Using the extrusion technique to fashion amorphous channel waveguide lasers

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We report the first neodymium-doped amorphous channel waveguide laser through extrusion. Single-mode operation was observed at 1058nm for a 10mm long channel waveguide. An output power of 13.3mW with 30% slope efficiency was measured.

Several fabrication techniques for amorphous two-dimensional integrated optic devices are already well-established [1,2]. Here we report the fabrication of amorphous single-mode channel waveguide lasers with low propagation loss, through the extrusion technique [3]. This robust manufacturing technique for buried three-dimensional optical waveguides is proposed for use with amorphous materials that otherwise would degrade if processed using conventional fabrication techniques.

The glasses used in experiments were available commercially from Schott. The F7 glass (core) doped with 3 weight% of neodymium oxide and F2 glass (cladding) had a refractive index, at 1.06μm, of 1.616 and 1.602 respectively. The glass thermal expansion coefficient and viscosity, in the range of 10^6 – 10^8poise, was assessed with a calibrated thermo-mechanical-analyzer. An expansion coefficient match and softening point ($10^{7.6}$poise), for the cladding and core glasses, of ±0.8x10^{-6}°C^{-1} and 549 and 535°C respectively were measured, suggesting feasibility of simultaneous extrusion. A fiber cane was fabricated from these glasses, having core and cladding dimensions of 11±1 and 720±10μm respectively, through a single step fiber drawing process. A disc of F2 glass was used as the fiber cane host (Fig.1). Four circular cavities each having diameter of 800±10μm were ultrasonically drilled. Four fiber canes, 18.0mm in length, were then inserted into each hole of the host glass disc. The extrusion process was performed at a constant die temperature, an applied pressure and a viscosity of 555±10°C, 1850Ncm^{-2} and $10^{7.6}$poise respectively. The stainless steel extrusion die had an internal taper of 120° and a rectangular exit aperture measuring 20 by 1mm. The final extruded glass product had length, width and thickness of 200, 20 and 1mm. From the annealed extruded slab, a 10mm long planar chip was cut and the end-faces were plane and parallel polished. The extruded product cross-section and channel waveguide core is shown in Fig.2. Interfacial defects, between the fiber cane cladding and host disc, are an artifact of drilling surface irregularity and could be reduced through chemical etching.

Pumped by a tunable Ti:sapphire laser, operating at 808nm, the laser performance of the channel waveguides was evaluated using the 1058nm $^4F_{3/2}\rightarrow{}^4I_{11/2}$ transition. In an attempt to match the waveguide asymmetry, the pump beam was shaped with a cylindrical lens telescope, prior to focusing with a X10 objective, in order to produce a 1.5:1 aspect ratio focused spot. A launch efficiency of ~31% was measured and a laser cavity was formed using lightweight thin mirrors butted against the waveguide end-faces. The input mirror was 98% reflective at the lasing wavelength (1058nm). Four output mirror sets, each with different reflectivity, were utilized and had 9,18,32 and 40% transmission at 1058nm. For each case, lasing threshold was noted and a waveguide propagation loss of <0.3dB/cm was estimated by the Findlay-Clay method [4]. For the 18% output coupler, the laser threshold was 22.4mW of absorbed pump power. With this configuration, for an absorbed pump power of 59.3mW, a maximum output power of 13.3mW with 30% slope efficiency was measured (Fig.3).

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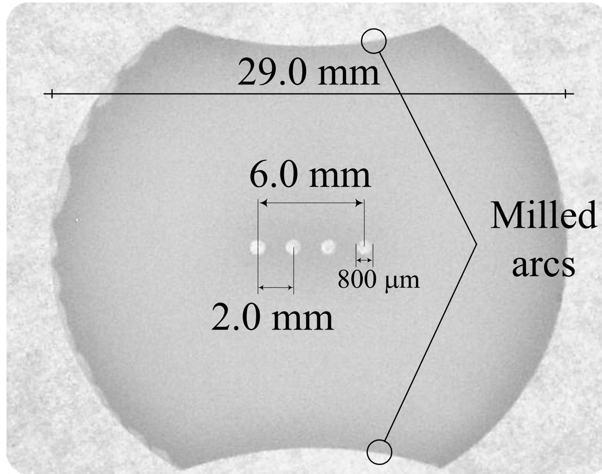

Fig. 1. Optical micrograph of the F2 glass disc with diameter and thickness of 29 and 18 mm respectively.

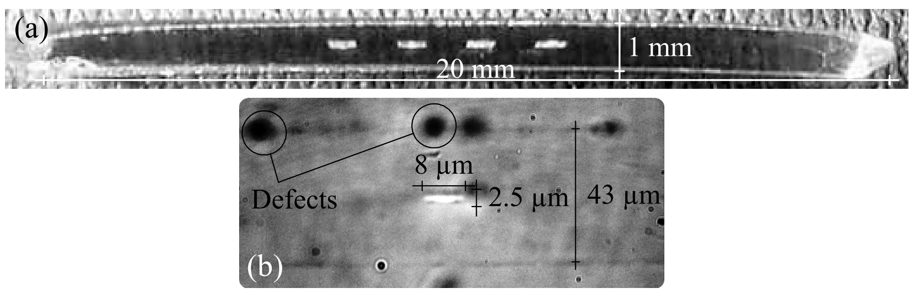

Fig. 2. (a) Optical micrograph of a cross section from the extruded product with the imbedded fibers illuminated. (b) A representative extruded channel waveguide (illuminated) with core size of 8 by 2.5 µm.

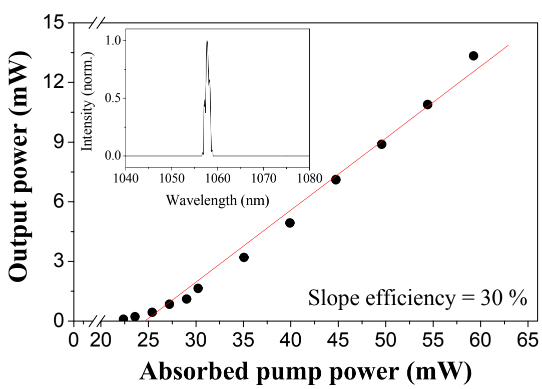

Fig. 3. (a) Output power against absorbed pump power for an extruded Nd^{3+}-lead-silicate channel waveguide laser. Maximum output power is 13.3mW with 30% slope efficiency. Inset is the laser emission at 1058nm.

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