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Bragg diffraction gratings formed in bulk fused silica by femtosecond Bessel beams

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Abstract: A femtosecond direct-write method using Bessel beams is investigated as a means for in-bulk diffractive element formation, the performance of the formed diffractive elements is analyzed with insights into possible mechanisms of fused silica modification using Bessel beams. Results are compared to direct-write using Gaussian beams for elements of similar geometry.

1. Introduction

Since the dawn of lasers there was a pronounced interest in modifying materials using radiation. With the increasing maturity of femtosecond laser technology it has become feasible to use lasers as tools for modifying bulk transparent media in useful ways, for example – by creating optical elements that may even not be realizable in other ways[1].

In this work a study of femtosecond pulse induced modification of bulk fused silica by a Bessel-Gaussian beam (referred to as Bessel beam further in this text) is presented. A comparative study is also presented on using Bessel beam vs. Gaussian beam for bulk fused silica modification with the intent of forming a transmitting Bragg grating.

2. The experiment

Tightly focused Gaussian beams provide good transverse as well as axial selectivity for bulk material modification, however, sometimes the axial selectivity may be viewed more as a drawback rather than an advantage. Bessel beams, on the other hand, even when tightly focused to produce modifications of similarly small transverse dimensions have the possibility to affect a more axially extensive region [2]. This quality of a Bessel beam is exploited in this work to produce Bragg gratings of various thicknesses

The experiment was performed using a DPSS Yb:KGW laser with a pulse duration of approx. 170 femtoseconds, wavelength centered at 1028 nm. The fundamental wavelength was used to form the gratings with the Gaussian beam and the second harmonic (514 nm) was used to record the gratings with the Bessel beam. Precise positioning stages (Aerotech) are used for translating the sample, the experiment sequence (power, pulse picking, positioning) was controlled using SCA software (Workshop of Photonics). A near-infrared transmitting microscope objective with NA=0.42 was used to focus both types of beams within the sample. A reducing telescope system was used to image the Bessel beam formed by an axicon with 1/75 magnification (referred to as focusing further in this text). The nature of the induced modifications was investigated by optical microscopy as well as direct measurement of grating performance.

The experiment was performed in three stages. At the first stage sets of laser parameters for the most homogeneous modifications were determined. The second stage was focused on optimizing the performance of gratings for each type of writing beam. To accomplish this grating geometry and pulse to pulse spacing was varied in order to determine the most effective grating. During the third stage gratings using each type of beam were recorded using the parameters determined and optimized during the previous stages, the performance of these gratings was then analyzed by measuring diffraction efficiency for the first order using a collimated 632.8 nm He-Ne laser, a high beam quality DPSS 532 nm CW laser and femtosecond pulse generated supercontinuum as light sources, these results were compared to theoretical predictions, the possible reasons for discrepancies between theory and experimental results are discussed in the following section.

2. Results

The first stage clearly revealed the advantages of focused Bessel beam geometry over the Gaussian beam waist. Modifications produced using the Bessel beam exhibited much better homogeneity along the axial direction and smaller transverse dimensions (partially due to the shorter wavelength), although it was found that the modifications had to remain separated along the direction of inscription, as opposed to the Gaussian beam formed inscriptions which were continuous in the direction of writing but modulated along the direction of propagation.

Gaussian beam induced modifications are birefringent with estimated (from grating performance) refractive index modulation values of 0.0029 for p-polarized and 0.0011 for s-polarized radiation at 532 nm. It should also be noted, that forming of modification lines was also sensitive to incident beam polarization and polarization along the direction of writing was chosen for the final grating. For modifications formed by Bessel beams there was no observed birefringence or writing polarization sensitivity and grating performance indicated the refractive index modulation to be 0.001 and is close to those achieved for isotropic modifications by other authors [3]. Table 1 outlines the parameters chosen for each type of grating after evaluating gratings of different geometries as well as main measured characteristics which fit well theoretic predictions [4].

Table 1. Optimized parameters for Bragg grating recording in the bulk of fused silica and main measured properties of these grating

Grating parameter	**Gaussian beam writing**	**Bessel beam writing**
d, µm	2	1.5
t, µm	90	342
dn	0.0029 / 0.0011	0.001
$\boldsymbol{\tau}$, h	~3	1.25
S, mm^2	1x1 mm^2	6x6 mm^2
$FWHM_{\Theta}$, deg	1.6	0.31
$HWFZ_{\lambda}$, nm	93	13.2
Diffraction efficiency, %	74.6 @ 532 nm	89 @ 632.8 nm

It is found that for similar geometry Bragg gratings recorded using a Bessel beam exhibit superior performance (diffraction efficiency for the first order of more than 90% is measured for the Bessel beam recorded grating and up to 76.5% for the Gaussian beam writer grating) as well as more than hundred times shortened recording times.

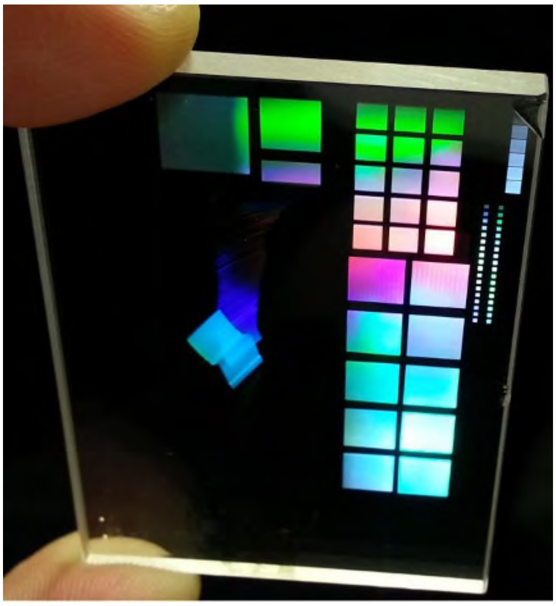

Fig. 1. Transmitting Bragg gratings formed in bulk of fused silica by Gaussian and Bessel-Gaussian beam direct writing.

4. References

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