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Arbitrary Optical Retardance Patterns Generated in Bulk Silica Glass by Laser-Written Stressors

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Abstract: We present micro-scale stressors written in bulk silica using an ultrafast laser. Stress from nanograting formation produces optical retardance, which is then tailored through control of the orientation, magnitude, and anisotropy of the stress field.

OCIS codes: (260.1440) Birefringence; (160.6030) Silica

1. Introduction

Laser modification of dielectric materials has been applied to many areas of photonics, including microfluidics [1], micromechanics [2], and optical device fabrication [3]. Here we extend optical device fabrication though an indirect approach of generating laser-written stressors in bulk fused silica. Stress fields from these patterns generate optical retardance in the bulk of the substrate. These laser written stressors may then be used as a building block for a new avenue of optical device fabrication through careful control of the magnitude, orientation, and anisotropy of the induced stress field. When considering the direct write approach to device fabrication, one can find many examples of laser-written stressors as a means to control optical retardance, including waveguide formation in crystalline materials [4] and birefringence control in waveguides [5].

These approaches are often based on a rectilinear stressor approach (i.e. lines or sheets of laser modified material), and while effective, have the disadvantage of generating broad area stress fields that are not easily controlled. Additionally, sharp corners often lead to stress concentration, increasing the probability of crack nucleation and ultimate device failure. In this work, we have chosen structures based on tubes formed by direct-laser writing as a means to efficiently generate stressors in bulk material, while avoiding high concentrations of stress.

2. Methods

Tubes are formed by focusing pulses from an ultrafast fiber laser (Amplitude Systèmes, 1030 nm, 275 fs, 400 kHz) in the bulk of a silica substrate using a 20x (0.4NA) objective. The substrate is translated in a circular motion with the aid of a pair of high-bandwidth flexure stages, forming rings with a maximum diameter of 100 um. Rings are then stacked with a fixed z spacing of 5 um to form a tube.

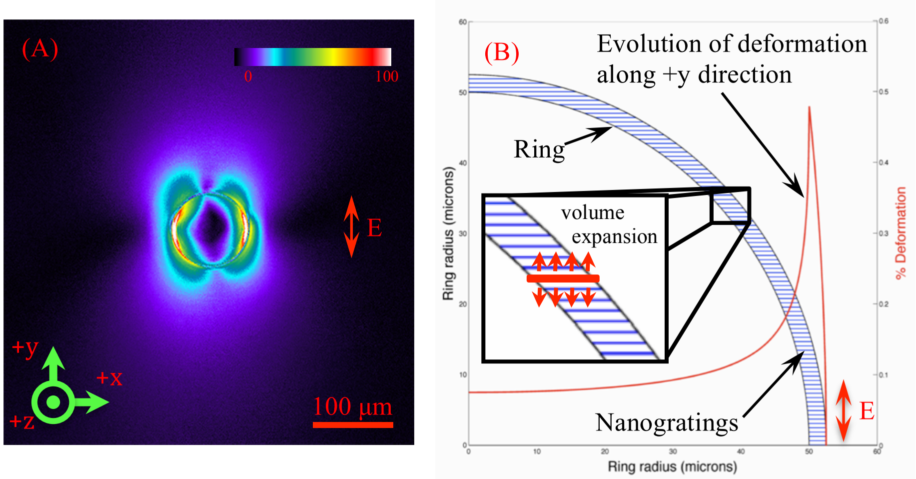

Fig. 1. Stress model (A) and resulting retardance profile (B) for a 128 layer, 50 µm diameter tube.

Fig. 1 shows an example of the stress field generated by a 50 µm diameter tube with 128 layers formed with 200 nJ pulses and a writing velocity of 1000 µm/s. The false-color retardance profile shown in (A) is obtained with a standard polariscope (LC Polscope, CRi Instruments). The resulting retardance profile is highly anisotropic, with the major axis oriented parallel to the writing polarization. This unique pattern may be explained by the model given in

(B), which represents a quarter section of a laser written wring. As the laser-modified zone is created, nanogratings are formed, generating a volume expansion possibly due to dissociation of elements within the substrate [6,7]. This expansion has been estimated to be on the order of ~0.03% per unit length [6]. The deformation profile is computed by calculating a linear segment length along the direction of the +y axis that perpendicularly intersects the lamella between the inner and outer radius as a function of the distance along the +x axis. This length is then used, along with information about the expansion of individual lamellae, to estimate the total deformation in each ring.

3. Results

Writing polarization plays a key role when fabricating tube structures, as demonstrated in Fig. 2A-D. Linear writing polarization (Fig. 2A-C) generates a highly anisotropic retardance field, whose orientation is directly dependent on the orientation of the writing polarization. More exotic polarization states, such as radial or azimuthal generate a retardance state which is almost entirely isotropic, as shown in Figure 2D. These polarization states are directionally independent, forming nanogratings that generate a continuous and homogeneous deformation around the circumference of the tube.

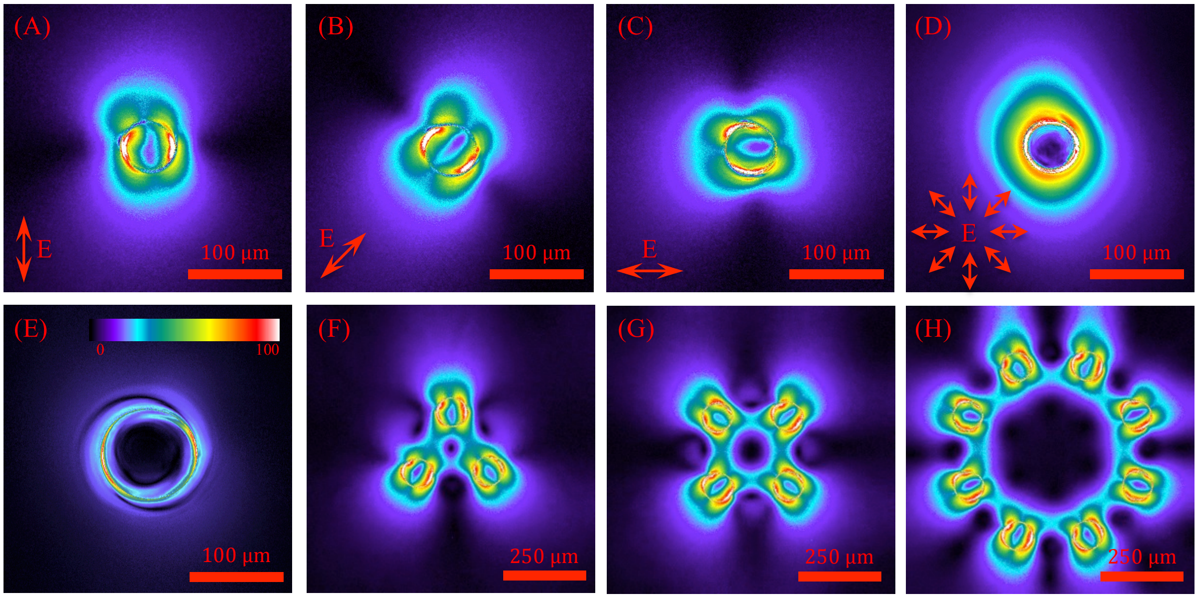

Fig. 2. Examples of tailored retardance states. Single-tube patterns with rotated retardance fields (A-C) written using liner polarization. An isotropic stress field is easily created using radial (D) or azimuthal (not shown) writing polarization. Polarization rotation may be employed to generate complex structures with 3D variation of retardance (E), as well as combinations of patterns for more complicated structures. In (A-F) the polarization state of the wring beam is given for clarity.

Variations tube structures and writing polarization states may be combined to form larger structures with more complex functionality, as shown in Fig. 2E-H. Rotation of linear polarization at fixed increments over a number of layers in a tube produces a vortex-like pattern (Fig. 2E), useful in generating radial and azimuthal polarization states in propagating beams. Tubes may also be arranged so that the interaction of stress fields produces more complex retardance fields (Fig. 2F-H).

4. References

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