

LETTERS

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Femtosecond fibre laser with a hybrid linear – ring cavity

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***Abstract*. A new type of a femtosecond self-mode-locked erbium fibre laser is proposed and fabricated. The original hybrid design of the laser cavity taking advantage of ring and linear cavity lasers allows continuous tuning of the pulse repetition rate in a broad range (more that 30 kHz) and provides a high reliability of the self-mode-locking regime.**

Keywords: *self-mode-locking, femtosecond fibre laser*.

Femtosecond fibre lasers can be successfully used to solve many fundamental and applied problems [1, 2]. Compared to conventional lasers on volume elements, they are more compact, reliable and have a high efficiency. Of special interest are all-fibre femtosecond lasers without precision optomechanical elements, because the cavities of these lasers are not subjected to misalignment due to vibrations, mechanical and thermal relaxation processes. The mode-locking regime in all-fibre femtosecond erbium lasers is very stable. Unfortunately, such lasers are technologically difficult to fabricate with a high precision for the specified pulse repetition rate, whose tuning range (by the fibre stretching) is very small (usually several hundreds of hertz) [3]. If a broader tuning range is required, the fibre cavity should have a break whose length is controlled; however, this break deteriorates the stability and reliability of the design. Non-fibre coupling out of radiation from the cavity [4, 5] can be also treated as a disadvantage for the majority of self-mode-locked fibre lasers with a controlled cavity length.

The aim of this paper is to develop a stable highly reliable self-mode-locked fibre laser having a broad range of continuous tuning of the pulse repetition rate, a fibre output coupler and a minimum number of volume optical elements in the cavity. The proposed design is based on the combination of ring and linear cavity lasers, which allows one to combine their advantages such as travelling-wave regime, the possibility of obtaining high repetition rates, and simplicity of tuning.

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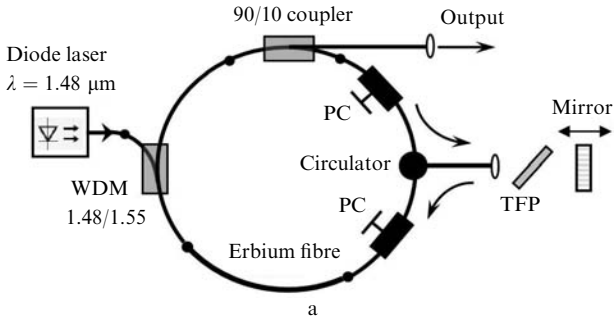
Figure 1a shows the scheme of the femtosecond fibre erbium laser. The cavity consists of two parts: an all-fibre ring part and a short linear segment with only two volume elements. The both parts of the cavity are coupled through a fibreoptic circulator, which plays the role of an optical diode for the ring part providing unidirectional lasing. A highly reflecting mirror confining the linear part of the cavity is glued to the piezoceramic translator, which is fixed on a precision translation stage. The displacement of the mirror changes the cavity length, thereby varying continuously the pulse repetition rate.

As an active waveguide we used in the laser a heavily-doped erbium fibre of length 1.8 m (LIEKKI) with the absorption coefficient 40 ± 4 dB m^{-1} at 1530 nm. Radiation is coupled out from the cavity through the 10-% fibre coupler. The self-mode locking is realised as in classical femtosecond fibre lasers – due to the effect of nonlinear polarisation rotation [5, 6]. A thin-film polariser placed in



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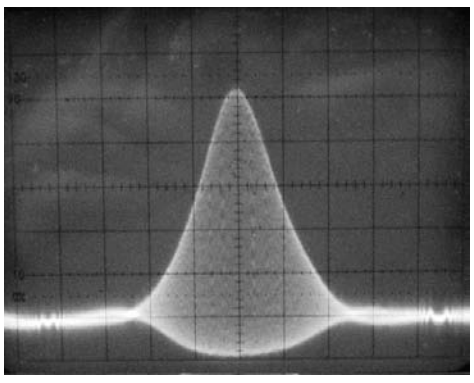

b

Figure 1. Scheme of the laser cavity (WDM – wavelength division multiplexer; PC – polarisation controller; TFP – thin-film polariser) (a) and autocorrelation function of a pulse (b).

front of the highly reflecting mirror in the linear part of the cavity served as a polarisation discriminator. To trigger the mode-locking regime, a slight perturbation of the cavity is required, for example, tapping the highly reflecting mirror mount. This regime was also triggered with the help of an electric pulse supplied to the piezoceramic translator.

The main parameters of the laser radiation are typical of fibre erbium self-mode-locked lasers. The average output power of the laser is about 20 mW for the pump power of 350 mW. The pump power at which the stable self-mode-locking regime is observed varies in the region from 250 to 350 mW. The central emission wavelength is 1565 nm. The FWHM of the optical spectrum in the self-mode-locking regime is about 15 nm and without self-mode-locking – less than 1 nm. The optical spectrum has a shape typical of soliton generation. The formation of an optical soliton in the laser is explained by the negative (anomalous) total intracavity group velocity dispersion at the lasing wavelength ($\sum \beta_2 \approx -0.04$ ps^2) [6]. For the present level of the intracavity power, the highest order solitons do not appear, therefore the single pulse regime on the cavity period and a high stability of the repetition rate are provided.

The pulse duration measured with an interference autocorrelator is about 200 fs (Fig. 1b), the fundamental pulse repetition rate of this laser is 30.4 MHz. The continuous tuning range of the pulse repetition rate exceeds 30 kHz and is restricted by the full travel of the precision translation stage (5 mm). The mode-locking regime is preserved upon continuous tuning of the pulse repetition rate. The accuracy of the mechanical frequency tuning is determined by the division value of the micrometer screw (10 μm) and is ~ 60 Hz. A finer frequency tuning can be performed with the help of a piezoceramic translator (with the sensitivity of ~ 30 mHz V^{-1}) on which the mirror was glued. Due to design restrictions (optimal ratio of the fibre lengths with the dispersion of different signs) and technological restrictions (splicing of short fibres) the proposed type of the laser can have the fundamental pulse repetition rate of approximately 20 – 100 MHz.

The study of frequency parameters of the laser revealed a good spectral purity and stability of intermode beatings: the signal-to-noise ratio of intermode beatings exceeds 70 dB, short-term stability of the intermode frequency is no worse than 1 Hz (the analyser resolution), the frequency drift (due to the absence of laser thermostabilisation) is no more than 30 Hz hour^{-1}. The laser has a high stability of the self-mode-locking regime: under laboratory conditions the continuous self-mode locking was observed within the entire working day without the use of any vibroacoustic isolation of the laser.

Thus, we have developed and studied a new type of a femtosecond fibre self-mode-locked erbium laser, which, due to the original hybrid cavity design, combines the advantages of a ring and linear laser. The most significant advantage of the proposed design is the possibility of continuous tuning of the pulse repetition rate in a broad range (more than 30 kHz) with a high (subhertz) accuracy as well as the high reliability of the self-mode-locking regime and simplicity of tuning.

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References

1. Adler F. et al. *Opt. Express*, **12** (24), 5872 (2004).
2. Gubin M.A. et al. *Laser Phys.*, **17** (11), 1286 (2007).
3. Inaba H. et al. *Opt. Express*, **14** (12), 5223 (2006).
4. Fermann M.E. et al. *Opt. Lett.*, **19** (1), 43 (1994).
5. Nelson L.E. et al. *Appl.Phys. B*, **65**, 277 (1997).
6. Tausenev A.V., Kryukov P.G. *Kvantovaya Elektron.*, **34** (2), 106 (2004) [*Quantum Electron.*, **34** (2), 106 (2004)].