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Femtosecond laser fabrication of periodical structures in bulk of transparent dielectrics

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Abstract

We present results of experiments in development technology of precision micromachining of materials by focusing the femtosecond laser radiation into the bulk of transparent materials. Conditions of the realization and some key parameters of special regime of micromachining have been defined. It implements at certain ratio between scanning speed and repetition rate of femtosecond laser pulses. Under mentioned conditions the area destroyed by laser radiation moves along the optical axis near focus region in both directions, forming (during transverse scanning) in a bulk of the sample "periodical" structures. In results of our investigation we demonstrate precision cutting crystals, glasses, polymers and creating cylindrical cavities 1÷2 microns in diameter with aspect ratio more than 200 directed along the axis of laser beam.

Peer-review under responsibility of the National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)

Keywords: microstructures; filament; microchannel; femtosecond radiation; photodisruption; photodegradation; focusing in a bulk.

Nomenclature

FS	femtosecond
f_d	focusing depth
PC	polycarbonate
NA	numerical aperture of lens
SA	spherical aberration

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1. Introduction

Femtosecond (FS) laser is the preferred tool for micro and nano-processing of materials, production of photonic and fluid devices: waveguides, couplers, optoelectronic systems, microchannels [Gattass R. G. et al. (2008)] on the basis of transparent polymers, glass and fused silica [Farson D. F. et al. (2008), Kim T. N et al. (2005)].

Polymers, glass, biomaterials under tight focusing of FS laser radiation have a strong nonlinear absorption, which leads to the formation in focal area the plasma microchannel, modification of the refractive index Δn along the axis and near the microchannel and finally to the optical breakdown and micro-destruction of material [Stuart B. C. et al. (1996), Burakov I. M. et al. (2007)]. All of these processes are highly nonlinear and have threshold nature. That is why, by selecting the laser intensity slightly above the threshold level which typical for such process, it is possible to achieve sub-diffraction quality of material processing.

Accurate focusing the laser energy to micro-region in a bulk of treated object needs for many applications. However, due to longitudinal spherical aberration, interior micro-disruption produced by FS pulses has not spherical but elongate shape, with dimensions depending on the parameters of FS laser radiation, sample material and experimental conditions [Sun Q. et al. (2005), Watanabe W. et al. (2000)].

The main purpose of this paper is to find the conditions of the appearance of phenomenon which not fully described before. We found that under certain conditions the breakdown produced by focused FS laser beam in transparent dielectrics is shifting along the optical axis near focus region in both directions, forming (during transverse scanning) in a bulk of the sample "periodical" structures with a number of specific features.

On the other hand, very important goal of this work is to study technology not only creation but also reduction the structures described above and demonstration the number of possible applications for using achieved experimental results in materials processing.

2. Experimental setup, samples and methods

The experimental setup is shown in Fig. 1 a). We used in the experiments the following objectives: 54-18-23-1064, N.A.=0.39, Special Optics; L PLAN 50X, N.A.=0.6, Leitz Wetzlar; aspherical lens, AL 1210c, N.A.=0.545, THORLABS. The radiation was focused in the bulk of a sample. The sample and the focusing objectives are mounted on computed controlled translation stages with micrometric precision. The entrance surface of the sample is perpendicular to the laser beam propagation (Z axis). The sample can be moved along three axes by three stepping motors (8MT173-50, Standa). To measure the power were used sensor PD300-3W, Ophir Photonics (350-1100 nm) and power meter Nova, Ophir Photonics.

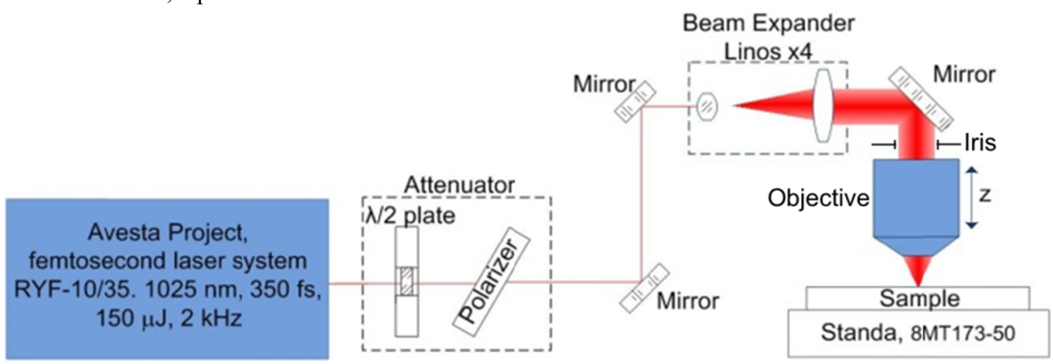

Fig.1. Experimental setup.

Samples of polycarbonate (PC), PMMA, fused silica and BK7 glass as plates 50x20x3 mm^3 with polished faces were used in the experiments. Figure 2 shows the comb of tracks of various lengths from exposure of FS-pulse; destruction created at different energies at a focusing depth f_d = 1089 mm (horizontal line). The picture obtained by NIKON LV100D microscope from the side face of the sample. The laser beam is incident from the top. The sample