Mode-locked Er fibre laser with variable wave plate based on liquid crystal

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Abstract: Use of half-wave liquid crystal variable retarder in Er fibre lasers mode-locked by non-linear polarisation evolution enables control over mode locking and stabilisation of its parameters by controlling the amplitude of satellites of the peak of radio-frequency beating between laser modes.

Application of electrically controllable elements on the basis of liquid crystals in laser cavities allows adjustment of the radiation parameters by variation of liquid crystal properties [1–3]. This work discusses the results of study of a mode-locked Er fibre laser having a half-wave liquid crystal variable retarder as one of its polarisation control elements.

The optical layout of the laser in question is presented in Fig. 1. The ring cavity of the oscillator included a 2.6-m stretch of active fibre, 20 m of passive fibre MetroCor, fibre isolator, polarisation beam splitter (PBS), mechanical polarisation controller (PC), fibre-coupled U-bench with variable wave plate based on liquid crystal (LC) and a fixed quarter-wave plate, as well as a WDM for coupling of single-mode pump radiation into the core of the active fibre. Typical output of the laser was 5–7 mW at 1.56 μm when pumped with 70 mW at 975 nm. Pulse repetition rate was 8.1 MHz, and the pulse duration did not exceed 400 ps (upper estimate obtained with a high-speed oscilloscope). The output laser spectrum is shown in Fig. 2.

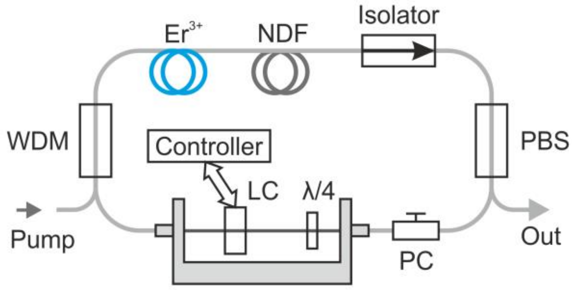


Fig. 1. Optical layout of the studied mode-locked Er fibre laser.

Preliminary adjustment of the laser to trigger mode locking by the effect of non-linear polarisation evolution (NPE) was effected through the in-line mechanical fibre polarisation controller. Further on, it was possible to examine the stability region of the mode-locked operation and to optimise its parameters by changing birefringence of the nematic LC cell, installed on the U-bench. The magnitude of a radio-frequency (RF) peak generated by beating between laser modes was selected as one of the laser parameters most sensitive to changes in birefringence of the LC cell. In order to improve the signal-to-noise ratio, this magnitude was measured around 500 MHz (the corresponding peak was generated by far-spaced laser modes). The dependence of this parameter on the voltage supplied to the liquid crystal cell is given in Fig. 3.

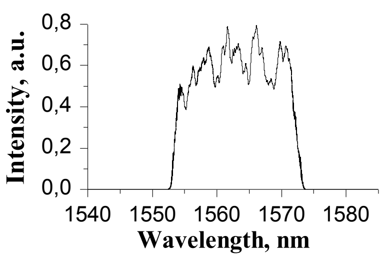


Fig. 2. Laser output spectrum

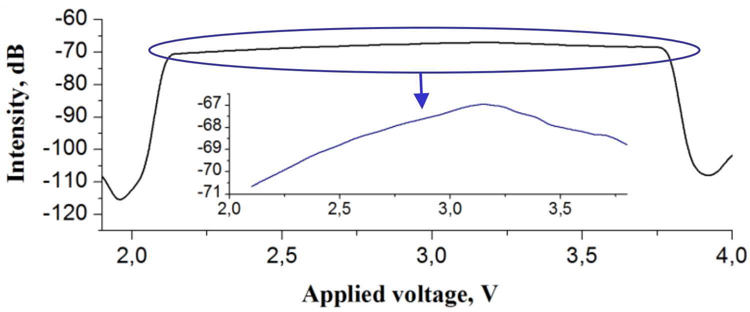
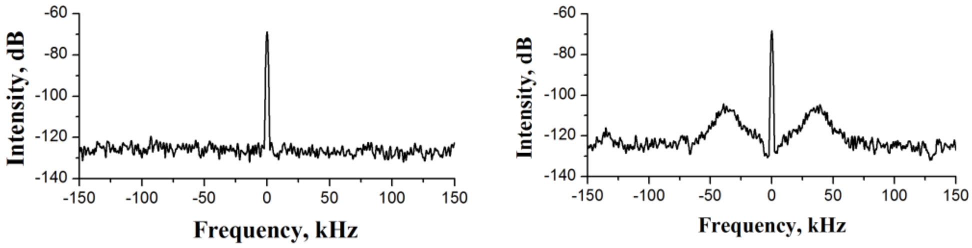


Fig. 3. Experimental dependence of the RF inter-mode beat intensity in the laser output around 500 MHz upon the voltage applied to the liquid crystal cell.

The data presented in Fig. 3 indicate that mode locking is preserved across a certain interval of LC cell birefringence values. However, within this interval, there is a distinctive dependence of the amplitude of the RF inter-mode beat peak upon the voltage applied to the LC cell with a well-defined maximum. This maximum corresponds to the most stable mode-locking operation in the absence of any side features in the RF beat spectrum (Fig. 4a). As the peak amplitude shifted from its maximum (driven by variation of birefringence in the liquid crystal cell) the mode locking stability deteriorated and satellite peaks could appear in the RF inter-mode beat spectrum on both sides of the main peak (Fig. 4b).



a b

Fig. 4. RF inter-mode beat laser spectrum around 8,1 MHz typical of the most stable (a) and less stable mode-locked operation.

Measured around the main frequency (8.1 MHz) in the RF spectrum, the dependence of the inter-mode beat peak amplitude on the voltage supplied to the liquid crystal cell exhibits no well-defined maximum. At the same time, within the range of birefringence values of the LC cell that preserve mode locking, there is a distinct dependence of the amplitude of side features observed around the main RF inter-mode beat peak upon the voltage supplied to the LC cell with well-defined minimum (Fig. 5).

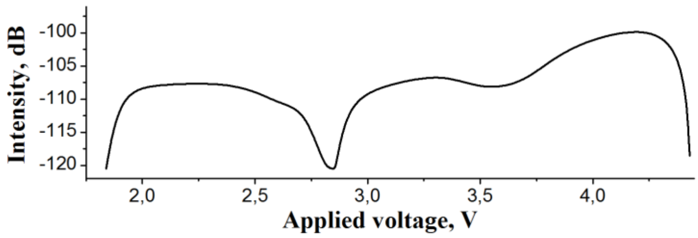


Fig. 5. Dependence of the inter-mode beat peak amplitude in the vicinity of main frequency (8.1MHz) upon the voltage supplied to the liquid crystal cell.

The findings presented in this work demonstrate that electrically tuned liquid crystal cells may be used in fibre lasers mode-locked by NPE for automatic tuning of mode-locked operation for best stability. The dependence upon the voltage applied to the liquid crystal cell of both the amplitude of a RF inter-mode beat peak far from the main frequency and that of satellite features to the inter-mode beat peak on the main frequency can be used to provide the error signal.

Fibre lasers mode-locked by NPE do not feature high long-term stability due to changes in the laser cavity birefringence arising from such factors as variations of the ambient temperature, mechanical creep of polarisation controllers, etc. Self-tuning of mode-locked operation to the best stability parameters in fibre lasers mode-locked by NPE with the help of actively controlled liquid crystal cells will allow efficient compensation of long-term birefringence variations in the laser cavity.

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