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APPLICATIONS OF RAMAN EFFECT IN HOLEY FIBRE

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Abstract: We demonstrate the application of Raman effect in Holey Fibre (HF) to produce an efficient Raman amplifier and modulator. Using a 75m long HF with an effective are of 2.85μm^2 we obtained internal gain of over 42dB for the amplifier and 11dB extinction ratio for the modulator.

There has been a rapid progress in the technology of Holey Fibre (HF) in recent years [1] and has led to the development of a number of novel devices. For example, we have recently demonstrated a nonlinear optical thresholder incorporated in an OCDMA receiver based on the Kerr effect in just 8.7m of HF [2]. In this paper we show that the Raman effect in a pure silica highly nonlinear HF can be exploited to produce nonlinear fibre optic devices namely Raman amplifier and Raman modulator with reduced length/power levels requirement.

The experimental setup for Raman amplifier is shown in Fig. 1. The maximum peak pump power that were launched into the HF was ~6.7W, and the maximum launched signal power was ~-10dBm. The HF used in this experiment has a core diameter of ~1.6μm, a measured effective area of 2.85μm^2 and loss of 40dB/km at 1550nm. 75m of the fibre was used in the experiments described here. The Scanning Electron micrograph (SEM) of the HF is shown in the inset of Fig. 1. The asymmetric arrangement of holes around the core results in linear birefringence. A beat length of 0.4mm was measured at 1550nm, and the fibre was shown to be polarization maintaining, with a polarization extinction of 21dB.

Fig. 2 shows the measured internal Raman gain (measurement by analysis of the temporal response of the signal beam to the pulsed pump beam) and noise figure for various probe signal wavelengths and fixed pump/signal powers. Maximum small signal gain of 42.8dB, and minimum noise figure of 6dB were obtained at 1640nm (the longest wavelength to which we could tune our signal laser). We also measured the internal Raman gain as a function of pump peak power for a signal wavelength of 1635nm with the signal power fixed at -10dBm shown as inset of Fig. 2. From this data we can estimate the Raman gain coefficient g_R using equation $G(dB) = 10x\log_{10}(\exp(g_R P L_{eff}/A_{eff}) - \alpha L)$, and the value turns out to be $7.5x10^{-14}$m/W. This is in good agreement with the number for pure silica reported in Ref [3].

To perform Raman modulator experiment, we used the same experimental setup with the 1600nm tuneable laser exchanged with a 20dBm, 1480nm CW semiconductor diode laser. Strong pump pulses generate a corresponding signal loss that is due to stimulated Raman scattering, which results in the formation of dark pulses at the signal wavelength, where the signal overlaps the pump pulses. Measured oscilloscope traces are shown in Fig. 3. To justify the performance of the modulator, we measure the extinction ratio (defined as the hole depth relative to the background CW level) as a function of pump peak power. Maximum extinction ratio of 11dB was obtained. It should be possible to obtain even higher extinction ratios by tuning the frequency separation of the signal and pump (10.5THz in this experiment) to lay closer to the peak Raman shift value which is around 13.2THz for pure silica, and also by better alignment of the polarization of the two beams relative to the principal axis of the fibre.

In conclusion, we have experimentally demonstrated the use of HF for an efficient Raman amplifier and modulator with 42dB internal gain and 11dB extinction ratio respectively. The reduced device length could be a benefit in terms of reducing the deleterious impact of Rayleigh scattering as well as significant from a packaging/environmental stability perspective.

[1] J. C. Knight, T. A. Birks, P. St. J. Russell, and M. Atkin, "All-silica single mode optical fiber with photonic crystal cladding," *Optics Lett.*, **21**, 1547-1549 (1996).

[2] J.H. Lee, P.C. Teh, Z. Yusoff, M. Ibsen, W. Belardi, T.M. Monro, and D.J. Richardson, "An OCDMA receiver incorporating a holey fibre nonlinear thresholder," *Proc. 27th European Conference on Optical Communication (ECOC' 2001)*, **PD.B.1.2**, 70-71 (2001).

[3] S. T. Davey, D. L. Williams, B. J. Ainslie, W. J. M. Rothwell, and B. Wakefield, "Optical gain spectrum of GeO_2-SiO_2 Raman fibre amplifiers," IEE Proceedings Journal of Optoelectronics, **136**, 301 (1989).

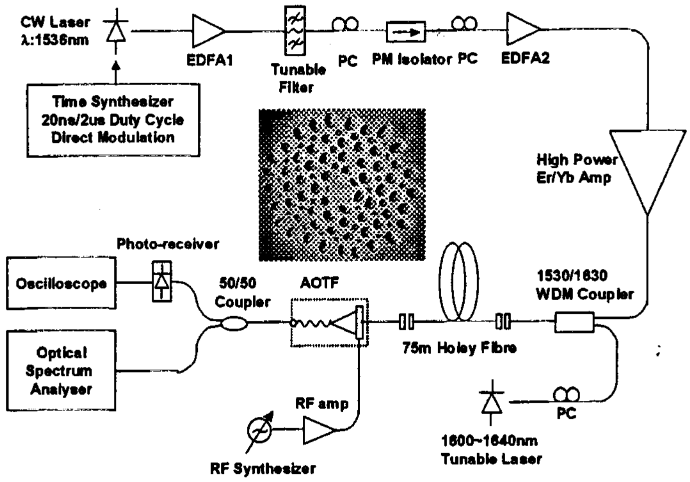

Fig. 1. Experimental setup. Inset, SEM of the HF.

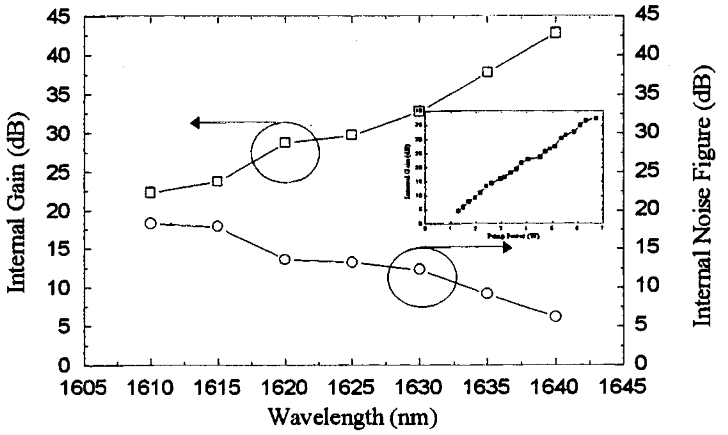

Fig. 2. Internal Raman gain and noise figure for various probe signal wavelengths. Inset, measure internal gain versus pump peak power at 1635nm.

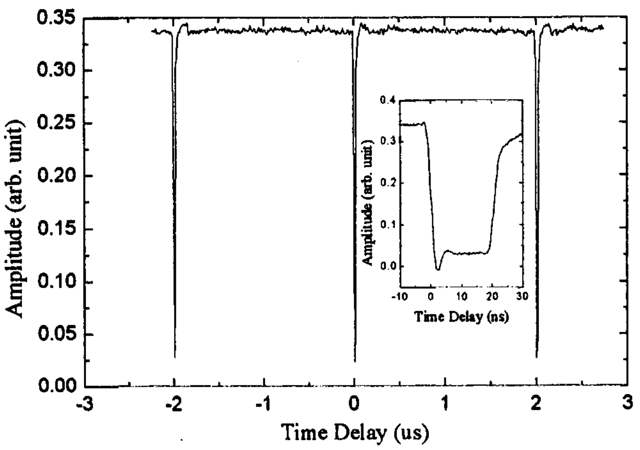

Fig. 3. Temporal profile of dark pulses at the modulator output. Inset, close up view of the square-shaped dark pulse (the temporal dip at the falling edge is due to ringing of the photoreceiver).