Two- and three-dimensional micromachining of transparent polymers using femtosecond laser pulses

George M. Whitesides and Eric Mazur

contributors: D.B. Wolfe, J.B. Ashcom, C.B. Schaffer, and J.C. Hwang

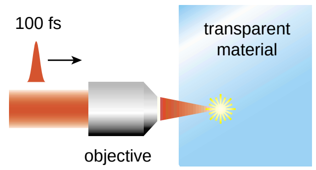
Introduction

Focusing femtosecond pulses into transparent materials produces an intensity at the focus high enough to cause localized structural and chemical changes. This process allows precise micromachining of glasses, crystals, and polymers.

High intensity leads to energy deposition via nonlinear absorption

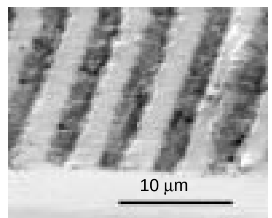
Tight focusing with microscope objectives and nonlinear nature of absorption confines structural alteration below diffraction limit

Short pulse duration minimizes energy necessary to cause nonlinear absorption, minimizing collateral damage.



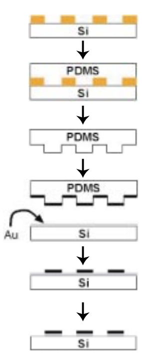
Surface machining of polymers

Microcontact printing is used to produce micrometer-scale circuits using elastomeric stamps. Surface machining of stamps with femtosecond pulses eliminates photolithographic step.

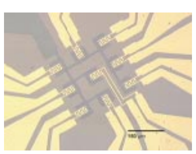


SEM of PDMS patterned with femtosecond laser pulses

Conventional microcontact printing



- Photoresist master made by photolithography
- PDMS cured over photoresist master
- PDMS removed from master to be used as a stamp for microcontact printing
- PDMS stamp coated with alkanethiol and placed in contact with gold surface
- Stamp removed and alkanethiol SAM attached to gold to serve as etch resist
- After etching, gold features are left on Si/SiO2 substrate

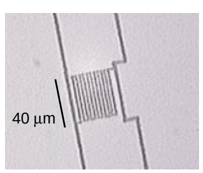


Optical micrograph of gold electrode pattern fabricated with above procedure. Finger separation is about 3 µm.

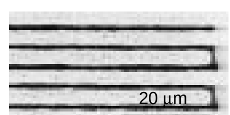
Laser surface machining of PDMS stamps

Non-photolithographic technique has advantages over lithographic techniques.

- Smaller features than transparency masks (for rapid-prototyping)
- Equivalent feature size (1 µm) to chrome masks
- Patterning of non-planar surfaces
- Large-area pattern fabrication



PDMS stamp of interdigitated finger electrode device for cyclic voltammetry. This device is part of a 100 mm^2 pattern that include large contact electrodes.

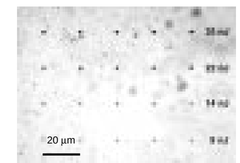


Optical micrograph of gold finger electrodes on silicon produced using femtosecond patterning of PDMS.

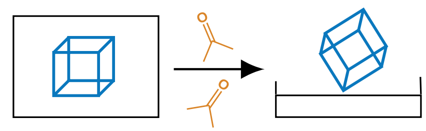
Laser-induced carbonization of bulk polymers

In polystyrene and polyacrylonitrile, tightly-focused femtosecond pulses produce local chemical changes. This allows the creation of 3D structures within the polymer with solubility properties different from the original material.

- Smallest altered region has 2-µm diameter
- Altered, weakly-conducting material useful for micro-electromechanical systems (MEMS)
- Altered material likely amorphous carbon
- Altered region resists solvation and can be freed from polymer matrix



Array of carbonized spots in polystyrene, showing minimum feature size of about 2 µm.



Technique allows 3D structures to be removed from polymer.

Rectangle of chemically altered polyacrylonitrile freed from polymer.

Future directions

Doping polymer to increase conductivity of chemically-altered regions

Optimizing polymer to give more robust structures

Direct writing onto curved PDMS surfaces (*e.g.*, for large-field IR detectors)

Fabrication of micrometer-scale device demonstrating mechanical and/or electrical capabilities (MEMS)

Investigation of new materials: application to sol-gels (colloidal silica suspensions) could induce localized glass formation

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