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Citation: AIP Conference Proceedings **1217**, 153 (2010);

View online: https://doi.org/10.1063/1.3377803

View Table of Contents: http://aip.scitation.org/toc/apc/1217/1

Published by the American Institute of Physics

UV written waveguide devices – Bragg gratings and Applications in Sensors

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Abstract. Ultra-violet laser direct writing provides a powerful way of creating integrated optical devices. The work reported here describes developments in this field, and particularly the use of two-beam writing to create Bragg gratings in planar integrated format. The work shows how these structures can be used in a wide range of applications, ranging from creation of wide-band couplers, through to extremely sensitive sensor devices. UV direct writing removes many of the constraints normally associated with planar integrated optics. It is a mask-free process that uses direct computer control and it dispenses with the etching steps normally required to make low-loss waveguide devices. The work reported will show how this flexibility of format may be combined with novel substrate structures to allow new device types.

Keywords: Ultra-violet laser; Integrated optical devices; Bragg grating; Waveguide devices
PACS: 61.46.Hk, 62.23.-c

1. INTRODUCTION

Direct UV writing has attracted recent attention as a powerful way of creating integrated optical channel waveguides. The breakthrough work by Svalgaard [1] using germania doped silica on silicon demonstrated that it could rival conventional "photo-lith & etch" methods for making low-loss, fibre compatible optical waveguides. The basic configuration is shown in figure 1.

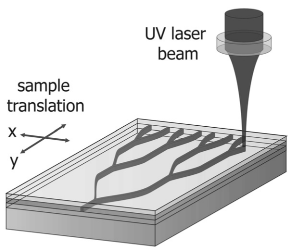

FIGURE 1. Showing the concept of Direct UV writing

CP1217, *International Conference on Advancement of Materials and Nanotechnology 2007 (ICAMN 2007)*
edited by W. T. Wui, N. Kamarulzaman, R. Y. Subban, K. Noorsal, M. H. Saleh, R. Ibrahim, R. Idris, I. Zainol,
and F. A. Zakaria

The technique relies on the availability of UV lasers capable of generating a photosensitive response in germania doped silica. The UV radiation creates a refractive index increase that can be further increased by the use of high pressure hydrogen loading. The achievable index increase is comparable to that used in single-mode telecom fibres, and thus it is inherently compatible with conventional telecomm fibre.

2. PLANAR BRAGG GRATINGS

Work at the Optoelectronics Research Centre, University of Southampton, has concentrated on the creation of Bragg gratings. The use of two-beam writing [2] allows for flexible inscription of Bragg gratings. The technique makes use of a frequency doubled Argon ion laser, the beam of which is modulated with an acousto-optic modulator. The two beam interference is shown diagrammatically in figure 2. The exposure of the laser is controlled by a PC as the sample is translated. By strobing the laser exposure appropriately with the movement of the sample through the grating it is possible to create Bragg gratings.

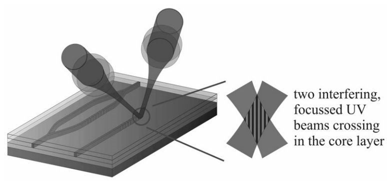

FIGURE 2. Concept of Direct Grating Writing

The direct writing technique has a number of advantages, in particular it is flexible in choice of period, and allows the use of the full photosensitivity of the germania doped silica on silicon substrate platform.

The ability to write gratings provides a way to measure accurately the properties of the underlying sample, for example as a function of UV exposure, or dopant concentration. This accuracy derives from the ability to measure Bragg wavelength accurately using telecomm measurement equipment. It is easily possible to make a measurement of one part in one million of effective modal index. This sensitivity can be used in a number of ways, firstly to create sensors, and secondly as a means to allow tunability in grating devices.

3. PLANR BRAGG GRATING SENSORS

The first use of direct grating writing to create a sensor was reported by Sparrow et al.[3]. The devices work by removing some of the glass near to the optical waveguide and replacing it with a liquid measurand. The optical mode of the device penetrates into the liquid, and thus the index of the mode is influenced by the refractive index of the liquid. By measuring the Bragg wavelength it is possible to make an accurate measurement of the properties of the fluid.

The device has been shown to work in a number of different situations, in particular, in distinguishing different fluids [4], in determining the build-up of biological layers, and even seeing the formation of a super-cooled stage in freezing of water.

The sensors formed by direct UV writing are particularly attractive because they make use of telecomm technology. The Bragg gratings are written to reflect around 1550nm, wavelengths that are routinely used in telecoms for optical transmission. This wavelength ranges means that components are readily available, including fibres, couplers and circulators to direct light, sources (laser and ASE), and measurement equipment (Optical spectrum analyzers, IR cameras, and Bragg grating interrogator systems).

4. TUNABLE BRAGG GRATING DEVICES

As well as making sensors, it is possible to create tunable Bragg grating devices by replacing the measurand fluid of a sensor with a liquid crystal. In recent work, a nematic liquid crystal, together with a planar electrode structure has been used to demonstrate tunable gratings spanning 140GHz. This tuning mechanism provides enough tuning to span the inter-channel spacing in a dense wavelength division multiplexing (WDM) telecom system, and so may provide a building block for a future reconfigurable optical add/drop (ROADM) technology. The device structure is shown in figure 3, and the tuning results in figure 4.

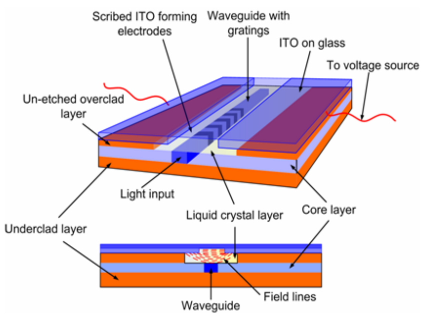

FIGURE 3. Configuration of liquid crystal tuned grating device.

Gratings provide a highly sensitive means to probe the properties of liquid crystals on a surface, and many intriguing results shown during our initial experiments are being investigated.

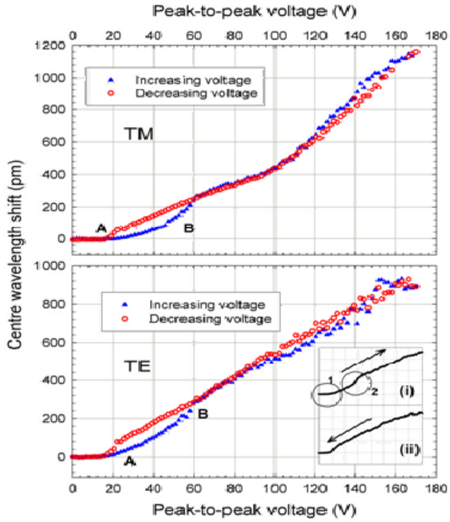

FIGURE 4. Tuning results for tunable grating device demonstrating greater than 100GHz tuning for applied voltages up to 170V.

5. NOVEL SUBSTRATE CONFIGURATIONS

Integrated optics using silica has traditionally made use of silicon wafers as a substrate material. The UV writing technique provides significant additional flexibility – removing the requirement for photolithography and etching, and even allowing the use of non-planar substrates. Recent work at the ORC will be reported in using the so-called “flat-fibre” substrate, which is formed by standard fibre production techniques. A conventional pre-form structure is collapsed by vacuum into a flat sheet, and then drawn to create a few-micron thick core, ribbon structure that can be many metres in length. We have demonstrated that the resulting substrate is suitable for UV writing, and is uniform enough for the formation of Bragg gratings. Figure 6 shows a cross-section of a flat-fibre device.

FIGURE 5. Showing a cross-section of a flat-fibre UV writing substrate.

Further recent work has involved the creation of substrates with pre-cut grooves formed by a polishing saw blade, which provides access for the optical mode to a micro-fluidic channel. Such substrates remove the need for etching a window, and provide a more flexible approach for device prototyping. An additional advantage is that it is simple to control the optical mode overlap with the measurand liquid in the fluidic channel, allowing for more information about the process to be obtained.

5. CONCLUSIONS

Direct UV writing provides an important new means of creating integrated optical waveguides. The technique is compatible with the formation of Bragg gratings, and can create a remarkable range of grating detunings. The technique has enabled many new devices to be prototyped, including sensors, and tunable Bragg reflectors.

The UV writing technique is inherently flexible and can be combined with new substrate formats to allow the creation of optical sensor waveguides with additional degrees of freedom.

ACKNOWLEDGEMENTS

This work acknowledges the support of EPSRC, DTI and Stratophase Ltd.

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