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# Femtosecond inscription of *Type-A* Volume Bragg Gratings in silver-containing phosphate glasses

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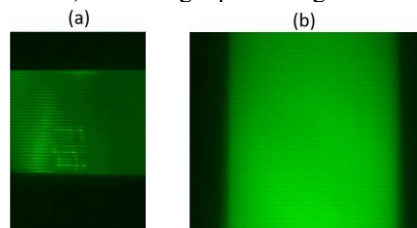
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Volume Bragg gratings (VBGs) have gained growing interest over the last decades for diverse applications. Typically, they are produced in photo-thermo-refractive glasses using UV light [1]. Later, femtosecond (fs) laser pulses were used to produce refractive-index modifications ( $\Delta n$ ), mainly type-1, in various other materials [2]. To obtain more freedom in designing optical systems, it is desirable to inscribe VBGs in glasses exhibiting a much higher  $\Delta n$ , such as silver-containing phosphate glasses. Indeed, a novel type of  $\Delta n$  has been demonstrated in such glasses, denominated *Type-A* (*A* from *Argentum*), which is related to the spatial distribution of the photo-induced silver clusters around the interaction voxel and exhibits two positive  $\Delta n$  peaks at each laser pass [3], reaching a value of up to  $2 \times 10^{-2}$  [4]. Recently, we demonstrated the first *Type-A* VBGs inscribed in silver-containing phosphate glasses with a Gaussian-Bessel beam. The most efficient grating was recorded in  $\sim 1$  hour at a velocity of  $20 \mu\text{m/s}$  for a transverse area of  $400 \times 400 \mu\text{m}^2$ . Indeed, there is a growing interest in writing high throughput VBGs suitable for industrial manufacturing.

For this reason, we report here the inscription of VBGs using a laser light-sheet to accelerate the recording time. The sample is a commercial silver-containing zinc-phosphate glass (AG01®, Argolight). A 1030-nm laser emitting pulses of 507 fs and a maximum output power of 100 W was used in burst mode, i.e., 10 pulses spaced 30 ns apart at a repetition rate of 200 kHz. The beam is focused into the glass sample by a cylindrical lens ( $f = 5 \text{ cm}$ ) in one direction, generating a light-sheet of  $900 \times 4.3 \times 449.7 \mu\text{m}^3$ . When propagating from air to glass, refraction extended the beam to a length of 1.43 mm in the glass material. Thus, we inscribe a VBG with only a single layer, with a periodicity of  $7.5 \mu\text{m}$  corresponding to a writing process achieved within 33 mins for 500  $\mu\text{m}$  of transverse length. Fig. 1(a) shows the fluorescence image of the inscribed VBG using the light sheet, where the periodic modification is composed of silver clusters. In addition to the recording time, a second method was used to overcome the period stability constraints that may affect the inscription process in general [5]. This convenient and widely used method is based on the use of a phase mask approach, generating an interference pattern with half of its periodicity. For this method, we apply ultrashort laser pulses (30 fs) and a low repetition rate (1 kHz). An 800 nm beam is focused by a cylindrical mirror ( $f = 40 \text{ cm}$ ) through the phase mask (period =  $14 \mu\text{m}$ ) into the glass sample. An  $800 \times 0.25 \text{ mm}^2$  grating was inscribed at 130 mW after the cylindrical lens and for a velocity of  $4.1 \mu\text{m/s}$ , corresponding to a one-minute inscription process. Fig. 1(b) reports a fluorescent image of the VBG showing the periodic modification corresponding to the half-periodicity of the phase mask. Indeed, using this low repetition rate laser, we generated mostly non-stable species (namely hole traps silver species) in addition to a small amount of stable silver clusters. The diffraction efficiency in transmission at 632.8 nm wavelength was measured for both VBGs at the Bragg condition, indicating a promising result.



**Fig. 1:** Microscopy fluorescence image (excitation at 365nm) of (a) VBG inscribed using the light-sheet (DLW parameters: laser power = 96 W); (b) VBG induced with the phase mask technique (DLW parameters: laser power = 130 mW, velocity =  $4.1 \mu\text{m/s}$ ).

In summary, we demonstrated the possibility to access experimental high-throughput inscription of *Type-A* based periodic structures in silver-containing phosphate glasses using the phase mask technique. A higher repetition rate laser is needed to promote a more efficient creation of silver clusters to obtain hereby higher diffraction efficiencies. Further optimizations are required to demonstrate higher efficiencies with *Type-A* refractive index modifications using the light-sheet method.

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