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Small-spot interference pattern for single-step 2D integration and wide wavelength detuning of planar Bragg gratings

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We present a single-step technique for defining 2D channel waveguide structures with internal Bragg gratings in photosensitive germanosilica-on-silicon using two interfering focussed UV beams. Through software control, grating detuning across the S, C, and L wavelength bands is also demonstrated.

Introduction: Direct UV writing provides an attractive route towards low-cost integrated optical components in photosensitive silica-on-silicon wafers [1]. Combining closely packed channel waveguides with a versatile Bragg grating tailored spectral response would allow the creation of compact systems for wavelength division multiplexing on a single optical chip. To this end we recently presented the first demonstration of simultaneously defined channel waveguides with integral Bragg gratings based on the interference of two focussed UV-writing beams [2]. This single-step approach was developed to promote optimal use of sample photosensitivity for both the waveguide geometry and Bragg grating superstructure, with the potential for implementing many aspects of advanced grating design, such as chirp and apodisation, without the need for a phase mask. In this paper we present two refinements unique to the small writing spot used during this process, extending the UV-written channel waveguide geometry to two dimensions, while also demonstrating a grating detuning response across the S, C, and L wavelength bands, a technique controlled entirely through computer software and requiring no modifications to our experimental setup.

Direct grating writing: In our direct grating writing arrangement two focussed beams are overlapped to give a micron-order near-circular spot with an inherent interference pattern in one dimension (Figure 1). Exposure of this intensity pattern onto a suitable photosensitive sample results in a periodic change in refractive index that can be extended, plane by plane, into a long grating in the simultaneously defined channel by on/off modulation of the writing beam during sample translation. When the sample is translated under a constant writing beam, the intra-spot interference pattern is averaged out and the focussed spot can be used to write standard channel waveguide structures, including the curves and junctions that form the basic building blocks of many larger integrated optical systems. The combination of these two techniques allows planar Bragg gratings to be inserted into complex UV-written devices in a single processing step, and is achievable as a direct result of the small writing spot fundamental to this process.

Experimental: Fabrication of direct-written gratings was performed using a frequency-doubled 244nm argon-ion laser, a high precision 3-dimensional translation stage, and an interferometrically-controlled acousto-optic modulator. A beam splitter was used to create two separate beam paths at an intersection angle of 29 degrees, and both beams were individually focussed and aligned to give a single 4μm interfering spot. Photosensitivity of the 3-layer germanosilica-on-silicon substrates used during these experiments was enhanced by deuterium loading at 150bar for one week, following which the samples were UV-written immediately at room temperature. A range of planar Bragg gratings based on variations of period, length, channel waveguide structure, and UV-writing conditions (speed, power, etc.) have been written and subsequently characterised using an optical spectrum analyser. A typical transmission spectra from a straight channel waveguide (NA = 0.12) with a 10mm long integral Bragg grating section is presented in Figure 2, demonstrating an unoptimised unapodised reflection peak of 98% with less than 0.3nm bandwidth.

In order to demonstrate the 2D capabilities of our direct grating writing technique, Mach-Zender structures were written in a single-step based on the arrangement illustrated in Figure 1. For each device two 5mm-long cosine-style y-splitter sections were used to seperate the two central arms of the structure by 200μm, corresponding to s-bend radii of ~ 60mm. For these initial experiments two 8mm long planar Bragg gratings with periods of 532 and 532.4nm respectively were incorporated into the two arms of each device, resulting in dual-peak spectral responses typical of that given in Figure 3. From the graph the distinction grating detuning response encompassing the S, C, and L wavelength bands, a result achieved entirely through software control. Based on these early results it is hoped that further optimisation of channel waveguide and Bragg grating characteristics will lead to highly efficient integrated optical devices for use in wavelength-selective planar systems.

References:

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Figure captions:

Fig. 1. Single-step definition of channel waveguides and Bragg gratings.

Fig. 2. Transmission spectra for a straight channel waveguide with a 10mm long integral Bragg grating.

Fig. 3. Reflection spectra for a 2D Mach-Zender channel waveguide structure.

Fig. 4. Demonstration of grating detuning across the S, C, and L wavelength bands.

Fig. 1.

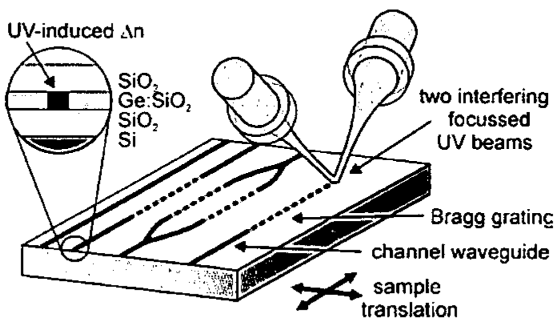

UV-induced Δn
SiO2
Ge:SiO2
SiO2
Si
two interfering
focussed
UV beams
Bragg grating
channel waveguide
sample
translation

Fig. 2.

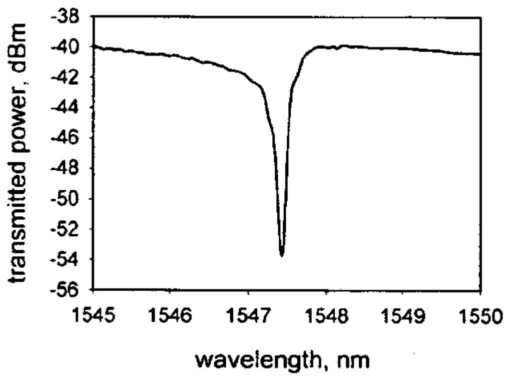
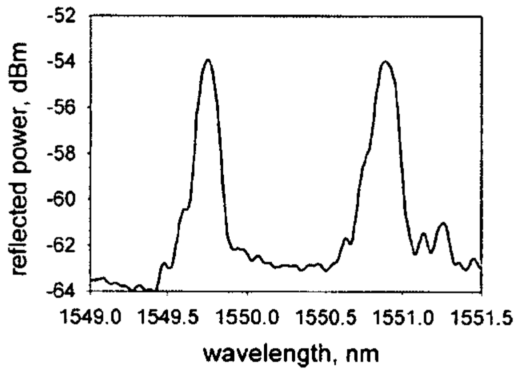
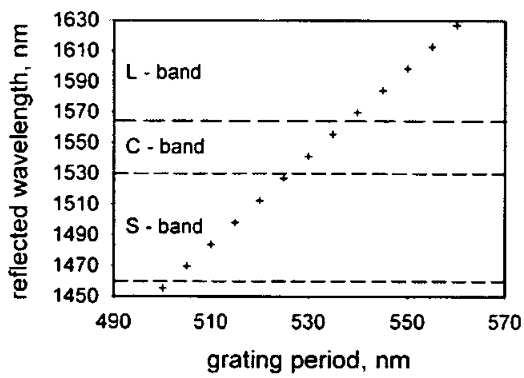

transmitted power, dBm
-38
-40
-42
-44
-46
-48
-50
-52
-54
-56
1545
1546
1547
1548
1549
1550
wavelength, nm

Fig. 3.



-52
-54
-56
-58
-60
-62
-64
reflected power, dBm
1549.0 1549.5 1550.0 1550.5 1551.0 1551.5
wavelength, nm

Fig. 4.



L - band
C - band
S - band
1630
1610
1590
1570
1550
1530
1510
1490
1470
1450
490
510
530
550
570
reflected wavelength, nm
grating period, nm

between the two grating reflection responses is clear, and future work will be aimed at integrating such gratings into larger optical systems.

Grating detuning: With the absolute period of our small-spot interference pattern defined by the refractive index of the host material and intersection angle of the two focussed beams, the process of centre-wavelength detuning [2] was applied to allow gratings of different periods to be defined via computer-controlled modulation of the writing beam, with no alteration to our optical arrangement. In this detuning process, each stepped exposure of the writing spot is slightly offset from the period of the original interference pattern by a predetermined amount, allowing a selectively different Bragg grating period to be defined in the photosensitive material. While this flexibility comes at an overall loss of grating contrast, an important feature for our direct grating writing process is that the effective wavelength range attainable by detuning is inversely proportional to the number of interference fringes present in the writing spot. In our system a spot diameter of 4μm with a 532nm period interference pattern results in approximately 8 interference fringes written per exposure. Compared to phase-mask-based schemes, which generally rely on repeated exposures of hundreds of interference fringes, this extremely small writing spot allows a much greater range of detuning from the native interference pattern than traditionally possible. This effect is dramatically demonstrated in the graph of Figure 4, where an effective detuning range of ~180nm, encompassing the full S, C, and L wavelength bands, is presented.

Summary: We have presented two refinements to our recently reported direct grating writing process, each specifically derived from our unique use of a micron-order circular writing spot with an inherent interference pattern. Using these processes, we have demonstrated single-step integration of planar Bragg gratings into 2D Mach-Zender structures and an 180nm wide