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A fiberized highly birefringent glass micrometer-size ridge waveguide

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ABSTRACT

We report the fabrication of a fiberized micrometer-size ridge waveguide using a sheet-stacking method. The fabrication conditions for maintaining the ridge geometry with micrometer dimensions were investigated and discussed. A loss of 3.9 dB/m was measured at 1.55 μm in the fiber ridge waveguide, showing no extra loss above the bulk loss of the glass. A high birefringence of 9.5×10^{-3} was measured in the waveguide at 1.55 μm which is close to the reported highest birefringence (1.1×10^{-2}) in optical fibers. Fusion splicing was successfully employed to splice the fabricated waveguide to a conventional silica fiber with reasonable loss.

1. Introduction

Compact microstructured optical fiber and planar waveguide devices play important roles in various technical areas including telecoms application, sensing, and biomedical diagnostics and imaging. The versatile functionalities of these waveguides arise from their novel wavelength-scale microstructured features as well as the excellent optical properties of the host materials.

The modern glass optical fiber, starting from the simplest circularly symmetric waveguide geometry, has been widely inspired by the geometrical structure and functionalities of glass or non-glass based planar channel waveguides. A successful example is the currently well-developed microstructured optical fiber [1,2], which has been inspired by works on planar photonic crystal waveguides [3].

Typical microstructured planar channel waveguides, such as slab waveguides, ridge waveguides and slot waveguides, are fabricated by various processing approaches, e.g., deposition, sputtering, etching, lithography and so on [4], at relatively low temperatures. The three-dimensional microstructures, either in the cross-sectional or longitudinal direction, can be directly fashioned on the planar waveguide.

On the other hand, glass fiber based microstructured waveguides are fabricated by the traditional preform-drawing method. In this case, a glass preform is drawn into fiber at the high temperatures required to reach a glass viscosity between 10^4 and $10^{6.5}$ poise. During the fiber drawing, deformation of the microstructure tends to occur because the glass suffers strong surface tension and chemical changes such as crystallization or phase separation at high temperature. Due to the strong surface tension of the glass it is difficult to maintain the geometry of a structured preform. Hence the fabrication of microstructured planar waveguide in the fiber format is challenging. In addition, although the cross-sectional structure of the preform can be proportionally scaled down and maintained in the final fiber, the longitudinal structure of the preform will be virtually lost in the fiber because of the large reduction ratio from the preform to the fiber. For example, when a preform with an outer diameter (OD) of 10 mm is drawn into a fiber with an OD of 125 μm, a longitudinal structured feature with a length of 1 mm on the preform will be elongated into a length of 6.4 m on the fiber. Many post-processing approaches, e.g., tapering [5,6] and laser writing [7], have been developed to create longitudinal microstructured features on the fiber after fiber drawing.

In comparison with planar waveguides, optical fibers have numerous advantages, e.g., the long length and low cost per unit length, due to the high yield and low propagation loss. However, planar waveguides typically have an advantage for sensing applications as they offer the possibility to exploit strong evanescent light matter interaction when their core is exposed to the environment. This means that (i) they can efficiently detect chemical changes of the environment surrounding the core and (ii) functional nanostructured materials (thin films, nanowires, etc) can be grown or deposited on the surface of the channel longitudinally to enhance the functionalities of the waveguide, in particular for the applications of chemical sensing. Fiberization of planar waveguides is a simple and neat idea to combine the advantages of both planar and fiber waveguides for realizing economic and compact photonic devices.

Amongst the various planar waveguides the ridge waveguide, which is formed by a long, narrow raised strip waveguide (with a

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refractive index of n_1) on top of a flat substrate with a refractive index of n_2 ($n_2 < n_1$) (as shown Fig. 1(a)) allowing for two-dimensional (2D) confinement of light both laterally and vertically, is the basic block of many integrated optical devices such as switches, splitters, amplifiers, and sensors [8].

Basically, a ridge waveguide can be manufactured on a planar waveguide wafer by removing selected parts of the surface substrate, for example by the wet or dry etching techniques [8]. Because the ridge waveguide is surrounded by air on three sides, this kind of geometry allows a strong overlap of the optical evanescent field with the surrounding medium. Hence, it provides a highly sensitive structure for chemical sensing. It is also one of the building blocks to construct other novel optical waveguides. For example, the slot waveguide, composed of an air (or low-index material) filled nanometer-wide slot embedded between two parallel high-index ridges (as shown Fig. 1(b)), provides optical field enhancement inside the low-index nanometer slot [9,10]. In addition, the ridged geometry also provides a convenient platform for adding heterostructures composed of other materials such as glass, metal, and semiconductor onto the top of the ridge [11–13]. Extra optics-related functionalities can thus be added onto the waveguides. Fig. 1(c) and (d) show the schematics of growing 2-dimensional (2D) thin film and 1-dimensional (1D) nanowire array [13] on the top of the ridge waveguide. All these derived nano-composite optical waveguides are promising for efficient lasing and sensing due to the wavelength- or subwavelength-scale features.

In this work we report the fabrication of a borosilicate glass-based fiberized ridge waveguide, as schematically shown in Fig. 1(e). The fiber was fabricated using a sheet-stacking method [14]. The loss was measured to be 3.9 dB/m at 1.55 μm in the ridge waveguide with ~1 μm dimensions, indicating that no extra loss was introduced from the fabrication beyond the loss of the bulk glass. The geometrical parameters of the ridged core have been analyzed to investigate the deformation of the ridge geometry during the fiber drawing. A high birefringence of 9.5×10^{-3} was measured in a fabricated fiber ridge waveguide at 1.55 μm. This is close to the reported highest birefringence (1.1×10^{-2}) in optical fibers. We believe that this fiberized waveguide can be a powerful

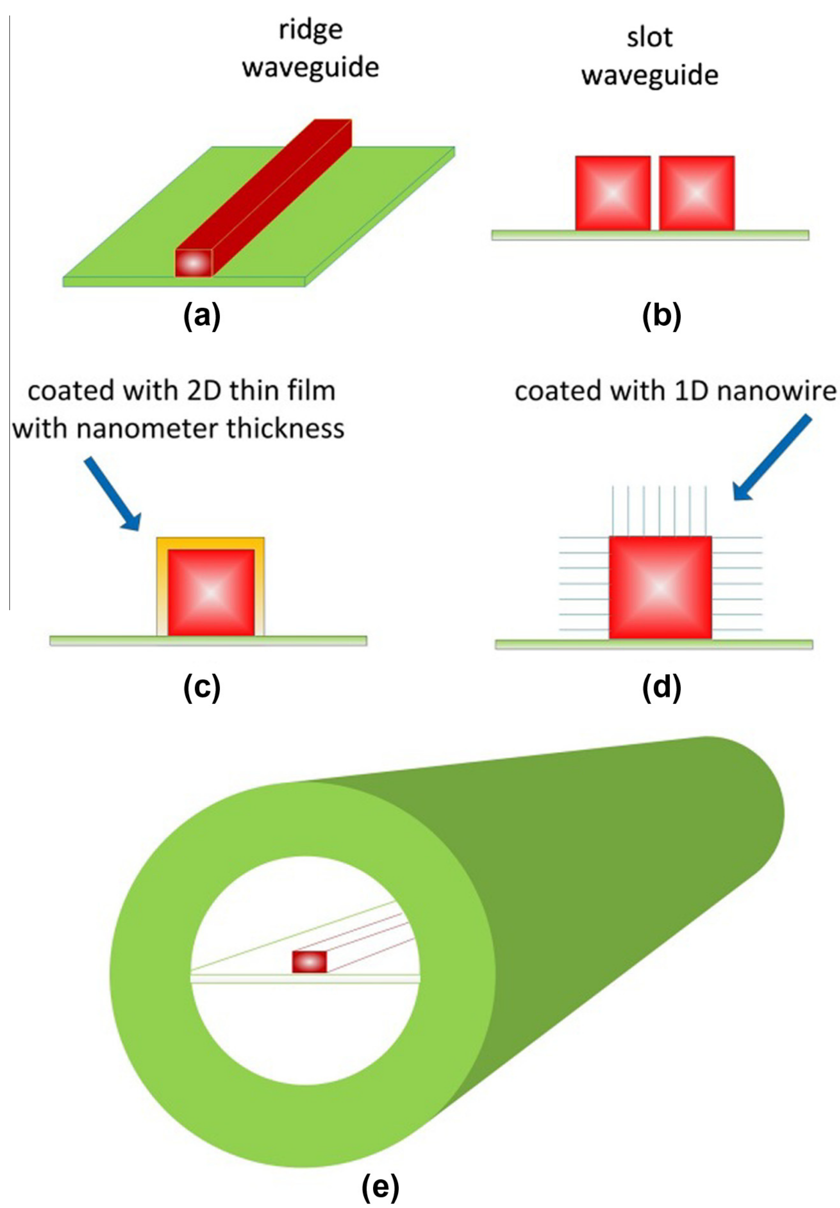

Fig. 1. Schematic diagrams of (a) ridge waveguide, (b) slot waveguide, ridge waveguides covered with (c) thin film and (d) nanowire array respectively. (e) Schematic of fiber ridge waveguide.