ION TRACK NANOSTRUCTURING OF DIELECTRICS

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Ion tracks in dielectric films offer unique possibilities for the realization of nanometer-sized structures at low cost and high throughputs. In combination with lithography they open up new ways for biofluidic, electric, magnetic and optic device fabrication. These tracks of distorted material are formed when dielectric materials are exposed to swift heavy ion irradiation with kinetic energies in the order of 100 MeV or more. Such fast heavy ions induce along their path a nanometer channel of transformed material, where each single ion track may exhibit properties markedly different from the surrounding bulk material.

The track diameter is between 1 and 10 nm and adjustable by the chosen ion and its kinetic energy. If the linear energy transfer (LET) of the ion projectile is high enough the transformed material will form a continuous string a few nm in size. Otherwise the tracks consist of nanometer sized small packets of transformed material, like a string of pearls. The latent tracks may be used directly, e.g. creating conducting and magnetic nanowires in insulating matrices, or when continuous they may be selectively etched into pores, and then used as they are for nanobiofluidic applications or as templates for growing nanostructures. Samples may be irradiated at densities from up to 10^{14} cm^{-2}, where all the material is transformed. Most often the densities are in the $10^6 – 10^{11}$ cm^{-2} region. Commercial irradiation can produce in the order of 10^{12} tracks per second, which equals to an area of 1 m^2 with a track density of 10^8 cm^{-2} (1 track per μm^2) per second!

The modified material may be used as it is, either as a new material composite with the undisturbed matrix or as modified individual tracks. Examples of recent achievements are amorphous magnetic tracks in paramagnetic crystalline matrix, strings of nanocrystalline silicon in amorphous SiO_2, and conductive graphitized nanowires in insulating diamond like carbon. Only imagination limits our use of this family of nanostructures. For example, the graphite nanowires in a diamond-like carbon (DLC) matrix could possibly be used in field emission flat panel displays.

Today, there are only a limited number of commercial products produced by the ion track technology. The superior properties of ion track membranes for these applications are the well-defined size and pore geometry. Low-dose irradiated polymer foils are used as filters in water purification, analytical membranes in biomedicine and chemical pollution studies, and as cell cultivating membranes. In research the foils have been used as templates, enabling groups without nanolithography in producing and studying thin long magnetic nanowires grown in ion track membranes. For example, the magnetization inversion behavior was measured on a single Co wire with 35 nm diameters. This high quality nanowire allowed a detailed study of the single domain wall movement upon external field changes. Of special interest are magnetic nanowires built up of alternating quantum layers of magnetic and non-magnetic materials, which may be studied for spintronics and high-density magnetic reading and storage devices.

Recently, the ion track technology has been combined with lithography to control patch sizes, matrices or more advanced patterns. For the use of the modified latent ion tracks only stencil masks or focused ion beams may be used. Thin film lithography may be used to address where pores should be etched out. Nanoprobe swift heavy ion beam irradiation enables higher contrast lithography with high aspect ratios and structuring of otherwise irradiation insensitive thin films. Low-dose ion track technology enables laboratories without lithography and cleanroom technology to create and study singular nanoscopic features of their own. By this ion track technology can elevate the accessibility and promote the uptake of nanotechnology in a unique way!

For ion-irradiated polymer resists, using annealing and UV-sensitization a novel approach has been demonstrated to produce 10-nm sized vials by ordinary optical lithography. Exclusively in UV-irradiated areas, lithographically defined by an ordinary Cr-mask, discontinuous ion tracks were transformed into continuous etchable tracks. UV-sensitization of ion tracks is well known for a few aromatic polymers and this lithographic process should be possible for them at least, but optical sensitization may also occur in other types of polymers like polyimide. Although having to accept the statistic spread of the Poisson distribution of ion tracks, a high number of vials give in sub-micron precision access to nanoscopic features to laboratories not equipped with advanced non-optical lithography, with their total cross-section and each individual size having less statistical spread than features in ordinary nanolithography.

Ion track technology offers a broad variety of scientific challenges. However, we want to emphasize a few major issues that are essential to study for a better understanding of future use of ion track technology: In particular from the theoretical point of view, the interaction of ions and matter in the high LET regime is yet not well described. This is especially true for complex material systems like polymers. The issues of material transformation during irradiation, thermal treatment, oxidation, and photon irradiation should be addressed to promote this technology into industrialization.

The scientific innovation is in the short time-scale especially on the ion track enabling of optical lithography. In the long time-scale the use of heavy ion material modification in latent ion tracks, whether continuous or pearl string nanoclusters, has enormous potential in creating novel nanotechnology materials.

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