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# A Small core $Yb^{3+}$-doped holey fibre laser and amplifier

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Abstract: We have fabricated an ytterbium doped holey fibre with an effective area of just 2.5μm$^2$ at the laser wavelength (1.03μm). Using this fibre, we have demonstrated a low threshold mode-locked laser using frequency feedback technique. Furthermore, by seeding with pico-joule femtosecond pulses, we obtain Raman solitons tunable from 1.06 to 1.58μm.

Holey fibres have shown remarkable optical properties[1] that cannot be obtained using conventional fibre technology. One of the key optical properties of the holey fibres is that it is possible to reduce a zero dispersion wavelength below 1.3μm with an appropriate design[2]. In general, the shift of the zero dispersion wavelength can be shifted towards short wavelengths by reducing the core diameter. Correspondingly, these fibres exhibit a large nonlinearity[3] relative to conventional fibres. Incorporating an ytterbium doped core in a small core holey fibre offers new opportunities to exploit these features for a variety of mode-locking techniques, and to reduce the lasing threshold. Furthermore, these fibres support optical solitons at the laser wavelength, allowing us to explore a range of different operation regimes in active devices. This paper reviews our recent work in which we have demonstrated the first mode-locked holey fibre laser[4], and a Raman soliton generation in an amplifier configuration.

Our ytterbium doped holey fibre was fabricated using a conventional capillary stacking technique. The core was formed by drilling out the central part of a conventional step index fibre preform, and approximately 70% of the core region was doped by the active ions. In order to obtain small dimensions, we used a two-step drawing approach. The central structure was drawn to obtain a cane, and this cane was then inserted into a jacket tube, from which the final fibre was drawn. The fibre had an outer diameter of 125μm, a core diameter of 1.6x2.7μm, and an air fill fraction of 70% as shown in Fig.1.

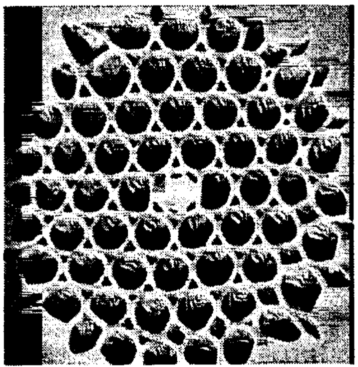
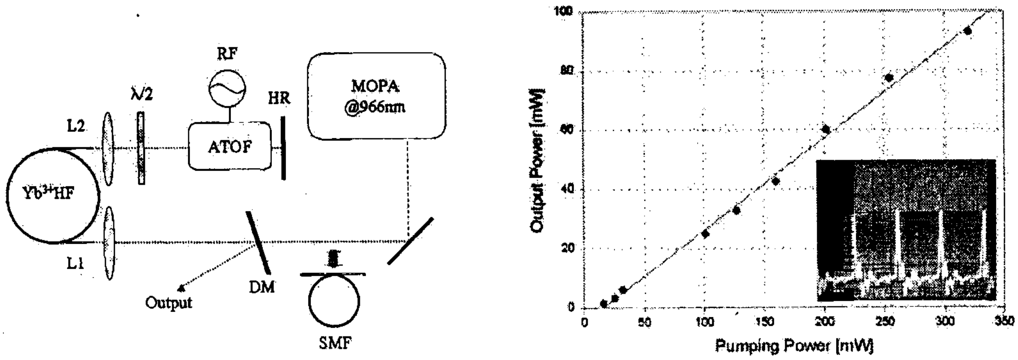


Fig.1. The SEM photograph of the central region of the fabricated ytterbium holey fibre.

The high index contrast between the core and the cladding, and the small dimensions, combined with the elliptical shape of the core, leads to a large geometrically induced birefringence. We measured the birefringence at 1550nm, and a beat length *B* of 0.3mm was recorded, which is, to our knowledge, the shortest value obtained so far, and agrees well with the value predicted (0.28mm) by our vector model[5]. The effective mode area ($A_{eff}$) and the zero dispersion wavelength were also predicted to be 2.5μm$^2$ (around 1.06μm) and~800nm, respectively.

Using 1m of the fibre, we constructed a Fabry-Perot type mode-locking cavity based on the frequency feed-back technique[6] as shown in Fig.2(a). Note that the normal cleaved end of the fibre near L1 acts

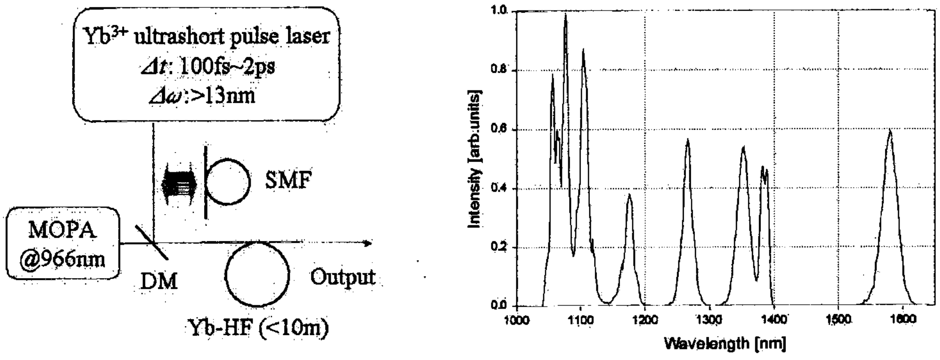


(a) (b)

Fig.2 The experimental setup for the mode-locked ytterbium holey fibre laser (a) and the output characteristics (b).

as an output coupler of the cavity. The fibre was pumped by laser diode MOPA, from which we obtained ~300mW at 966nm. A half wave-plate was inserted to match the optical axis between the fibre and an acousto-optical tunable filter (AOTF). The laser output showed a reasonable slope efficiency of ~75%, as shown in Fig.2(b). The mode-locking self-starts for pump powers greater than 30mW. The spectral width was 0.1nm, from which we estimate the pulse duration to be ~15ps by assuming a Gaussian spectral shape. In addition, by changing the frequency of the RF driver of AOTF, we were able to tune the mode-locked output from 1030 to 1050nm.

Using a relatively longer length (5~10m) of the fibre with the forward pumping laser diode MOPA configuration, as shown in Fig.3(a), we realised a nonlinear amplifier. Broadband pulses, which were generated within a stretched pulse mode-locking cavity at a 60MHz repetition rate[7], were used to seed the amplifier. The pulse duration of the seeds was 100fs~2ps dependent on the chirp. Once generated, the Raman shifted seed pulses can propagate through the fibre without resonant loss, allowing us to make use of a longer length of the fibre. Using this configuration, tunable Raman solitons were generated with the aid of amplification, which were tuned simply by changing the pump power. Single pulse operation was achieved from 1.06 to 1.33μm using moderate pump powers, while multiple soliton generation was observed using high pump powers (Fig.3(b)). This is believed to be a consequence of pulse break-up during amplification. In the latter case, we observed the wavelength shift up to 1.58μm. An average power of ~20mW was obtained at the output. The autocorrelation measurement in the single pulse regime showed a pulse duration of ~200fs, and time-bandwidth product of ~0.65.



(a) (b)

Fig.3 The experimental setup of Raman soliton generation (a) and the measured spectrum at the output with higher pump power (b). SMF: single mode fibre to control the initial chirp, and DM: Dichroic mirror.

In summary, our recent small core ytterbium doped holey fibre demonstrates extraordinary optical properties, including high birefringence ($B$~0.3mm at 1550nm), a small effective area ($A_{eff}$~2.5μm$^2$ at 1.06μm) and anomalous dispersion at the lasing wavelength. Using this fibre, we have performed the first mode-locked laser experiment using the holey fibre based upon the frequency shift feed-back technique. Furthermore, Raman soliton generation was demonstrated using pico-joule femtosecond seed pulses. The broadband tunability with reasonable pulse quality of the nonlinear amplifier is promising for a range of applications such as spectroscopy.

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