FT-IR investigation of netlike polymerization of SU-8 resist layers during photo- and X-ray lithography processes

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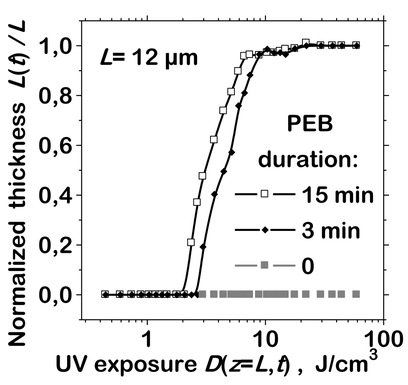
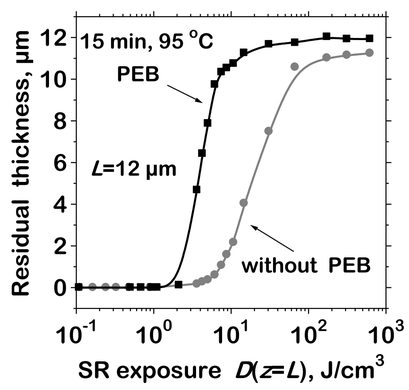
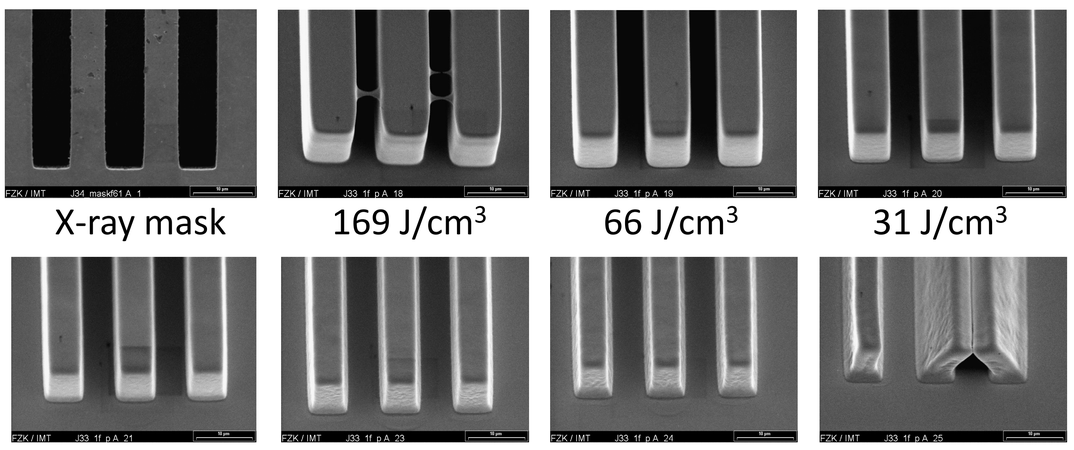
Abstract. Layers of multi-component SU-8 resist, which includes a diglycidyl ether of bisphenol A novolac as a monomer, were investigated by the FT-IR spectroscopic method for a wave number range of 600 - 5000 cm^{-1} after each step of the photo and X-ray lithography processes (coating, pre-exposure baking, exposure, post-exposure baking, development). The doses of absorbed both photo and X-ray radiation were varied from 0.1 J/cm^3 to 6000 J/cm^3 with uniform dose distribution in the layer depth. It was found that the monomers are bonded to each other in initial pre-polymer by means of the end disrupted epoxy groups. The band intensity at the 914 cm^{-1} wave number is decreased after heating of exposed SU-8 layer with an increase of a dose of absorbed radiation because of a disruption of the glycidyl groups. The disrupted bonds of the pre-polymer molecules connect to each other with a net polymer formation, and the intensities of FT-IR spectral bands at 1076, 1110, 1128 and 1150 cm^{-1} are enhanced. In contrast to photolithography, an X-ray exposure results to a disruption of the epoxy groups of the pre-polymer molecules as well as a formation of polymer ester bonds -C-O-C- during both the exposure process and post-exposure baking. The relative quantity of disrupted epoxy groups and the correspondent amount of a new formed polymer bonds in the resist layer are grown with an increase of the dose of the absorbed radiation up to saturation at about 1000 J/cm^3. The dose dependence of a relative number of monomers in the insoluble phase of the residual polymer area after the development process corresponds to the characteristic curve of a relative residual thickness of the resist layer. The dose of about 1 J/cm^3 is a threshold for an appearance of the insoluble phase of the layer on a substrate surface. At approximately 30-60 J/cm^3 the shrinkage and swelling of the layer with the insoluble phase becomes close to zero. The mass ratios of the insoluble and soluble phases in the resist layer in dependence on the dose of absorbed X-ray radiation were determined, the quantity of absorbed photons and the track lengths of photo- and Auger-electrons were calculated in order to model the SU-8 netlike polymerization. The physical-chemical properties of SU-8 polymer, the mechanism and optimization of X-ray lithography processes using synchrotron radiation are discussed.

UV and X-ray lithographic characteristic curves of SU-8 resist and SR dose dependence of SU-8 microstructure forms [1, 2]

Two threshold doses:
about **1 J/cm^3**
and **30÷60 J/cm^3**.

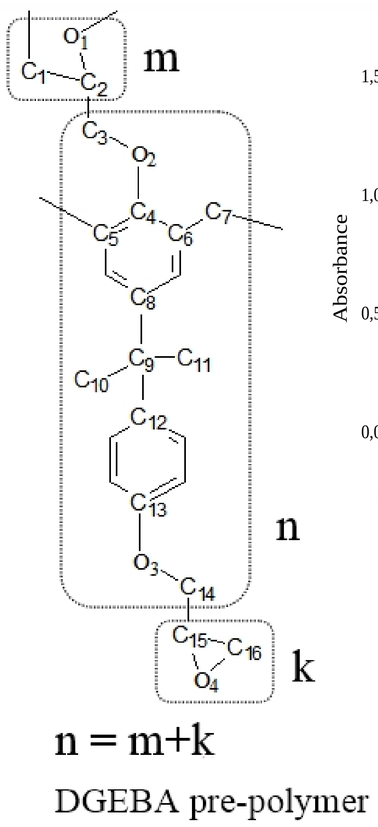


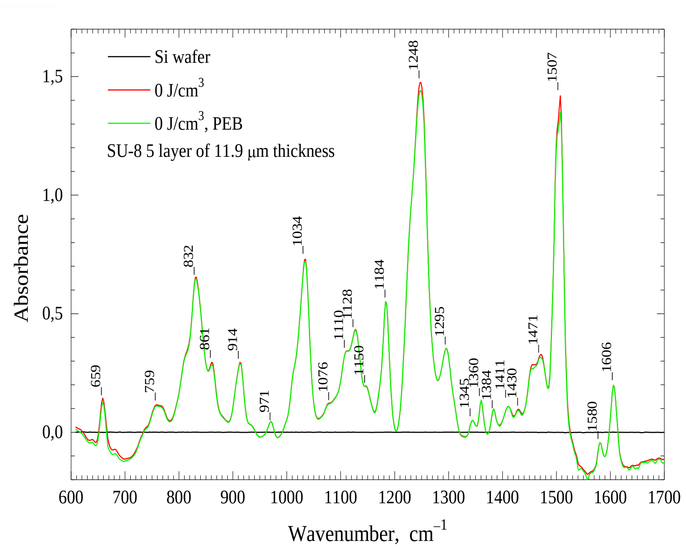


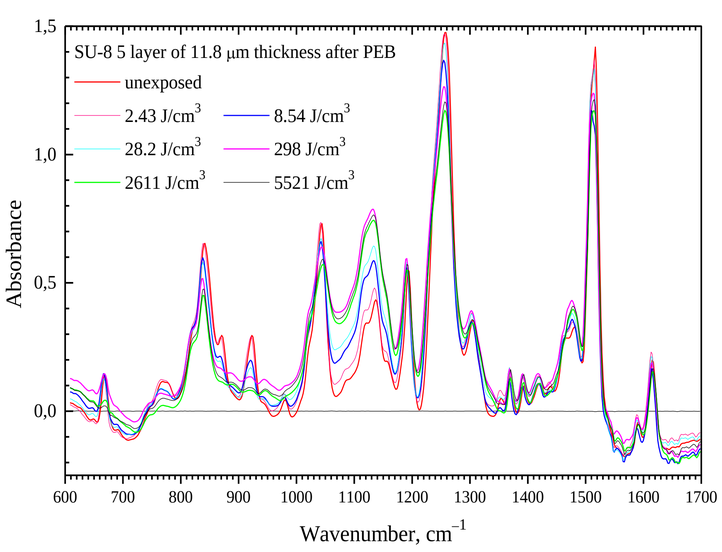


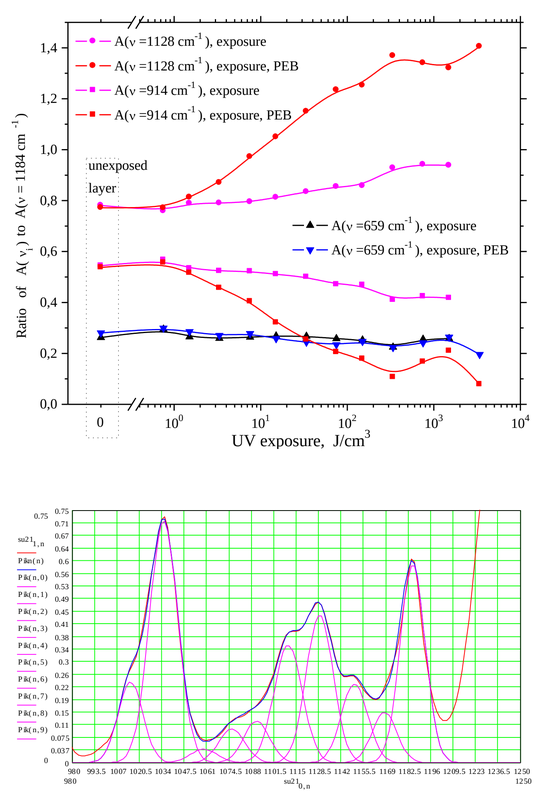
Shrinkage effect of microstructures at exposures < 30 J/cm^3.
Cracks and swelling at L/L(t)≈0.95÷0.99.

MIR ad FT-IR spectra of SU-8 resist layers in dependence on dose of absorbed UV and synchrotron radiation









Figures of scheme (on the left) of initial DGEBA pre-polymer and lithographic polymer and IR spectra examples of (1) an unexposed SU-8 layer after soft and post-exposure baking and (2) SU-8 layer after post-exposure baking for different SR exposures. (3) The relative intensity of IR absorbance bands of for 12 μm thick SU-8 layers in dependence on dose of absorbed UV radiation.
(4) The convolution of IR absorbance bands of deformation vibrations of C-O-C bonds of crosslinking DGEBA-polymer.

Conclusion

In the work, the polymerization extents for both SU-8 pre-polymer and UV and X-ray lithographic polymers were determined by FT-IR spectroscopy method with variations of the lithography exposures. The ratio *n/m* for SU-8 pre-polymer molecules corresponded approx. 1.8. A qualitative SU-8 lithography microstructure is filled by one SU-8 polymer molecule with the ratio $\frac{m_{SU8polymer}}{m_{pre-polymer}} \approx 1.54 \div 1.65$.

Literature

[1] E. Reznikova, J. Mohr, H. Hein. Deep photolithography characterization of SU-8 resist layers. Microsys. Technol. 11 (4-5), 282-291 (2005)
[2] E. Reznikova, J. Mohr, V. Nazmov, P.-J. Jakobs. Soft X-ray lithography of high aspect ratio SU8 submicron structures. Microsy. Technol. **14**, 1683-1688 (2008).

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