Maskless Nonlinear Direct-Write Femtosecond Laser Lithography And Applications

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Conventional lithography is a leading high-throughput patterning method for mass production. But the dramatically increasing cost of lithographic equipment and mask sets, which is a consequence of pushing optical lithography to its limits, makes alternative, maskless lithographic techniques very attractive. One of them is the recently developed maskless femtosecond laser lithography which can provide a potential alternative solution for the mask cost issue. Especially, for small-scale manufacturing applications, this patterning technology could be very promising.

Diffraction is the limiting factor in conventional photolithography. Structure sizes are restricted to a value in the order of the radiation wavelength. In general, this is also true for optical maskless lithography. Using maskless lithography in combination with femtosecond laser radiation, however, enables structure sizes far below the diffraction limit. This super resolution is the consequence of the well defined threshold for femtosecond laser photoresist exposure and the nonlinearity of the laser-photoresist interaction.

Further rapidly advancing femtosecond laser technology is three-dimensional microstructuring by multiphoton illumination technique. Taking its origin from multiphoton microscopy, it is now becoming an important microfabrication tool. We will discuss recent advances in two-photon polymerization (2PP) technique and in a more general version of this technology, called two-photon activated (2PA) laser processing. We will characterize different materials which can be structured by this technology, discuss resolution limits, and demonstrate a broad range of applications.

In our work we apply near-infrared Ti:sapphire femtosecond laser pulses (at 800/780 nm) for 3D material processing. When tightly focused into the volume of a photosensitive material (or photoresist) they initiate 2PP process by, for example, transferring liquid into the solid state. This allows the fabrication of any computer-generated 3D structure by direct laser ”recording” into the volume of photosensitive material. We will report on recent advances of this technology and future short- and long-term prospects.

There are two kinds of negative photoresists which can be patterned by 2PP technique: radical-curing and cationic photoresists. Inorganic-organic hybrid polymers (ORMOCERs), used in our work, belong to the radical-curing class. In these photoresists absorption of light generates free radicals that initiate polymerization process. We will provide detailed description of ORMOCERs and their microstructuring characteristics. In cationic systems (an important example is the commercially available SU-8 photoresist, which we also apply in our work) an acid is generated upon laser irradiation. In this case polymerization does not take place during laser irradiation (only after a post-exposure bake). This is an important property of cationic photoresists, since the difference in the refractive index of exposed and unexposed area is negligible which provides flexible irradiation strategy and allows one to combine direct laser-beam writing (serial processing) and holographic exposure (parallel processing).

2PP of photosensitive materials irradiated by femtosecond laser pulses is now considered as enabling technology for the fabrication of 3D photonic crystals and photonic crystal templates. In particular, 2PP allows one to introduce defects at any desired locations, which is crucial for the practical applications. To realize photonic crystals with a full photonic band gap, 3D microstructuring of high refractive index materials is required. The most attractive option is to fabricate templates which are later infiltrated with a high refractive index material, followed by the removal of the original structure. Application of most negative photoresists for the fabrication of templates is rather complicated, since the structures fabricated in these materials are quite stable and not simply soluble. In case of positive photoresist the polymer is weakened and is usually more soluble in developing solutions. This is very attractive for the fabrication of 3D templates. Possibilities to use positive photoresists for the fabrication of PC templates will be discussed.

Recently, we and some other groups in the world have studied possible applications of 2PP technique in biomedicine, looking for novel biocompatible and bioactive materials which can be structured by 2PP. Applications such as tissue engineering, drug delivery, and medical implants could greatly benefit from this approach. In particular, 2PP is a very interesting technique for the fabrication of drug delivery systems and medical implants. These and other bio-medical applications of 2PP will be reviewed.