to 100nm-350nm RMS and showed a greater dependency on focus spot overlap. The surface roughness of laser ablation was also dependent on the material properties. For the same laser ablation parameters, soda-lime glass surfaces were smoother than fused quartz. For some applications, especially those using quartz, smoother channels are desired. A hydroxyethyl methacrylate (HEMA) polymer coating was applied and roughness of coated channels was improved to 10-50nm RMS.

Direct-write Femtosecond laser ablation on Electro Spun Polycaprolactone (PCL) nano fiber tissue

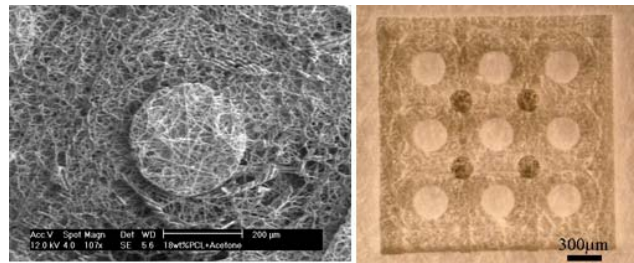


Figure 5. Scanning Electron Microscope image of structured ES-PCL (a) and optical images of poles and holes (b).

Meshes of nanoscale electrospun (ES) poly-caprolactone (PCL) fibers are widely used in tissue engineering scaffold applications. ES PCL meshes were structured to fabricate cell growth micro-pockets with a scanned femtosecond laser. The femtosecond laser was seen to be an effective way for flexibly structuring the surface of ES PCL scaffolds. With the advantages of direct-write femtosecond laser ablation, this laser micromachining technique was used to make a desired pattern on PCL to control cell deposition and growth. 300 μm diameter poles and 200 μm holes were made with optimized laser parameters to achieve high quality desired patterns on PCL. This fabrication is collaborative work between the Nanomanufacturing core technology group and the Nanofiber Synthesis core technology group.

Publications

1. "Femtosecond laser micromachining of dielectric materials for biomedical applications", *Farson, Choi, Zimmerman, Steach, Chalmers, Olesik, and Lee*, (accepted, J. Micromech. Microeng.)
2. "Structuring electrospun polycaprolactone nanofiber tissue scaffolds by femtosecond laser ablation", *Choi, Johnson, Nam, Farson, Lannutti*, J. of Laser Applications (19:225-231 2007)
3. "Femtosecond laser micromachining and application of hot embossing molds for microfluid device fabrication", *Choi, Zhang, Gram, Farson, Lee, Yi, Lu, and Lee* (submitted to J. Laser Applications)
4. "Femtosecond laser machining of dielectric materials for biomedical applications", *Choi, Zimmerman, Farson, Chalmers*, Proc. of ICALEO, Scottsdale, AZ Nov. 2006
5. "Optimizing Membrane Sandwich Electroporation Through Microfabrication And High Speed Spin Disk Confocal Imaging" *Henslee, Fei, Hemminger, Choi, Chiang, Lu, Farson, and Lee* Proc. Of AIChe, Salt Lake City, Nov. 2007