



Laser induced periodic surface modification of polymer: A direct method

V Velmurugan, E Srinivasan
Center for Nanotechnology Research
VIT University, Vellore.
INDIA.

Abstract: In this paper we present the results of the investigations carried out on SU-8 – a negative tone photoresist for surface modification. The photo polymer is coated and exposed optimally to UV light to create stable structures. The surface modification is carried out with a low power (150 mW) CW laser. The minimum line width of the line pattern that was created by simple set up is 7.1 microns and large area (1mm²) periodic deformation is done by creating laser interference pattern on the polymer surface.

Key words: Surface, modification, SU-8, laser, Interference, direct writing.

I. Introduction

Laser induced surface modification of polymers is a technique that finds many applications in the areas of food processing, electronics, optoelectronics, aerospace[1], 3-D polymer microlenses[2], 3D polymer nanostructures for photonics[3]. The use of polymeric structures are exploited for its chemical and thermal resistance property, early processing and low cost. Laser induced surface modification could be of more advantages than other type of sources in terms of the precision, cleanliness of the finished surfaces and throughput. The comparison of the results by different authors in terms of the exposure studies cannot be done because of large trial and error based methods[4]. Excimer laser are predominately used for restructuring polymers, but in this work we used a low power(532nm, 150mW DPSS, CW) laser to restructure a commercially available negative photoresist (SU-8) and the laser direct writing threshold, polymerization property, surface roughness, pattern width variations were analyzed. The use of low power laser to create uniform periodic structures by direct method on SU-8 is reported for the first time.

II. SU8

SU-8 (supplied by MicroChem Corp) is an epoxy based photo resist and sensible to wavelengths in the range of 300nm to 500nm. It is available with different combination that can serve a good recipe for various process steps (Table 1).

Table 1 SU-8 properties

Property	SU-8(2000 series)	SU-8(3000 series)
Softening point (°C)	210	200
Thermal Stability in Nitrogen (°C @ 5% weight loss)	295	277
Thermal stability in Air (°C @ 5% weight loss)	279	-
Young's modulus (GPa)	2.0	2.0
Coefficient of thermal expansion (ppm/°C)	52	52
Elongation at break (%)	6.5	4.8
Tensile strength (MPa)	60	73
Thermal Conductivity (W/m K)	0.3	0.2
Dielectric strength (V/μm)	112	115
Volume resistivity (Ω/cm)	2.8×10^{16}	1.8×10^{16}
Surface resistivity (Ω/cm)	1.8×10^{17}	5.1×10^{16}

The structure (Fig 1) shows nearly 8 epoxy groups in each molecules and this becomes highly cross linked and allows to form high aspect ratio structures. The UV absorption spectrum (Fig 2) of SU 8 coated on glass plate after UV exposure done by Hitachi U-2800 Double beam Spectro photometer shows maximum absorption at 350nm. It is said to have multifunctional glycidyl ether derivatives of biphenol-A, triarylsulfonium, hexafluoroantimonate salt, photoacid generator and a thinning solvent[4].

Fig 1. Chemical structure of SU-8.

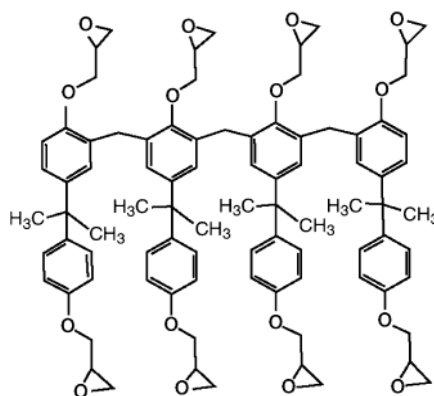
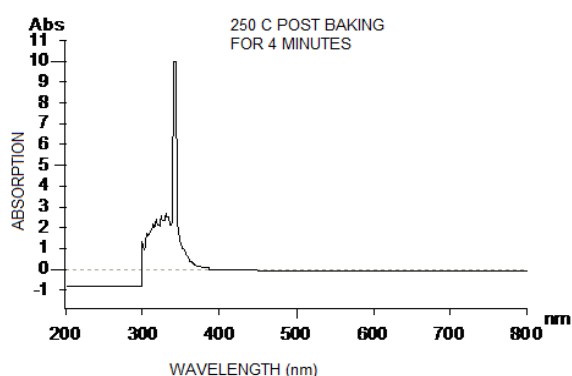


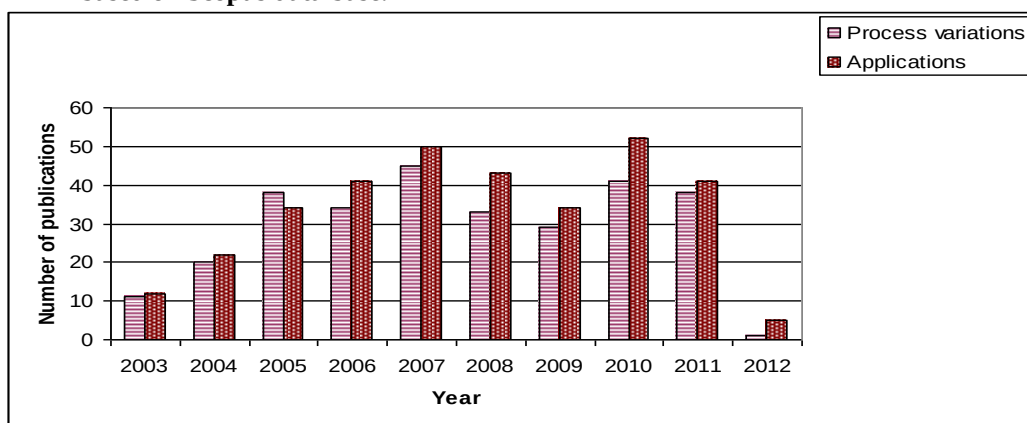
Fig 2. Absorbance of SU-8



SU-8 upon exposure cross-links in two steps (i) formation of a strong acid during the exposure process, followed by (ii) acid-initiated, thermally driven epoxy cross-linking during the post exposure bake. The average molecular weight is around 7000 and such a low molecular weight allows SU-8 to dissolve in variety of organic solvents.

SU-8 has good cohesion to bind to itself but has poor adhesion and bonding with other materials. The typical bonding strength varies from 23MPa to 92MPa. The adhesion is poor on glass and good with Gallium Arsanide. Variation of the process sequence and addition of adhesion promoters will enhance the bond strength with the substrate[5]. SU-8 can be modified based on specific applications, like addition of materials like CNT, Diamondoids, gold[6], Gamma butyrolactone[7]. Several applications like tuning of polymer for biomedical sensing and actuating[7], polarization control devices[8] and photonic structures[3] could be good examples of use of SU-8. The Research efforts could be classified as the variation in the process and applications. The statistics (Fig 3) shows the number of publications based on that.

Fig 3. Publications with 'SU8 process variation' and SU8 applications' in their titles based on Scopus data base.



III. Direct writing technique and experimental setup

The parameters that govern the process of direct writing are the energy of the incident light, wavelength, type of exposures (pulsed or continuous), absorptivity of surface, melting or ablating threshold, reflectance of the surface, heat conductive property, velocity gradient during the time of melting, shape of the pulse, thermal diffusion length, roughness of the surface, etc.,.

The determination of exact power level for specific application is crucial in surface modification because the final product could be deteriorously affected if an excessive or insufficient amount of power is applied. Material absorbs different amount of energies at different wavelengths. If a material is not absorbing sufficient amount of energy at a particular wavelength, increase in the power density can promote the energy absorption by the material at that specific wavelength. Even though SU-8 has the maximum absorption at 350nm (Fig 1), our experimentation with 532nm source yielded good result due to use of suitable optics. SU-8 is subjected to standard UV exposure and this makes the resist to become transparent to the visible region and also helps in removing the gluing property of the resist. An under dosage of UV light may retain the crossover and thereby fails to form rigid structures[5].

Laser interference based surface modification is a method to produce periodic structures over large area using two interfering highly-coherent light beams. Due to large change in the intensity surface modification can be easily done.

IV. Results

Surface modification was carried out in two methods (i) by direct focusing of laser beam on the substrate and (ii) by creating interference pattern on the sample. Two sets of samples were prepared by cleaning glass plate with acetone at 55°C for 10 minutes and finally rinsed in deionized water and dried using nitrogen torch. SU-8 is coated on the glass using spin coater. The optimized values for coating are, the spinning speed: 4700rpm, duration: 100seconds and for every 15 seconds 2 drops of SU-8 were added. The SU-8 film is subjected to UV light exposure for 7 seconds to have complete polymerization. DPSS laser(Compass 315m from Coherent Inc) with a wavelength of 532nm having variable power upto 150mW was used for the experiment.

A microscopic objective (45X) was placed at a distance of 10mm from the laser. First set of samples are kept at 0.3mm from the objective. The calculated power density at that position is $235.78 \text{ kW mm}^{-2}$. The sample is moved in one direction at different speeds to create line patterns. Fig 4 shows one of the line pattern formed. For higher speeds, the surface didn't initiate the modification and at lower speeds (0.25mm/Sec) polymer gets deformed and the line width varies with the exposure timing (Fig 5). The minimum line width obtained is 7.1 microns and the structures were stable for a long period of time.

Fig 4. Optical microscope photographs of the line pattern (8 microns) , (b) 3 D view showing the pumps created by the exposure.

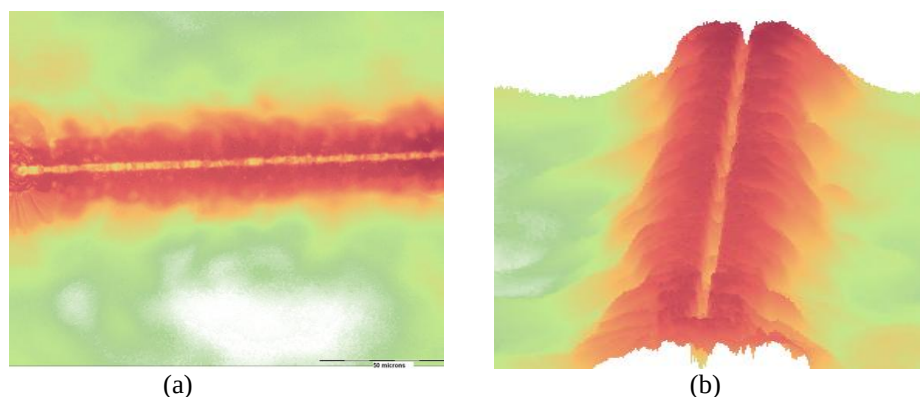
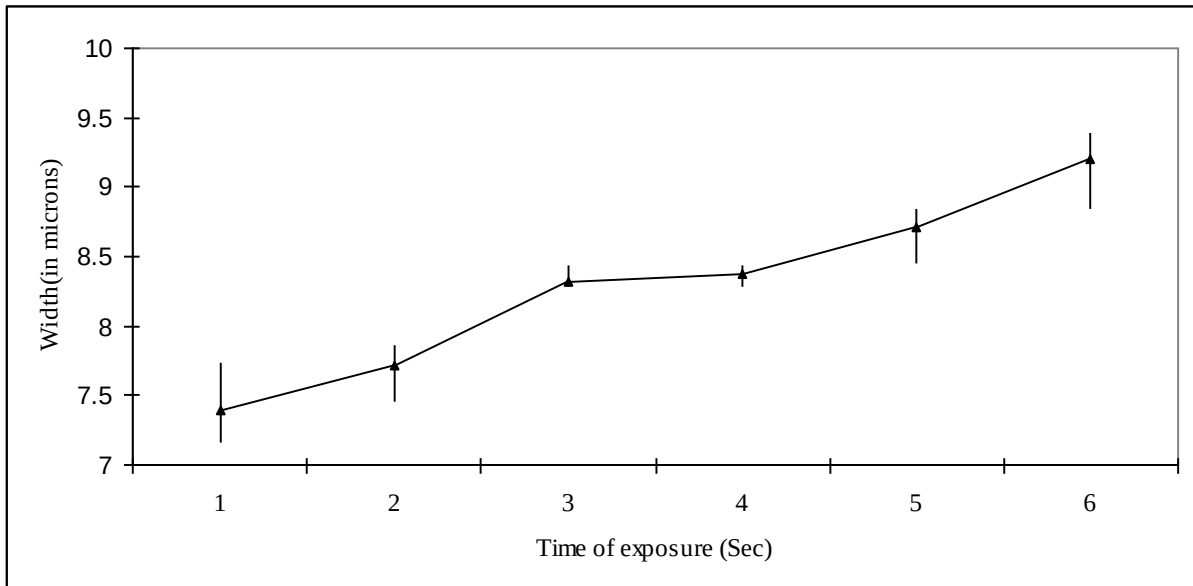
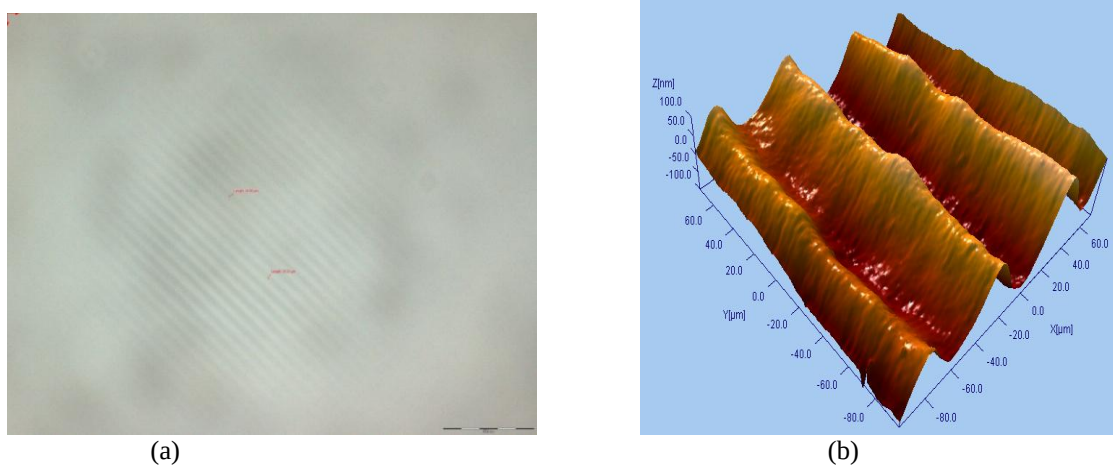


Fig 5. Variation of line width for different exposure timings



Second set of samples were restructured by interference method. Mach zender's interference was tried and the interference pattern obtained is focused on the sample with a concave lens. The patterned samples are characterized by Nano scratch tester and NSOM. For imaging, the sample is sputtered with silver using magnetron sputtering. The image (Fig 6) shows minimum line width of 60 microns and the surface roughness was increased by 1.34 times.

Fig. 6. (a) High resolution Interference patterns imaged by NSOM and (b) portion of the interference patterned characterized by nano scratch tester.



V. Conclusion

In conclusion, low power laser beam interaction with the photoresist has been investigated. Removal of photoactive and gluing property of the resist was done by making a film at optimized coating and the exposure parameters. These values have resulted in better deforming the polymer surface. Periodic patterns formed by direct laser interference on the surface resulted in structures that are stable for long period of time.

VI. References

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