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Direct UV writing of Bragg grating channel waveguides in a single step process

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We present a development of Direct UV writing that allows simultaneous definition of channel waveguides with or without Bragg gratings in a single process in photosensitivity locked planar silica-on-silicon samples.

Keywords: direct UV writing, photosensitivity locking, Bragg grating, channel waveguides

Introduction

Direct UV-writing is a Planar Lightwave Circuit fabrication process based on the refractive index increase occurring in specific materials in response to irradiation in the UV. This increase in index has conventionally been used to fabricate periodic index modulations in the core of photosensitive fibres to form Bragg gratings [1]. Previously this index change has been implemented in planar technology to allow direct definition of channel waveguides and hence complex devices in photosensitive planar channels [2]. This process results in low loss channel waveguides manufactured without the need for photolithography or etching processes. In previous work on directly written structures, planar Bragg grating have been fabricated using a secondary exposure through a phase mask [2] onto existing channel waveguides.

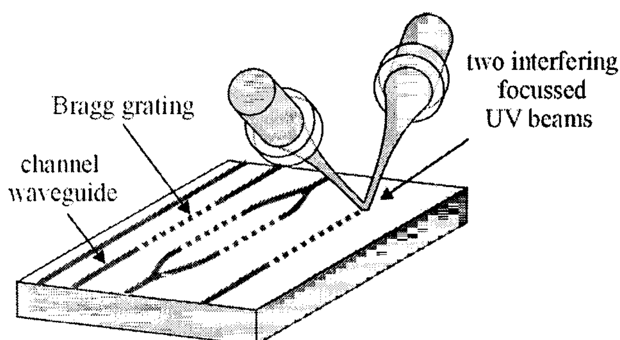

Figure 1: Simultaneous Direct UV writing of channel waveguides and Bragg gratings using focused beam interference in the photosensitive core of a 3-layer silica-on-silicon sample

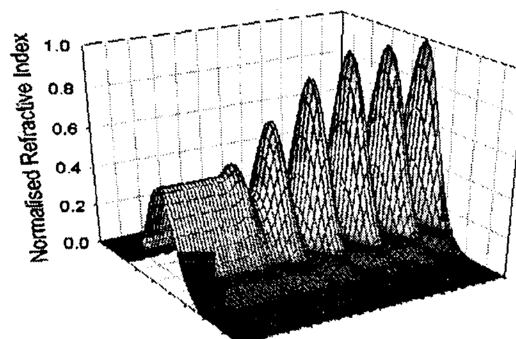

Figure 2: Illustration of the refractive index profile of a channel waveguide connecting to a Bragg grating structure when using the simultaneous writing technique showing the build up of the grating strength along the channel

Recently, we have reported the first implementation of a variant of Direct UV writing allowing the simultaneous definition of channel waveguides with integral Bragg gratings in a single step [3]. Our single-step process is based on a writing spot with a periodic modulation and was developed to allow both the grating and channel to utilise the full photosensitivity of the material with no need for a phase mask. This is achieved using two writing beams, each individually focused and aligned to create a single writing spot with an intrinsic interference pattern defined by the wavelength and intersection angle of the two beams (Figure 1).

As the sample is translated relative to the spot, the intensity of the laser is modulated with a period such that the maxima of the intensity pattern in the writing spot overlaps the maxima of the

previous exposure, inducing a channel waveguide with an inherent Bragg grating index modulation. To define standard channel waveguide structures the sample is translated with the writing power held constant, and so the effect of the intra-spot intensity pattern is averaged out resulting in a uniform channel. Since all structures are defined in the software, entire devices comprising of multiple waveguide structures containing gratings can be written in a single process.

Bragg gratings and channel waveguides that are defined at the same time provide improved control of the grating and channel contrast than over the two-step techniques. Rather than the grating index modulation adding to that previously defined for the channel structure, the grating modulation contrast can be the maximum Δn available from the photosensitive material. This can result in high contrast gratings that are average-index-matched to reduce unwanted Fabry-Perot reflections (Figure 2).

Deuterium loading has long been used to enhance the photosensitivity of germanosilicates [4], reducing the need for excessive dopant levels. However, the conventional approach of deuterium loading used in fibres is problematic for planar samples, as the thin over-clad layer typical in silica-on-silicon samples (~20μm) results in the deuterium diffusing rapidly out of the core. To this end our group has developed a 'Photosensitivity locking' technique, a process of thermally cycling freshly deuterium loaded silica-on-silicon samples to produce a non-volatile photosensitivity enhancement. It is likely that the locking mechanism is due to thermally induced bonding of deuterium to the oxygen atoms present at the germanium sites, increasing the percentage of germanium oxygen deficient centres in the silica matrix. This development is important because our interferometric beam setup has an increased sensitivity to phase errors that can arise from the sample cooling process used by other workers to reduce deuterium out-diffusion [2].

Experimental

The samples used during these experiments were 3-layer silica-on-silicon wafers, some manufactured in-house using flame hydrolysis deposition (FHD), and some commercially produced wafers supplied by Alcatel Optronics UK. The core layers of each wafer were germanium doped to produce an initial intrinsic photosensitivity. Samples that were enhanced through deuterium loading were loaded at ~150 bar for >5 days. Photosensitivity locked samples were subjected to heat treatment of 1400°C for 5 seconds after removal from the deuterium cell to initiate the locking process.

Direct UV writing into the samples was performed using a CW frequency doubled Ar-ion laser (λ at 244nm) and the beam power controlled via an acoustic optical modulator. To produce the intra-spot interference pattern the beam path was split to form two separate branches that were recombined at an angle of 29° in the plane of the sample. Each beam was individually aligned and focused to a controllable spot size (3 to 6μm) at the point of intersection (Figure 1). The samples were mounted on a computer controlled 2D translation stage providing translation relative to the writing spot.

The gratings were analyzed using an EDFA based ASE source coupled to a polarization controller. An OSA was used to monitor both the reflected and transmitted spectra from the Bragg gratings.

Results

In our deuterium-locked samples a Bragg grating reflection of greater than 80% with FWHM of 0.1nm was achieved, an example spectral profile of which is given in Figure 3. After the initial result, we retested one of the very first wafers that was subjected to photosensitivity locking 18 months ago and used this new writing process to compare the photosensitivity to a newly locked sample. The resultant channels waveguides and Bragg gratings were virtually identical for the same UV writing conditions. Figure 4 is a mode profile of a full length channel and grating, confirming the behaviour of the channel as expected.

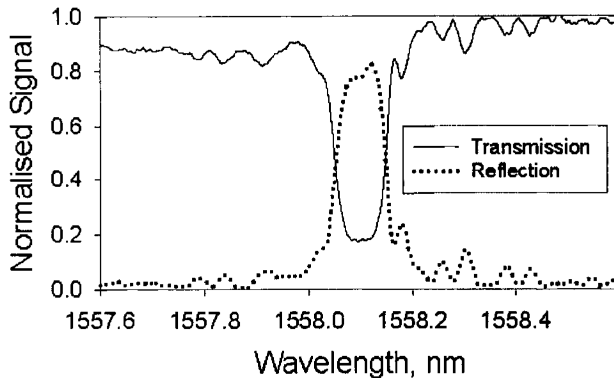

Figure 3: Spectral response from simultaneously written channel and Bragg grating demonstrating >80% reflection with a FWHM = 0.1nm

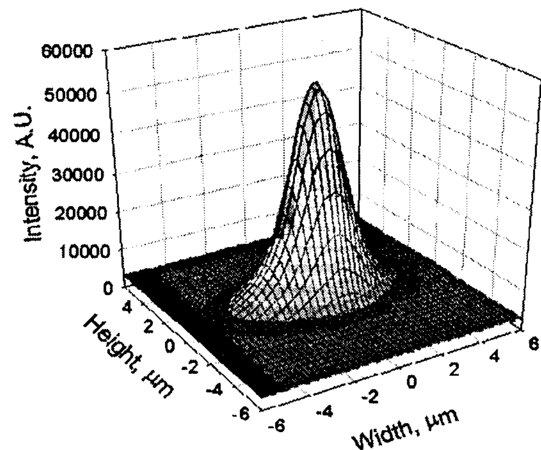

Figure 4: Mode profile of channel waveguide with Bragg grating, $1/e^2$ full width= 5µm x 4µm

One of the significant advantages of this grating writing process is centre-wavelength detuning [3]. This process was used to produce a wide range of Bragg gratings of various pitches from the same fixed interference pattern. Figure 5 demonstrates such a range of gratings, all written with the same fluence. As shown by the graph, it is possible to write gratings covering the entire C-band with no change to our setup, the defined period of the grating controlled solely through software. It should be noted that the limiting factor to the range of wavelengths measured in Figure 5 is the output range of the broadband source used during our analysis, not the writing process.

As the peak reflected wavelength of a given grating is dependent on the effective refractive index of the channel waveguide (as defined by the Bragg relation $\lambda_b = 2\Lambda n_{eff}$), writing gratings with the same period but different translation speeds allowed us to assess the variation in strength of the UV induced channel waveguides with the writing power, or *fluence* [5]:

$$F = \frac{I_{UV} \times a}{v_{scan}}. \qquad (1)$$

Where F is the fluence ($KJcm^{-2}$), I_{UV} is the average laser intensity ($KJcm^{-2}s^{-1}$), a is the writing spot diameter (cm) and v_{scan} is the translation velocity (cms^{-1}). Fluence is an integrated representation of the energy incident on the material, but is not alone sufficient to characterise the writing process. This is because the resultant channels and gratings also depend on the absolute spot size and translation speed for a given beam power. Our technique of simultaneous writing of channels and Bragg gratings provides an accurate and robust measurement of the response of the material. Figure 6 shows the relationship between n_{eff} and fluence for different peak powers (and

hence translation speeds). This data helps provide an insight into the different processes occurring within the glasses.

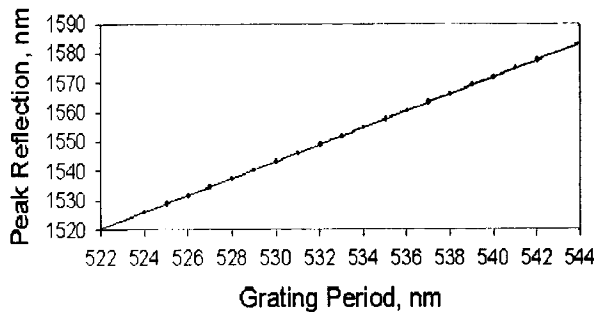

Figure 5: Range of grating periods achievable through centre wavelength detuning, demonstrated across the C-band

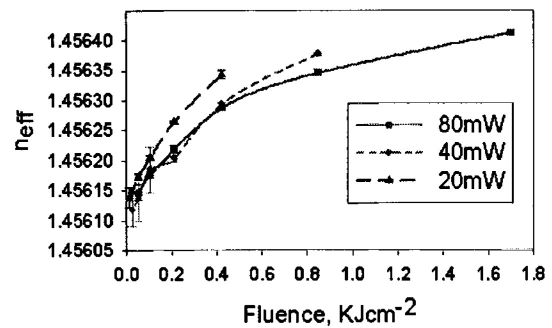

Figure 6: n_{eff} vs. fluence, demonstrating the effect of different writing spot powers

Conclusion

In conclusion, we present a development of the process of direct UV writing that allows us to define both a channel waveguide and Bragg grating structure in a single step, with initial results providing a reflectivity >80% and FWHM of 0.1nm. This process requires no phase mask and is entirely computer controlled. Computer based operation allows full control over the grating parameters including the ability to centre-wavelength detune the grating period from the period of the interference pattern in the writing spot. Using this detuning process, we have demonstrated the writing of Bragg gratings with peak reflections over the entire C-band. In parallel we have developed a 'photosensitivity locking' technique that results in a persistent photosensitive enhancement that has a lifetime of well over a year at room temperature.

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