Tunable modelocked bismuth-doped soliton fibre laser

S. Kivistö, J. Puustinen, M. Guina, O.G. Okhotnikov and E.M. Dianov

A modelocked bismuth-doped soliton fibre laser is reported. A stable passively modelocked operation in an anomalous dispersion regime is achieved using a dilute nitride (GaInNAs)-based semiconductor saturable absorber mirror and a transmission grating pair for dispersion compensation. The laser generated 0.9 ps soliton pulses with a repetition rate of 7.5 MHz and wavelength tunable from 1153–1170 nm. These are the shortest pulses obtained so far from Bi-doped fibre lasers.

Introduction: Ultrafast modelocked fibre lasers based on neodymium, ytterbium, erbium, thulium, and thulium-holmium doped active fibres have been proved to generate high quality short optical pulses in a broad wavelength range [1–5]. However, the development of practical ultrafast fibre lasers in the 1150–1400 nm window has lacked suitable gain fibres. Lasers operating in this wavelength range are needed for various applications in optical communications as well as for generating visible short pulses at yellow–red by frequency doubling [6].

Recently, the first bismuth-doped fibres and fibre laser have been reported to offer optical amplification and broad emission spectra in the range 1100–1300 nm [7–9]. High power continuous wave Bi-doped fibre lasers have been developed by employing active fibres with lengths of a few tens of metres [6, 10]. The requirement for using a long length Bi-doped fibre, determined by the relatively low values of pump absorption and gain coefficients, is an undesirable feature in modelocked systems that would favour a short fibre cavity. Preliminary investigations of short pulse generation in a mode-locked Bi-doped fibre laser employing a dilute nitride semiconductor saturable absorber mirror (SESAM) led to the generation of pulses with duration of ~50 ps [11]. Owing to the large normal dispersion of the long-length cavity, narrowband fibre Bragg grating reflector and non-optimised SESAM in this demonstration, the pulse has a low quality and a narrow spectral bandwidth.

In this Letter, we demonstrate a modelocked soliton Bi-doped fibre laser delivering stable ~0.9 ps pulses with a repetition rate of 7.5 MHz and tunable from 1153–1170 nm. The short pulse operation is initiated by a fast dilute nitride based SESAM. The operation in a soliton regime was achieved using careful dispersion management with a transmission grating pair and an improved Bi-doped fibre allowing for the cavity with a reduced length. To our knowledge, this is the first demonstration of modelocked Bi-doped fibre laser operating in a soliton regime and delivering the shortest pulses.

Experimental: The schematic of the bismuth-doped fibre laser is shown in Fig. 1. The laser cavity comprises 12 m of Bi-doped silicate glass fibre with an absorption of ~1.2 dB/m at the pump wavelength of 1062 nm, a 1062/1165 pump coupler, and a fibre loop output mirror with ~95 % reflectivity at the lasing wavelength. The laser was core-pumped with a 1 W Yb-doped singlemode fibre laser.

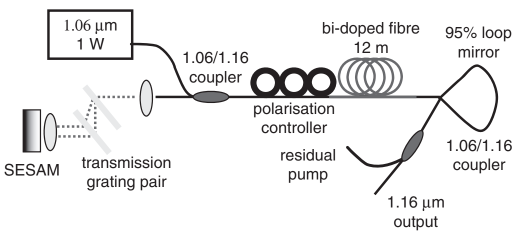

Fig. 1 *Cavity setup of modelocked Bi-doped fibre laser*

The Bi-doped silica fibre was drawn from a preform synthesised by the surface-plasma chemical vapour deposition (SPCVD) method under oxygen deficiency. The core glass was composed of 97 mol:% of SiO_2 and 3 mol:% of Al_2O_3. The bismuth concentration in the core glass was $\sim 3 \times 10^{18}$ cm^{-3}. The glass composition and the bismuth concentration were determined by an X-ray microprobe analysis. The fibre has an outer diameter of 125 µm, a core diameter of 8.4 µm, a core/cladding refractive index difference of $\Delta n = 5.5 \times 10^{-3}$, and a cutoff wavelength of ~1100 nm [12].

The length of the doped fibre was optimised in order to achieve efficient pump absorption and, consequently, sufficient gain, while minimising the length and dispersion of the fibre section of the cavity. The splice loss to a standard singlemode fibre was ~0.3 dB. The overall cavity losses were further minimised using a loop mirror and a pump coupler with high reflectivity and extinction ratio, respectively. An additional dichroic fibre coupler was used at the output of the laser to separate the residual pump and the signal light.

The normal group velocity dispersion (GVD) of the optical fibre at 1.16 µm wavelength range was compensated for by a transmission grating pair with 1250 lines/mm and a grating separation of ~19 mm. A polarisation controller was used to prevent the decrease in the diffraction efficiency of the grating pair. The GaInNAs-based semiconductor saturable absorber mirror grown by solid source molecular beam epitaxy ensured a self-starting passive modelocking [13]. The SESAM consisted of four GaInNAs quantum wells with a width of 6 nm grown on top of 24.5 pair GaAs/AlAs DBR. The DBR stopband had a centre wavelength of ~1140 nm with approximately a 150 nm bandwidth. The absorption recovery time of the SESAM was ~2 ps.

Results: Our cavity design enabled stable short-pulse operation with a repetition rate of 7.5 MHz. A typical pulse train observed with an oscilloscope is shown in Fig. 2. The autocorrelation trace and the corresponding sech^2-fit, shown in Fig. 3, reveal a pulse duration of 0.94 ps. The aperture of the objective, focusing the beam onto SESAM, provides spatial filtering of wavelength components dispersed by the grating pair. A continuous wavelength tuning, in the range 1153–1170 nm, could be achieved by moving the objective in the transverse direction. Fig. 4 presents the tunable spectra with spectral width of ~2.0 nm. The average cavity dispersion was estimated to be ~ -0.4 ps^2 [14]; it consists of double-pass fibre dispersion of ~0.3 ps^2 and double-pass grating dispersion of ~ -0.7 ps^2. The typical pulse energy of the laser was ~0.2 nJ. At the loop mirror output the pulses acquire a small chirp resulting in a time–bandwidth product of 0.40. This small chirp could be expected from the cavity dispersion map, which includes pulse propagation over long fibre in the cavity and in an output pigtail that comprises an additional fibre coupler for separation of residual pump light.

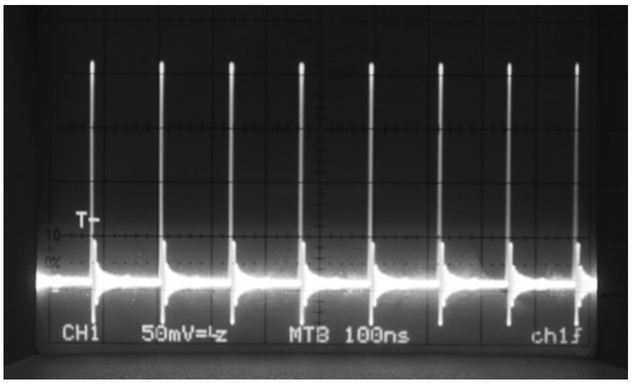

Fig. 2 *Oscilloscope picture of generated pulse train*

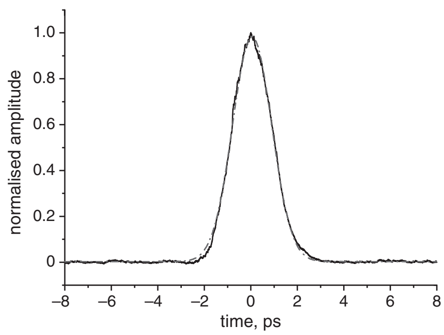

Fig. 3 *Autocorrelation trace (line) fitted with sech^2 function (dashed line)*
Pulse width is 0.94 ps

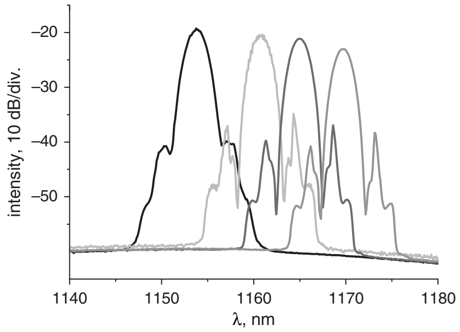

Fig. 4 *Tunable optical spectra*
Spectral width is 2 nm

Conclusion: A modelocked subpicosecond soliton Bi-doped fibre laser is demonstrated. The laser delivers nearly transform-limited ~0.9 ps pulses tunable in the wavelength range 1153–1170 nm. These record short pulses from a Bi-doped fibre laser are achieved with careful cavity design incorporating a fast dilute nitride SESAM and a transmission grating pair. This is an important step towards practical demonstration of pulsed Bi-doped fibre lasers operating in the 1150–1480 nm range.

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