70 GBit/s fibre based source of fundamental solitons at 1550 nm

S.V. Chernikov[1], D.J. Richardson[2], R.I. Laming[2], E.M. Dianov[1], D.N. Payne[2]

[1]General Physics Institute, 38 Vavilov Street, 117942, Moscow, Russia.
[2]Optoelectronics Research Centre, Southampton, SO9 5NH, U.K.

Abstract: We report the generation of a 70 Gbit/s CW soliton train with a mark-space ratio of 1:11 from a fibre system based on the nonlinear propagation of a dual-frequency beat-signal within dispersion decreasing fibre.

Ultra-high bit-rate sources of soliton pulses capable of operating in the Gigahertz region are of considerable interest for the next generation of optical fibre telecommunication systems, as well as for optical signal processing. At present mode-locked external-cavity laser diodes [1,2], gain-switched diodes [3] and, more recently, actively mode-locked erbium-fibre ring lasers [4] have been employed to generate the necessary soliton pulse trains for long-haul transmission experiments at bit-rates in the range of 2-10 Gbit/s. Recently, an alternative all-optical method of ultra-high frequency soliton generation has been suggested, based on the nonlinear propagation of a beat signal between two narrow-linewidth lasers in an amplifying fibre or alternatively, a fibre of steadily decreasing dispersion [5,6]. The technique enables the generation of high-purity soliton pulses at repetition rates ranging from tens to hundreds of GBit/s (coresponding to the initial frequency separation of the lasers). In the first experimental demonstrations of this technique 25ps bunches of solitons at 200 GHz [6] and 1 μs trains of solitons at repetition rates in the range of 80-130 GHz [7] were generated in a fibre of steadily decreasing dispersion.

In this paper we report for the first time the generation of a truly CW train of high purity solitons around 1.551 μm in a dispersion decreasing fibre. Repetition rates in the range 60-90 GHz with mark-space ratios (MSRs) in the range 1:5 to 1:11 have been achieved.

The experimental configuration is illustrated in fig.1. Two, pig-tailed single-frequency DFB lasers DFB1 and DFB2 were combined using a 50:50 coupler. The combined signal was then passed through a polarisation-sensitive isolator (isolator 1) into an erbium-doped fibre amplifier (EDFA) with counter-propagating pump. Polarization controllers were included in both inputs to the combining coupler in order to maximise and equalise the relative intensities of the input signals. The laser wavelength separation could be varied between 0 and 2.5nm by independently varying the temperature of the diodes. The EDFA was pumped using a Ti:Sapphire laser operating at 978 nm which was coupled into the EDFA via a WDM coupler. The input pump power was accurately stabilised using a servo-circuit and Bragg cell placed in front of the launch optics. The amplified diode-laser beat signal emerging from the EDFA was passed through a second polarisation insensitive isolator (isolator2). Up to 300 mW of amplified signal was available at the isolator output. A 1 km section of dispersion-shifted fibre (DSF) ($|D| < 1.5$ ps/nm/km at 1551 nm) was spliced to the isolator output, followed by the dispersion-decreasing fibre (DDF) of length 1.6 km. The tapered DDF was fabricated using a recently developed technique [8]. The dispersion at the fibre input was D = 10ps/nm/km and the dispersion at the output D = 0.5 ps/nm/km at 1.55 μm. The dispersion-length profile was designed to be close to a hyperbolic form. The total system loss was 2dB. A 90:10 coupler was spliced to the DDF output to facilitate real-time monitoring of the pulse-train shape by a background free autocorrelator, optical spectrum analyser and an average power meter.

The implementation we adopted is slightly different to previously published techniques [5,6] in that we added a section of DSF before the DDF. The DSF was used to spectrally enrich the beat signal through four-wave mixing prior to soliton formation and compression in the DDF. This enrichment permitted us to extend the range of application of the particular DDF to lower repetition rates and correspondingly lower input powers than would be possible with the DDF alone. The basic mechanism of soliton train generation however remains the same.

The spectrum of a 300 mW beat signal from the laser diode/EDFA combination after propagation through the DSF is shown in Fig.2a. Four-wave mixing generates sidebands $\approx$ 10 dB below the main signal components and was independent of the wavelength separation for separations up to 0.7nm. Autocorrelation functions measured at the input and output of the DSF were fitted well by a sinusoidal beat signal of the form $G(\tau) = 1 + 2\cos^2(\pi R \tau)$, where R is the repetition rate and τ the time delay, giving a 3:1 relation between the maximum to minimum SHG intensity (Fig.2b) for the autocorrelation trace.

Following spectral enrichment in the DSF the soliton train was generated in the DDF. Figs.3(a,b) show the spectrum and corresponding autocorrelation function measured at the DDF output for a DFB wavelength separation of 0.57 nm (70 GHz). The autocorrelation trace shows that we have generated a train of well-separated pulses with a period of 14.3ps. There is no background on the autocorrelation function and the trace is flat between pulses. The individual pulses have a good sech^2 form with no pedestal. The half-width of the autocorrelation function corresponds to a soliton duration of 1.3ps.

The optical spectrum (Fig.3a) contains a discrete number of lines separated by $\approx$0.57 nm and corresponds to a 70 GHz periodic signal. The heights of the discrete peaks in the spectrum can be fitted by a continuous envelope which corresponds to the optical spectrum of the individual pulses forming the train. The autocorrelation function and spectrum provide an excellent fit to a train of 70 GHz solitons with durations of 1.3ps (corresponding to a MSR of 1:11).

Investigation of the system behaviour over the a complete range of input beat-signal parameters (frequency separation and average power) indicate that high-quality soliton trains could be obtained for repetition rates in the range 60-90 GBit/s with MSRs in the range 1:5 to 1:11 from this single configuration.

In conclusion, we have experimentally generated stable, CW trains of high-purity, fundamental solitons in a dispersion decreasing fibre at repetition rates in the range of 60-90 GBit/s, using the technique of soliton-train formation from a dual-frequency beat-signal generated by a combination of two DFB diode lasers and an EDFA combination. We believe that this simple, highly-stable and widely tunable all-fibre component source based on DFB laser diodes and an EDFA has great potential for use in future ultra-high bit-rate telecommunication systems.

References

1. N.A.Olsson, P.A Andrekson, J.R. Simpson, T. Tanbun-Ek, R.A. Logan K.W. Wecht, Electron.Lett., 27, 695 (1991).
2. L.F.Mollenauer, M.J. Neubelt, M. Haner, E. Lichman. S.G. Evangelides, B.M Nyman, Electron.Lett., 27, 2055 (1991).
3. M.Nakazawa, K.Suzuki, E.Yamada, H. Kubota, Y. Kimura, OFC 92 (San Jose), PD11, 355 (1992).
4. L.F.Mollenauer, E.Lichtman, G.T.Harvey et.al., Electr.Lett.,28,792 (1992).
5. E.M.Dianov, P.V.Mamyshev, A.M.Prokhorov, S.V.Chernikov, Opt.Lett, 14, 1008 (1989).
6. P.V.Mamyshev,S.V.Chernikov,E.M.Dianov,IEEE J of Quant. Electr., 27, 2347 (1991).
7. S.V.Chernikov,J.R.Taylor,P.V.Mamyshev,E.M.Dianov, accepted for publication Electron. Lett. (1992).
8. V.A.Bogatyrev et.al.,IEEE J.of Lightwave Technol.,9, 561(1991)

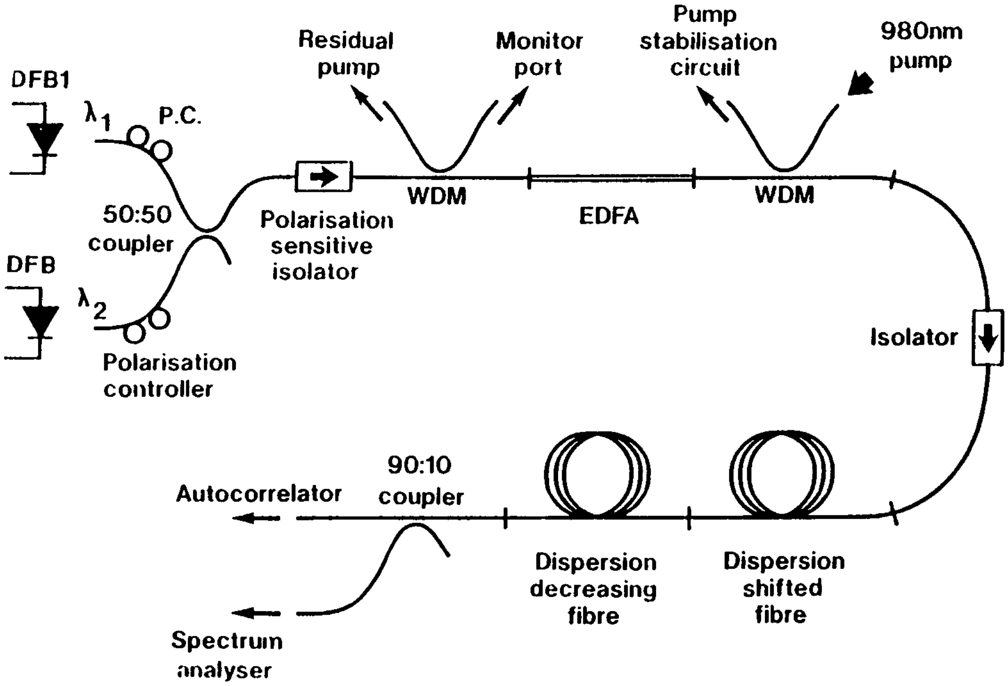

Fig.1 Experimental configuration

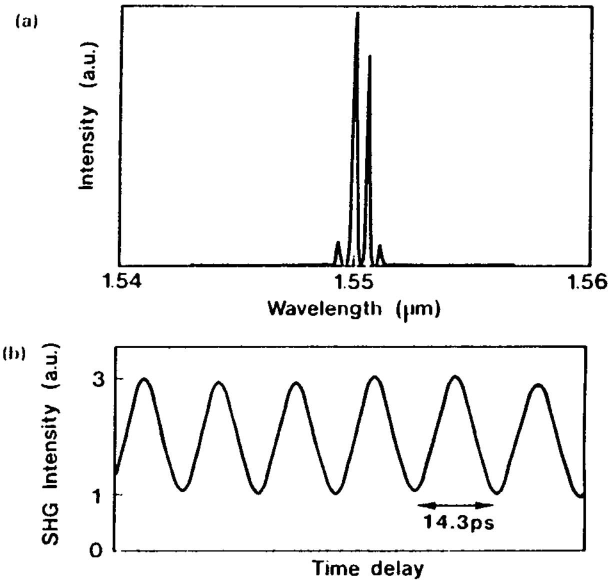

Fig.2 Spectra (a) and autocorrelation function (b) of the amplified beat signal at the end of 1.0 km DSF.

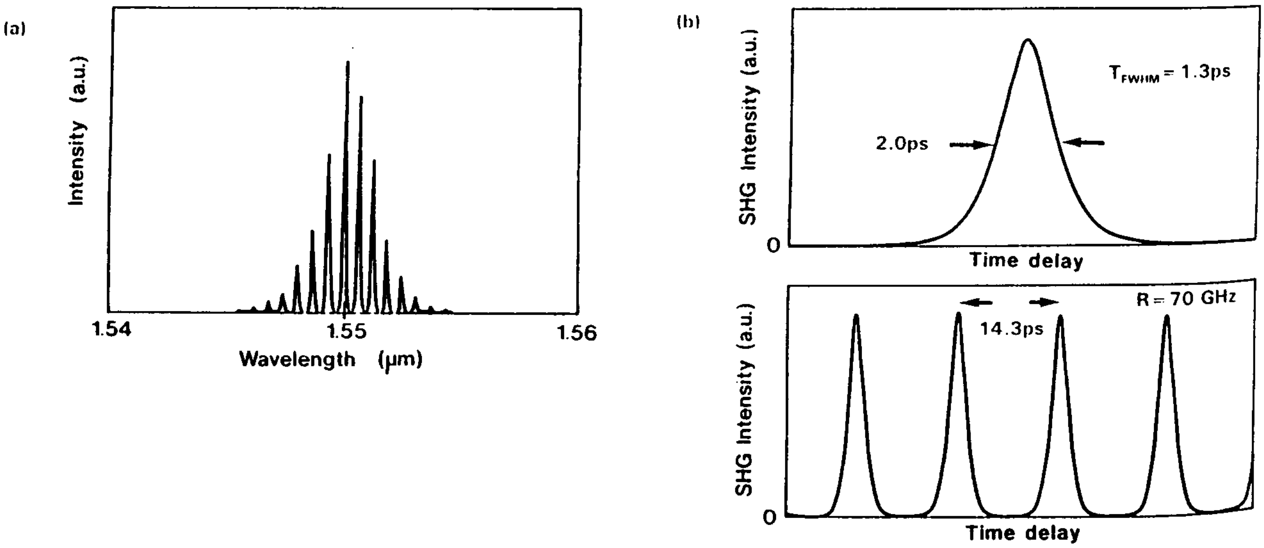

Fig.3 Spectrum (a) and autocorrelation function (b) of 70 GBit/s soliton train at the output of DDF.