Chapter 10
Micromachining and Patterning

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Abstract Laser micromachining and patterning by laser ablation is used for the fabrication of micro-fluidic and micro-optic components. Irradiation configurations comprise direct spot writing, mask projection, and multiple beam interference. The fabrication of grooves, micro channels, micro lenses, dielectric masks, gratings, and diffractive elements is described. Special attention is paid to layer ablation in order to create planar optical structures.

10.1 Introduction

Laser micromachining and patterning comprises the utilization of lasers for creating a specific surface relief by pulsed ablation of material. Materials treated are polymers, glass, ceramics, metals, and composite materials. To create a predefined pattern, either a mask containing this pattern is projected onto the sample, or the intensity pattern is formed by two- or multiple beam interference, or a direct write process is accomplished by focus scanning. The mask can contain a fixed pattern (stencil mask or Cr on quartz mask), it can be a variable aperture (variable slit, hole), it can contain only fully transparent and opaque areas, or even gray levels. Multiple beam interference is usually applied for the generation of periodic patterns. The beams are generated by reflective or diffractive beam splitters and recombined on the sample. Combinations of mask imaging and interference of selected beams are possible. Periods ranging from about 300 nm to some μm are made this way.

Applications (except drilling, cutting, marking, which are treated in Chap. 13) are mainly in the fields of micro fluidics and micro optics. Micro fluidic applications comprise the fabrication of grooves, micro channels or channel systems, and the fabrication of periodically patterned surfaces with increased or diminished hydrophilicity or tribology. Micro optical elements, which can be fabricated by ablative micro fabrication, comprise planar optics (e.g., masks, gratings, diffractive elements, planar waveguides), where the binary or multilevel or continuous
(e.g., sinusoidal) profile is either produced on the surface of a substrate, or it is generated by patterning of a coating on the substrate. In addition, 3D micro optics, for example, micro lenses, are made by using variable masks or processes providing the desired smooth relief profile. Complex functionalities are obtained by, for example, creating a micro lens on a fiber tip.

Whereas in the case of metal micro machining, often femtosecond (fs) lasers are applied to minimize heat affected zones (HAZs) (see Chaps. 2 and 4), for micro machining of polymers, glasses and ceramics, UV-lasers are mainly used enabling sufficient (linear) absorption even of weakly absorbing materials. Whereas Nd:YAG lasers are typically used in a scanning spot mode, for complex shaping using mask technology, excimer lasers are best suited delivering high pulse energy with nearly flat top beam profiles [1]. This chapter addresses micromachining with (nanosecond (ns)) pulsed lasers utilizing ablation of bulk or layered material and surface patterning by mask projection or direct writing.

10.2 Direct Writing

A laser process is called a direct write process, if the laser beam is delivered to the work piece on a predefined line in a continuous or quasicontinuous way. This can be accomplished with a focused beam by scanning the beam or by moving the work piece. In contrast, the simultaneous irradiation of multiple lines or spots or extended areas is termed mask projection. The term laser direct writing is often used for additive processing such as deposition of metallic lines by laser induced decomposition of metal organic compounds or by laser induced printing or forward transfer (Chap. 11). Also the material modification by femtosecond laser induced alteration of the refractive index is often accomplished in a direct write mode (Chap. 9). All these processes are not treated in this chapter; we concentrate on ablative direct writing, where material is removed in a sequential mode.

Using scanning ablation, one has to consider that the morphology of the line or channel made by this method can look different from that observed in the case of static ablation. For the fabrication of channels in stretched polylethylene-terephthalate (PET) by ArF-laser ablation, it has been observed that the structure on the ground of the channel depends on the ramp angle produced when starting the process [2]. This ramp angle in turn depends on the combination of mask size, fluence, laser repetition rate, and scanning velocity. Furthermore, for precise machining by direct writing, the ablation behavior at varying angle of incidence of the laser beam on the surface has to be taken into account. For focused 266 nm-ablation of Ormocer- and SU8-material, it has been shown that the dependence of the angle of incidence is significant at high fluences, but can be negligible in a certain low fluence regime [3].

Even below the material ablation threshold, significant changes in the surface morphology are possible. For instance, laser direct writing on polyimide with a continuous wave argon ion laser at 351 nm leads to melted lines which influence the alignment of organic liquid crystals [4].