Bragg gratings in two-layer core planar silica-on-silicon waveguides and application to integrated lasers

P.V.S. Marques, J.R. Bonar, A.M.P. Leite and J.S. Aitchison

A neodymium-doped glass waveguide laser based on a new structure employing two core layers is reported. This double-layer structure allows a photosensitive layer to be integrated with an efficient gain layer. Singlemode operation was obtained with a lasing threshold of 93 mW and an efficiency of 0.6%.

Introduction: Since the discovery of photosensitivity by Hill and co-workers [1], much effort has been directed towards the development of Bragg gratings in optical fibres and their extension to planar silica waveguides. While the application of Bragg gratings in fibres is well developed, their use in an integrated format is not so common. The two-dimensional nature of on-chip integration coupled with the use of Bragg gratings offers a number of potential benefits including on-chip spectral analysis, compact wavelength division multiplexing devices and novel laser structures. The use of Bragg gratings to form the cavity of a waveguide laser offers the prospect of monolithic integration, single longitudinal mode operation and precise wavelength control.

In integrated rare-earth-doped glass, lasers have been demonstrated in waveguides based on flame hydrolysis deposition (FHD) [2, 3], PECVD [4] and ion-exchange [5]. These integrated lasers typically use small waveguide lengths, which require high rare-earth concentration to attain sufficient gain to reach threshold. However, there are limitations at very high rare-earth doping levels owing to formation of rare-earth clusters that degrade the optical gain. The appearance of rare-earth aggregates can be minimised by a suitable choice of a co-doped silica host. It was indeed demonstrated that phosphorous is a suitable co-dopant, increasing the solubility of rare-earth ions [6].

Intra-core Bragg gratings offer an elegant solution to form on-chip laser cavities, Successful UV photo-imprinting of Bragg gratings is closely related to the core dopants employed, that determine the UV absorption bands associated with photosensitivity. Typically, germanium-doped silica shows a much more efficient photosensitive response than the phosphorous-doped glass used for efficient rare-earth doping. Therefore, to produce an integrated structure which has both high photosensitivity and high optical gain has been a challenge.

In this Letter we report a new laser configuration based on a waveguide core which combines two layers produced by FHD, with the same refractive index but with different doping characteristics: one exhibits high photosensitivity, while the other has high rare-earth solubility. This solution allows Bragg grating fabrication with the most common UV laser sources emitting above 200 nm, and provides a suitable route towards monolithic integration.

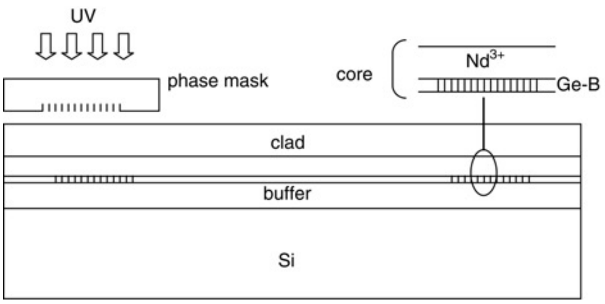

Fig. 1 *Schematic representation of laser structure*

Experiment: A schematic representation of the structure is shown in Fig. 1. The waveguides were fabricated by a combination of flame hydrolysis deposition and reactive ion etching (RIE). Initially, a 2 µm photosensitive layer was deposited on top of a 15 µm-thick pure oxide lower cladding, obtained by silicon oxidation. This photosensitive layer was doped with germanium and boron. Boron was added for two main reasons: to enhance photosensitivity [7], and to compensate the rise in the refractive index of silica due to a higher germanium doping level, thus helping to maintain the refractive index of the photosensitive layer within the required range. A second core layer, 4 µm thick, was then deposited and consolidated. This layer was doped with neodymium and used a phosphorous/aluminium based silica host, produced using an aerosol doping technique [3]. The Nd^{3+} concentration is estimated to be $\simeq 0.21$ wt% by comparison with measured samples produced under similar conditions [3]. The core ridges were formed using photolithography and RIE. Finally, an over-cladding layer with the refractive index matching that of the thermal oxide buffer was deposited to give environmental protection and reduce scattering loss. The total core thickness was 6 µm and the relative index difference between the core and cladding layers was 0.75% (the two core layers were index matched). The total sample length was 5 cm.

The laser cavity was defined by two Bragg gratings, fabricated by UV exposure using a KrF excimer laser (248 nm) through a fused silica phase mask, as shown in the inset in Fig. 1. To enhance the photosensitivity response, the samples were hydrogenated for two weeks at 100 atm (room temperature). The 8 mm-long Bragg gratings were monitored during the UV exposure using a white light source and an optical spectrum analyser. Because of a smaller overlap between the optical mode distribution and the photosensitive layer in comparison with a uniform Ge-doped core, the gratings reached saturation at around 80% reflectivity, and had a bandwidth of about 0.8 nm. The distance between gratings was 25 mm, corresponding to a free spectral range of about 4.1 GHz (0.015 nm). Since the active layer was doped with neodymium, the Bragg wavelength was situated near the peak of the fluorescence band, centred at 1053 nm.

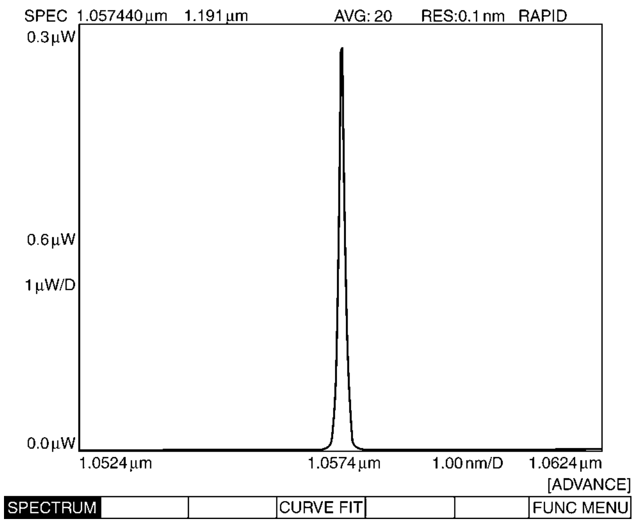

Fig. 2 *Laser output spectrum for pump power of 200 mW (waveguide core section 8 × 6 µm²)*

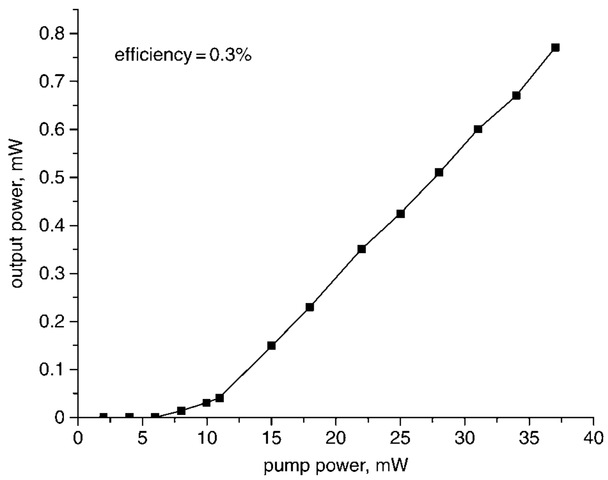

Fig. 3 *Laser output power against estimated coupled pump power (waveguide core section 8 × 6 µm²)*

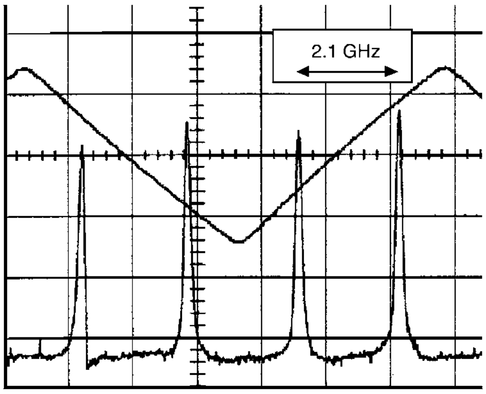

Fig. 4 *Fabry-Perot scan of waveguide laser emission, using free spectral range of 2.1 GHz*

Measurements were conducted in a $8 \times 6\ \mu m^2$ core section waveguide. The waveguide laser was pumped at 802 nm using a Ti:Sapphire laser. The output spectrum was recorded with an optical spectrum analyser, and a typical result is displayed in Fig. 2. The threshold for laser operation was 93 mW (estimated coupled pump power, determined by taking into account non-absorbed pump power, Fresnel reflections, coupling, and scattering losses), and a slope efficiency of 0.3% was obtained as shown in Fig. 3. Since the gratings are expected to have similar reflectivities, the total efficiency is expected to be approximately 0.6%. In Fig. 4 the result of a Fabry-Perot scan is represented, demonstrating single longitudinal mode operation. Monomode operation is thought to be due to the combined effects of slightly shifted gratings and laser cavity mode spacing.

Conclusions: An integrated laser with Bragg reflectors was demonstrated using a two layer core structure combining good photosensitivity and rare-earth solubility. This solution allows effective Bragg gratings to be fabricated using a 248 nm laser source. A neodymium laser operating at 1057 nm, with a pump power threshold of 93 mW and a estimated total efficiency of 0.6%, oscillating in a single longitudinal mode, was successfully demonstrated.

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