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Review

Recent developments on microablation of glass materials using excimer lasers

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Abstract

For many years, the development of effective laser machining techniques for making glass-based microcomponents and devices has been a critical factor in the birth of new photonic and biomedical microsystems. In this article, the characteristics and abilities of excimer lasers for micromachining of a wide range of glass materials are reviewed and studied. Following the introduction, the special features of excimer lasers are discussed. The typical micromachining system used for glass materials is presented. Then, the fundamental micromachining parameters and the associated morphologies of machined surfaces are evaluated. The approaches by controlling the ablation rate for making the curve surfaces are specifically formulated. Although a wide range of commercially available glasses is covered in this article, two types of the most widely used glasses, borosilicate glass and fused silica, are thoroughly examined to illustrate the complexity in micromachining the glass materials. The procedures to machine single, arrayed, curved microstructures are described. The utilizations of these procedures for making microneedles, optical waveguides, submicron grating, and microlenses are specifically demonstrated. Finally, recommendations for future efforts are presented.

Keywords: Ablation; Curved surface; Excimer laser; Fused silica; Glass; Diffraction grating; Microlens; Micromachining; Microneedles; Waveguides

Contents

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1. Introduction

In the past decade, there has been a strong demand for a variety of photonic and medical components and devices by a variety of industries, including telecommunication, medicine, entertainment, instrumentation, optical data memory/storage, and remote sensing and imaging. Frequently, these types of optical and medical elements are made from different types of transparent materials. A wide range of transparent glasses are often selected because of their high availability and low cost, in addition to their exceptional optical and chemical properties. However, the conventional processes for machining glasses to a feature size at micrometer levels, including grinding/polishing and plasma etching, are not only time consuming but also costly. In this article, a non-conventional technique using excimer lasers for micromachining a wide range of glass materials is presented.

Excimers are gas-type lasers that offer the most efficient access to the ultraviolet (UV) or deep UV region with short pulse rates and durations, leading to high pulse intensity. The short wavelengths allow for high-energy intensity and high resolution in machining, which is specifically critical in working on tough glass-type materials. While the ultimate resolution of an optical system is limited by diffraction effects, which is proportional to the wavelength of the radiation involved, the excimer laser, normally with a short pulse time ($\sim$10 ns), allows high-intensity energy to be absorbed in a very thin surface layer for the effective removal of material from a target area. Consequently, excimer lasers are capable of machining material from the target directly and do not require photoresists for pattern transfer, or clean-room facilities as demanded in conventional semiconductor processes. As compared to other types of lasers, excimer lasers can be more effectively used for machining glass materials, where high precision and high surface quality machining is required. Recently, they have been used for a broad range of applications, including ink jet nozzle drilling, via drilling in printed circuit boards, removal of short cuts in electronic circuitry, wire stripping, fabrication of diffraction grating, microfluidics, microlenses, microgears, and optical waveguides [1–4].

The machining mechanism for excimer lasers to directly remove material is usually referred to as ablation, in which the material explodes into vapor and is ejected in the form of species such as atoms, molecules, ions, and clusters due to the interaction of an intense laser pulse with the material. The process is often envisaged as a sequence of steps, initiated by the laser radiation interacting with the solid target, absorption of energy and localized heating of the surface, and subsequent material evaporation. The macroscopic effects of ablation include plasma, acoustic shocks, and cratering of the surface. To ablate a high precision and high-quality structure at micrometer scales, the interaction between the laser and material must be well understood and controlled. As a result, in this article the responses of a wide range of glass materials during excimer laser ablation are examined with a goal of making high precision and high-quantity microstructures for opto- and bio-electronic applications.

Following Section 1, the characteristics of several major excimer lasers are assessed and the basic components of an excimer laser system for micromachining of glass materials are presented. The major material properties and processing parameters governing the ablation process are identified and can be used for appropriately guiding the ablation process for making flat and curved surfaces for different optical or bio-applications. Although a wide range of commercially available glasses, including borosilicate, Nd-doped, and Pyrex glasses, fused silica, and crystal quartz, is covered in this article, the ablation of two types of the most widely used glasses, borosilicate glass and fused silica, is specifically considered for making different microstructures to illustrate the complexity in micromachining the glass materials. The surface morphologies ablated by different types of excimer lasers are examined and the rationale for causing the undesirable surface roughness is also discussed. Finally, recommendations for future efforts and trends are included.

Note that the present article is focusing on direct ablation of optical microstructures. Other manufacturing approaches by excimer lasers, such as surface treatment, laser-induced etching, and hybrid laser techniques, are beyond the scope of this paper. However, information on these non-ablation micromachining techniques, especially the laser-induced backside wet etching and laser-induced plasma-assisted ablation, can be found in a recent article by Tseng [4]. Furthermore, fused silica is highly pure synthesized silicon dioxide (SiO_2) with a highly cross-linked non-crystalline structure, while quartz is a crystalline SiO_2. Each has a very high melting temperature with excellent optical qualities and exceptional transmittance. In general, the fused silica or crystal quartz is much more difficult than the other types of glasses, including the popular borosilicate glass, to machine by lasers. For the sake of clarity of the presentation, from now on, the term "consumer glasses" will be used to those non-fused silica and non-quartz glasses.