Direct-write depressed cladding waveguide Bragg-gratings in ZBLAN glass

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Abstract: Strong waveguide Bragg-gratings (10 dB reflectivity) were fabricated by the direct-write technique in ZBLAN glass. Based on a depressed cladding, an array of 169 periodic and in phase modifications was placed inside the core.
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1. Introduction

Heavy-metal fluoride glass is well known for its high infrared transparency due to its low phonon energy, especially in its most common composition ZrF_4-BaF_2-LaF_3-AlF_3-NaF (ZBLAN). This makes it an excellent host for mid-infrared emitting rare-earth ions [1]. The mid-infrared wavelength region is of particular interest for many applications like laser ranging, testing of infrared countermeasures, molecular spectroscopy and process monitoring [2], These applications demand a robust, simple and cheap laser source. We recently demonstrated a highly efficient Tm^{3+}:ZBLAN waveguide laser emitting at 1.9 µm with a slope efficiency of 50% [3]. The device is based on laser-written depressed cladding waveguides with butt-coupled bulk mirrors. However to obtain a robust laser system it is desirable to integrate the Bragg-gratings into the waveguide in the form of distributed feedback (DFB) or distributed Bragg reflector (DBR) structures, thereby resulting in a monolithic device with narrow line width output. While this approach has been demonstrated in phosphate glasses which respond with a positive index change when irradiated with femtosecond laser pulses [4], fabricating similar structures in glasses, such as ZBLAN, which respond with a negative index change is a major challenge. Indeed, axial point-by-point grating structures [5] tend to suffer from either a weak reflectance associated with small mode-overlap or large scattering losses associated with small or large diameter voxels. In this paper we show that strong gratings, similar in structure to conventional gratings comprising planes of index change, can be inscribed using laser direct-write methods inside ZBLAN. In this case the planes of index change are constructed from a lattice of smaller point features.

2. Design and Fabrication

The grating consisted of an array of periodic, according to the Bragg-condition, refractive index modifications along the core arranged in a hexagonal lattice (figure 1). Each line of periodic index modifications is in phase with each other by locking them to the position synchronous output of the translation stages as recently demonstrated by Brown *et al.* [6].

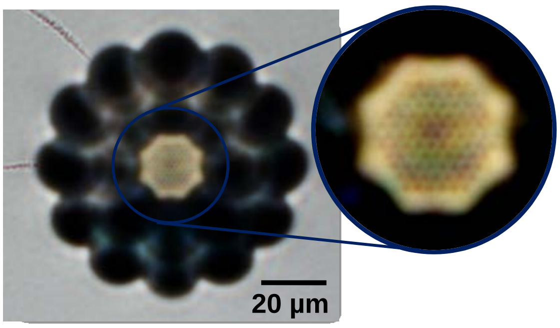

Fig. 1: End on microscope image showing the cladding of the waveguide and the hexagonal lattice of modification being periodic along the core and in phase with respect to each other.

The depressed cladding waveguide Bragg-gratings are fabricated in a three-step process. First the output of a commercial ultrafast Ti:sapphire oscillator (FEMTOSOURCE XL 500, 800 nm centre wavelength, 5.1 MHz rep.-rate, 550 nJ pulse energy, 50 fs pulse duration) is focused into the bulk ZBLAN sample for fabricating the bottom part of the cladding in the cumulative heating regime [7] (cladding $\Delta n \approx -1.6\times10^{-3}$). Then the repetition rate of the laser is changed to 100 kHz with an external electro-optic pulse picker for inscribing the grating. The 100 kHz pulse train is 50% duty cycle on/off-modulated synchronised to the position feedback provided by the encoder of the translation stages (Aerotech). After the grating fabrication the repetition rate is changed back to 5.1 MHz for inscribing the top part of the cladding. Throughout the entire process the sample is kept untouched and the same focusing objective (1.25NA 100× oil) for grating and cladding inscription is used to achieve the necessary accuracy.

3. Results

The waveguide Bragg-grating is based on a depressed cladding waveguide with a 15 µm core to provide single-mode guiding at 1550 nm. The cladding is build-up from 2 rings, the first with 8 modifications and the second with 12 20 µm diameter modifications. This results in a total cladding thickness of 33 µm. Figure 2a) shows the transmission and reflection spectrum of a 5.8 mm long 2nd order grating at 1550 nm. The grating features a transmission dip of 10.5 dB ($\kappa L = 1.88$) and has a 3 dB width of 230 pm. The grating consists of a 7 ring hexagonal lattice (169 lines along the core) with 1.5 µm pitch. Even though the structure is highly complex, the total fabrication time is below 10 minutes due to the high repetition rates involved.

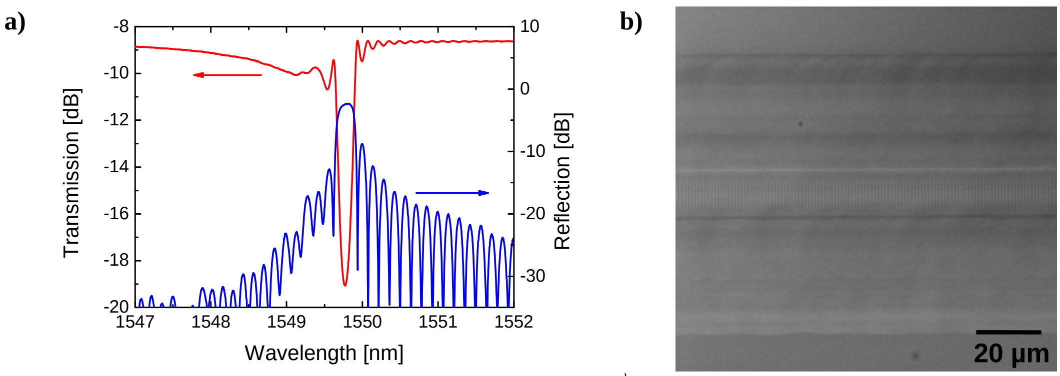

Fig. 2: a) Transmission and reflection spectrum of a 10.5 dB strong 5.8 mm long 2nd order grating inscribed into ZBLAN glass; b) corresponding transmission differential interference contrast image looking down from the top onto the grating revealing the ≈1 µm period modifications inside the core.

4. Summary

To the best of our knowledge we have demonstrated, for the first time, that it is possible to construct Bragg grating structures from a lattice of point features within the core of a depressed cladding waveguide. This approach opens up new avenues such as the fabrication of mode conversion based on anti-symmetric gratings [8], mode selective gratings [9] and monolithic DFB waveguide lasers.

5. References

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