FIBRE LASER SOURCE OF DUAL-WAVELENGTH FEMTOSECOND PULSES

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Mode-locked erbium-doped fibre soliton lasers offer a range of desirable properties e.g. tunability and high pulse quality that make them suitable for applications in future nonlinear transmission and computation systems [1-3]. In particular, energy quantization effects caused by the soliton regime of operation of such lasers results in excellent individual pulse parameter stability with regard to pump power fluctuations. This feature is a result of the specific output of fibre soliton lasers, which consists of a number of soliton pulses and a non-soliton component. The output pulse parameters i.e. duration and energy are fixed by the cavity design. The number of circulating pulses is defined by the ratio of the average intracavity intensity to average soliton intensity. Generally this ratio is not an integer, causing the formation of a non-soliton component which plays the role of an energy buffer. Any excess stored intracavity energy (caused, for example, by small fluctuations of pump power) leads to changes in the non-soliton component leaving the parameters of the solitons largely unaltered. This excellent pulse amplitude stability allows complex, amplitude-sensitive nonlinear processing to be investigated such as that reported here.

A recent theoretical study of the propagation of coloured solitons (solitons with different frequencies) indicates the possibility of the suppression of the soliton interaction forces [4]. To investigate or successfully exploit this possibility requires the simultaneous or synchronous generation of picosecond pulses at different wavelengths. In this paper we propose a simple method for the synchronous generation of several ultrashort pulses at different wavelengths.

The technique is based on the recombination of chirped pulses [5]. If one produces in some manner a linearly-chirped pulse, splits it into two components, time delays one of the pulses and subsequently recombines them, then an intensity beat signal will be obtained in the temporally-overlapping region. Providing the pulses are linearly chirped, the beat frequency is constant throughout the overlapping region, although the instantaneous frequency associated with each individual beat lobe is different. If one is then able to compress each of these individual beat lobes into a discrete pulse then one can simultaneously generate pulses with a range of different wavelengths.

The experimental set-up is shown in Fig.1. The soliton source is a passively mode-locked fibre ring-laser based on nonlinear polarization evolution [2]. The laser cavity comprises 5m of Er^{3+}/Yb^{3+} codoped fibre with Yb^{3+} and Er^{3+} ion concentration of 5000 ppm and 800 ppm respectively, 150 m of standard telecom fibre (NA = 0.1, λ_{co} = 1230 nm, D = - 17 ps/nm km) and a polarization-dependent optical isolator. With 100 mW pump power from a conventional Nd:YAG laser we have 5 mW output power at 1545 nm in a mode-locked regime. Since the pulses propagating in the main 150 m standard-fibre section of the laser are fundamental ($N = 1$) solitons [6], the 85% coupler placed before this section couples out higher-order solitons enabling us to easily obtain a strong chirp across the pulses on propagation in further sections of +GVD fibre.

Passively mode-locked fibre soliton lasers usually operate with many pulses within the cavity [2] and the instability of the repetition rate is a serious problem. To overcome this problem we have incorporated a specially-designed amplitude modulator within the cavity to provide pulse-timing synchronisation. The modulator consists of a $LiNbO_3$ acoustic transducer clamped directly onto the fibre [7], which has the merit that it produces no additional cavity loss or etalon effects. The acousto-optic perturbation of the birefringence that this provides interacts with the polariser to give the slight amplitude modulation (a few %) required for pulse synchronization. In such a configuration the laser produces a train of 2.5 ps pulses with a reasonably clean spectrum (Fig.2a) and a stable repetition rate of 160 MHz.

The 85% laser output was spliced to 200 m of fibre with positive GVD (D = 5 ps/nm km) resulting in temporal broadening to 4.2 ps and a five-fold spectral broadening (Fig.2b). The chirped pulses were then launched into 3 m of highly-birefringent fibre ($B = 3 \times 10^{-4}$) resulting in a delay $\tau_p \approx 3$ ps between the orthogonal states of polarization. By setting the state of polarization at the input of the birefringent fibre so as to excite both eigenpolarization modes equally and careful alignment of the orientation of the fibre polarizer we obtained two well-resolved spikes with 3.5 nm spectral separation (Fig.2c) and amplitude beat period of 2 ps (Fig.3a).

To transform the sine-like amplitude modulation into solitons, we have used a nonadiabatic compression technique. The beat signal is launched into 900 m of dispersion shifted fibre with D= -1 ps/nm.km (Fig.1) whereupon the combined effect of multisoliton compression and soliton self-frequency shift results in the formation of two 400 fs solitons centred near 1560nm. Fig.2d shows the spectrum at the output of the dispersion-shifted fibre and Fig.3b represents the corresponding autocorrelation trace. Note that the effect of SSFS changes both the temporal and spectral separation of the emergent pulses.

In conclusion, using a passively mode-locked fibre ring laser as a master source we have experimentally demonstrated an all-fibre source of 400 fs pulses at two different wavelengths. In order to stabilize the repetition rate we have exploited a new, clamp-on piezo-electric transducer based on a $LiNbO_3$ crystal. In the present configuration we used a nonadiabatic method of pulse compression which gives significant changes in the central wavelength separation of the generated pulses and leads to less defined temporal separation. Using an adiabatic method of compression using for example dispersion-decreasing fibre[8] we can expect the generation of several subpicosecond pulses possessing both well-defined temporal and spectral separations.

References

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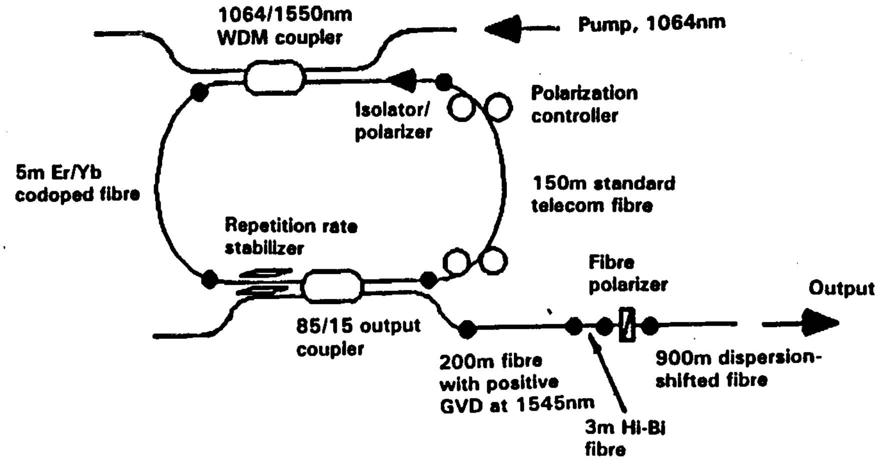

Fig.1 Experimental configuration

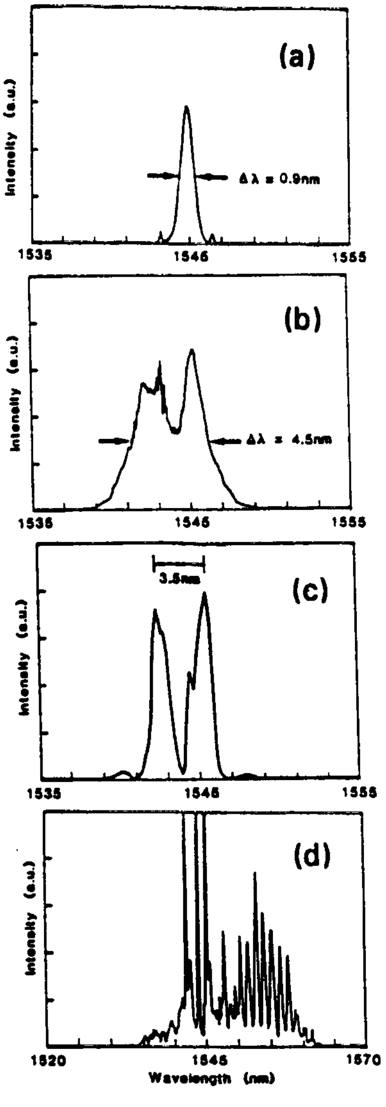

Fig.2 Spectral characteristics of the source:
(a) at the output of the soliton laser;
(b) after 200m of the fibre with positive GVD;
(c) after 3m of Hi-Bi fibre + polarizer;
(d) at the output of the system

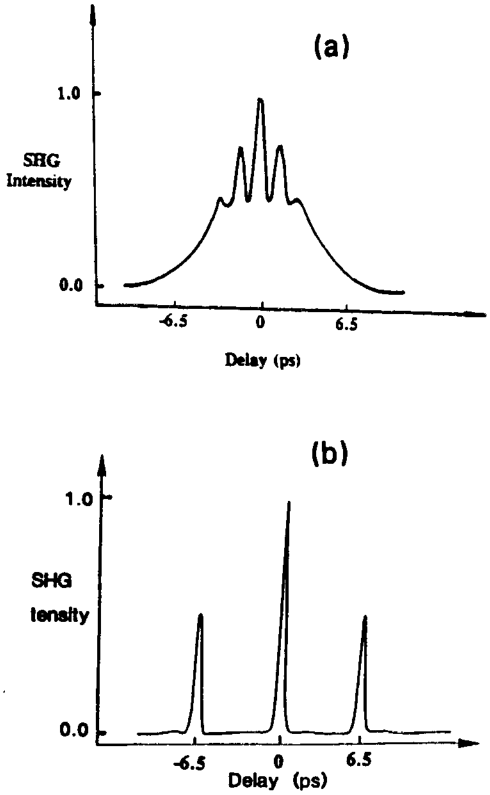

Fig.3 Autocorrelation traces at the input (a) and output (b) of the dispersion-shifted fibre