Generation of Pairs of Solitons in an All-Fibre, Femtosecond Soliton Source

D.J. Richardson[1], V.V. Afanasjev[2], A.B. Grudinin[2], and D.N. Payne[1]

[1]The Optoelectronics Research Centre, Southampton University, Southampton, UK

[2]Russian Academy of Sciences, General Physics Institute, Moscow, Russia

Abstract. We demonstrate both experimentally and theoretically the generation of single and pairs of sub-100 fs soliton pulses from a passively mode-locked, all-fibre module.

1. Introduction

In recent years much work has been devoted to the development of convenient solid-state laser sources of ultrashort pulses (1,2). Passive generation of femtosecond pulses in optical fibres is of particular interest. In this paper we report for the first time the generation of pairs of solitons in an all-fibre femtosecond fibre laser/amplifier combination.

2. Experiment

The experimental configuration (fig.1) consists of two main components: a master oscillator based on the Figure-8 fibre laser and an external erbium-doped fibre amplifier (EDFA) [3]. Although ultimately potentially diode pumpable, for convenience in our experiments both units were pumped from a common 3W Ti:Sapphire laser operating at 980nm. With only 20 mW of pump power, approximately 10 bandwidth-limited soliton pulses of 450 fs duration, at 1558 nm, circulated within the laser cavity. The cavity round trip frequency was 5 MHz. The average laser output power coupled into the amplifier was 80 μW (laser output coupling α_c=30%). The amplifier pump power was varied between 320-410 mW.

With an initial amplifier length of 5.4 m (NA = 0.15, λ_{co} = 1230 nm and Er^{3+} doping level of 800 ppm) and pump power of 320 mW, a total power gain of 29dB was obtained and pulse compression from 450 fs down to 90 fs was observed at the amplifier output (Fig.2), together with simultaneous Soliton Self Frequency Shift (SSFS) from 1558 nm down to 1590 nm. (inset). The time-bandwidth product for these pulses is 0.33, in reasonable agreement with that expected for a $sech^2x$ pulse shape.

In order to study the nonlinear dynamics of pulse propagation along an amplifier, the erbium-doped fibre was gradually cut-back from the initial starting length of 5.4 m. A graph of the experimentally-

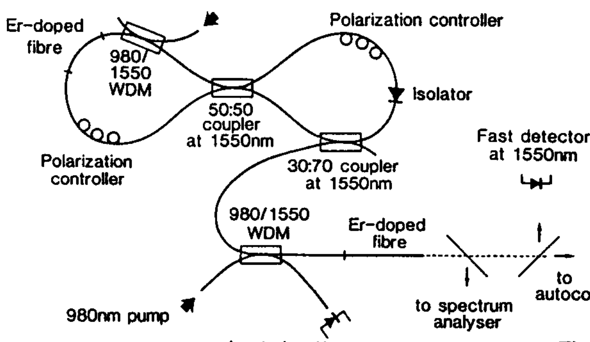

Fig.1 Experimental configuration.

Springer Series in Chemical Physics, Vol. 55 Ultrafast Phenomena VIII
Editors: J.-L. Martin · A. Migus · G.A. Mourou · A.H. Zewail

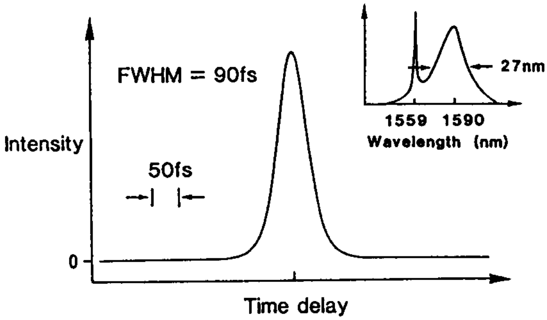

Fig.2 Autocorrelation trace and spectra of 90 fs solitons obtained at the end of the 5.5m long EDFA section

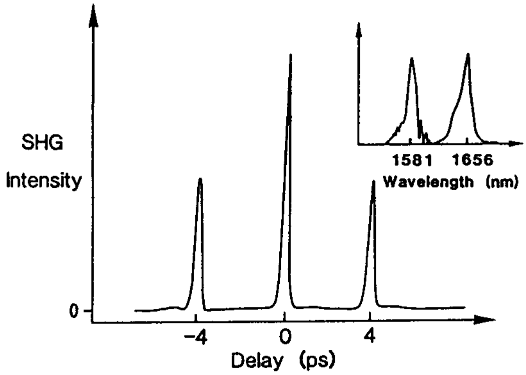

Fig.3 Auto-correlation trace and spectra of a pair of spectrally and temporally separated 100 fs solitons.

determined pulse duration against amplifier length (asterisks) is shown in Fig.4, where one can see, that the pulse undergoes a dramatic change in duration (by a factor of 10 within a distance of 20 cm) after propagating 2.8m within the amplifier. The shortest single pulse at the amplifier output (50 fs at 1590nm) was obtained at a pump power of 300 mW with a fibre length of 3m. On increasing the amplifier gain multiple coloured soliton generation was observed.

The three-level nature of erbium-doped fibre amplifiers and the effect of SSFS provide us with an elegant way to generate individual, or even sets of spectrally 'cleaned' coloured solitons. By using an over-long amplifier the excess (unpumped) length acts as an absorber for wavelengths within the original signal band, whilst passing with minimal attenuation the SSFS, red-shifted components which fall outside the erbium absorption band. Fig.3 shows the experimental spectrum and autocorrelation trace obtained at the output of a 6m long fibre amplifier, pumped with 300mW at 980nm. We have obtained two 'cleaned' solitons with approximately the same intensity, but with a 75nm wavelength separation.

3. Theoretical Model

Although the effects which determine the general behaviour of the amplified pulse compression are readily understandable, the complete set of cut-back data (output signal power, residual pump power, signal correlation function and spectra) provide us with experimental date with which to test theoretical models. We have modelled the data by numerically solving the nonlinear schrodinger equation for the system, introducing a z-dependence for the amplifier gain. Note, that due to the output coupling and the discrete change in dispersion between the laser fibre (3.5 ps/nm.km) and the amplifier fibre (13 ps/nm.km) the input pulses to the amplifier have a soliton number $N \approx 0.2$-0.3 with respect to the amplifier fibre and as such can be considered as almost linear pulses at the amplifier input. The solid curves in Fig.4 represent theoretical estimates of the pulse duration against amplifier length which are in good agreement with the experimental results (curve 1 in Fig.4). The curves (1-4) in Fig.4 show results for different values of the input pulse power, defined by the laser output coupler (a_c=30% for

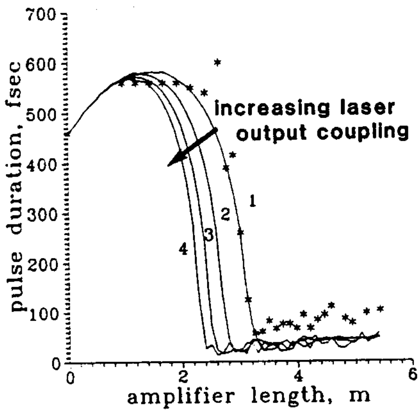

Fig.4 Effect of increasing oscillator coupling on pulse evolution along EDFA

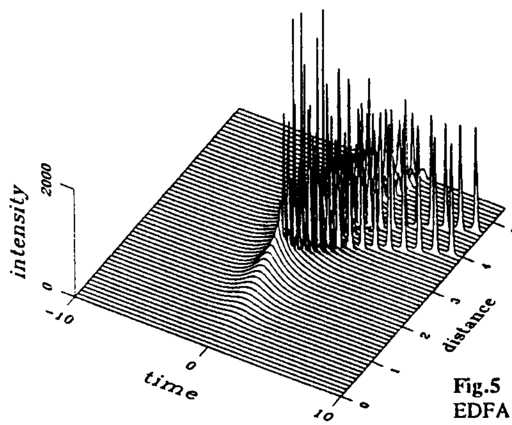

Fig.5 Dynamics of pulse evolution along EDFA for generation of pairs of solitons.

curve 1, 50% for curve 2, 70% for 3 and 90% for 4). One can see that an increase in the input soliton number results in a shorter compression length. Fig.5 shows the dynamics of the pulse evolution for an overlong amplifier. Note the almost linear pulse amplification process before the rapid compression and dual coloured soliton generation.

4. Conclusion

Our results show that it is possible to generate reasonably clean individual (or sets) of fundamental solitons starting from an almost linear pulse. In our opinion this is important as it allows us to generate sub-picosecond, fundamental solitons from for example, a combination of a laser diode and an EDFA.

References

1. M.E. Fermann, M. Hofer, F. Haberl, A.J. Schmidt: Optics Letters, 16, 244, 1991.
2. D.E. Spence, P.N. Kean, W. Sibbett, Optics Letters: 16, 42, 1991.
3. D.J. Richardson, A.B. Grudinin, D.N. Payne: Paper TUG6, Proceedings OFC (San Jose), 1992.
4. V.V. Afanasjev, V.N. Serkin, V.A. Vysloukh: "Amplification and compression of femtosecond optical solitons in active fibres", Sov. Lightwave Commun., to be published.