Semiconductor Core Fibres: A new platform for nonlinear optics?

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Abstract: Advancements in semiconductor core fibres fabricated via the high-pressure chemical deposition technique are reviewed. Transmission measurements will be presented for different core materials, including more recent nonlinear characterizations of the hydrogenated amorphous silicon fibres.

OCIS codes: 060.2270, 060.2290, 060.4370.

1. Introduction

The nascent field of semiconductor core fibres is attracting increasing interest as a means to exploit the optoelectronic functionality of the semiconductor materials directly within the fibre geometry [1]. Compared to their planar counterparts, this new class of waveguide retains many of the advantageous properties of the fibre platform such as robustness, flexibility, and long waveguide lengths. Furthermore, through the use of microstructured optical fibre (MOF) templates these fibres also offer the potential for complex two dimensional waveguide design, thus extending the opportunities beyond what is achievable on-chip [2]. In this paper we review our efforts regarding the optical characterization of semiconductor fibres fabricated via a high pressure chemical deposition technique. Results of transmission measurements obtained for fibres with different core materials and geometries will be presented. More recently, the high Kerr nonlinear coefficient and relatively low optical losses of the hydrogenated amorphous silicon (a-Si:H) core fibres have allowed for the first nonlinear characterizations of the semiconductor core fibres. These measurements will also be presented together with preliminary demonstrations of nonlinear device functionality, from which we can benchmark their performance for nonlinear applications.

2. Optical Characterization

The semiconductor fibres are fabricated using a high pressure chemical deposition technique [3]. This technique is highly flexible in terms of the different materials that can be incorporated into the fibre templates simply through the choice of precursors and via control over the deposition conditions such as the temperature and pressure. Furthermore,

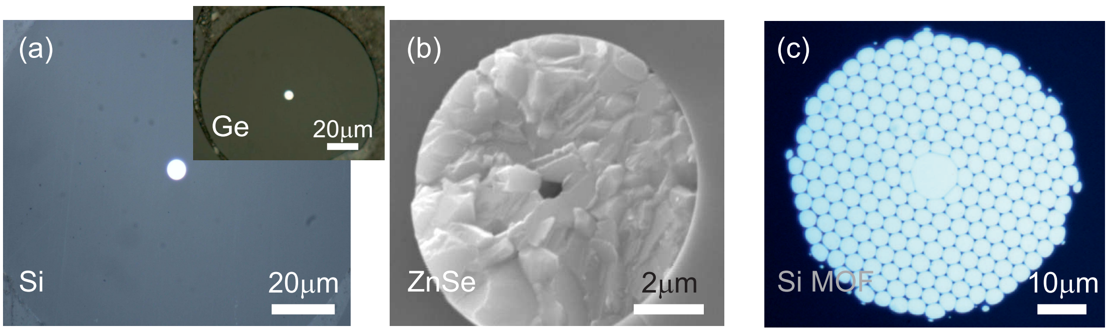

Fig. 1. Semiconductor core fibres. Step-index: (a) microscope images of silicon and germanium (inset) core fibres, (b) scanning electron microscope (SEM) image of a zinc selenide core fibre. (c) Silicon microstructured fibre.

it can be easily adapted to fill a range of capillary sizes, and/or MOF structures, so that the waveguiding properties can be optimized for specific applications. To illustrate these features, Fig. 1 shows a selection of microscope images of some of the semiconductor fibres fabricated using this technique. Here Figs. 1(a) and (b) show step-index fibres with silicon, germanium (inset), and zinc selenide core materials, and Fig. 1(c) shows a silicon microstructured fibre fabricated by completely filling a hollow-core silica MOF with the high index semiconductor. The lowest optical losses that have been measured for these core materials as of to date are: $\sim 0.8\,\mathrm{dB/cm}$ and $\sim 0.3\,\mathrm{dB/cm}$ for hydrogenated amorphous silicon (a-Si:H) at the wavelengths $1.5\,\mu$m and $2.7\,\mu$m, respectively, $\sim 4\,\mathrm{dB/cm}$ for germanium at $10\,\mu$m, and $\sim 0.5\,\mathrm{dB/cm}$ for ZnSe at $2\,\mu$m [2].

The small core sizes and relatively low optical losses of these semiconductor fibres have also allowed for the first observations of nonlinear transmission [4]. This is illustrated via the spectral broadening induced on a pulse propagating through a $5.7\,\mu$m diameter a-Si:H core fibre at a wavelength of $1.54\,\mu$m in Fig. 2(a). Significantly, a-Si:H is emerging as an important material for nonlinear photonics owing to its high Kerr nonlinearity and low fabrication costs. Characterization of the nonlinear parameters via fitting the transmission data, as illustrated in Fig. 2(b), reveals a Kerr coefficient of $n_2 \sim 1.8 \times 10^{-13}\,\mathrm{cm^2/W}$ and a two-photon parameter of $\beta_{\mathrm{TPA}} \sim 0.7\,\mathrm{cm/GW}$, so that the nonlinear figure of merit $\mathrm{FOM_{NL}} = n_2/\beta_{\mathrm{TPA}}\lambda$ of ~ 1.7 for this amorphous material is around three times larger than that of crystalline silicon. The nonlinear properties of these a-Si:H fibres will be discussed in relation to future device development, where we will demonstrate the potential for all-optical control using cross-phase (e.g., Fig. 2(c)) and cross-absorption modulation [5].

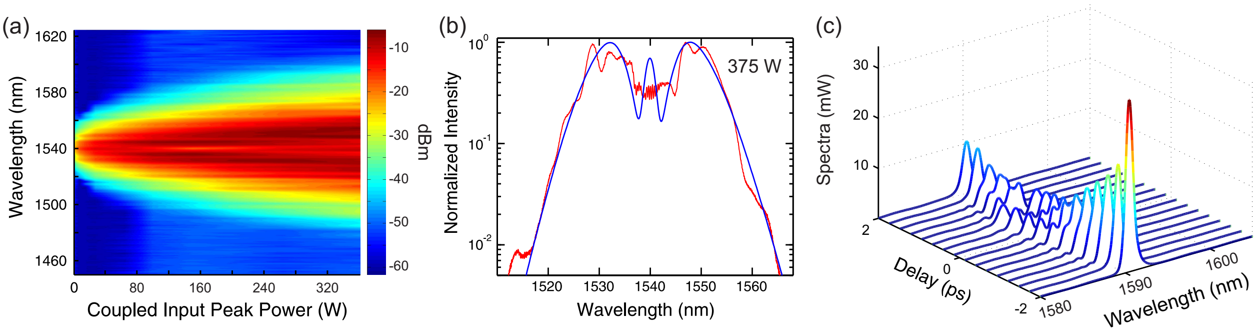

Fig. 2. Nonlinear characterization of a a-Si:H fibre with a $5.7\,\mu$m diameter core. (a) Spectral broadening as a function of input peak power. (b) Output spectrum together with a fit to determine the strength of the Kerr nonlinear coefficient. (c) Cross-phase modulation induced on a weak probe pulse due to the presence of a high power pump.

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