Noise Characterization of a Mode-Locked, All-Fiber, All-Normal-Dispersion Ytterbium Ring Oscillator Using Two-Channel Polarization Control by a Computer

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Abstract: Mode-locked operation of an all-fiber, all-normal dispersion Yb-fiber ring laser is actively optimized by a two-channel polarization controller according to the measured, normalised, single-sideband noise power.

OCIS codes: (140.3510) Lasers, fiber, (140.3615) Lasers, ytterbium, (140.7090) Lasers, ultrafast

1. Introduction

Passively mode-locked fiber lasers have gained scientific interest because of their potentially compact, environmentally stable and alignment-free design. Mode-locked operation of an Yb-fiber laser operating at around 1 micron can be obtained either in the net positive or negative dispersion regime. The former solution typically results in a more compact cavity design, since there is no need for intra-cavity dispersion compensating elements such as a grating pair, prism pair, a hollow-core photonic crystal fiber, a higher-order mode fiber or a chirped fiber grating. Stable, cw mode-locked operation of an all-fiber, all-normal-dispersion ring laser, however, requires spectral filtering of the pulses. In [1], it was obtained by a fiber-integrated spectral filter having a spectral bandwidth of ~15 nm. Recently, we also reported on an all-fiber, all-normal dispersion ring oscillator where pulse-shaping was based on nonlinear polarization rotation in the fiber together with spectral and temporal filtering by a fiber integrated polarizing element [2]. In the experiment, fiber-polarization controllers were used, in which the different paddles were manually set for optimum cw mode-locked operation of the laser.

In this paper, we report on a similar all-fiber, all-normal-dispersion Yb ring oscillator, in which the polarization controller element is replaced by an electronically controllable device. This simple upgrade in the laser setup, together with some improvement in the laser control electronics and data analysis hardware and software, allowed us to perform a detailed analysis on the mode-locked laser performance as the function of different polarization states of the optical pulses reaching the fiber integrated polarization element. Based on such an analysis, one can precisely control the mode-locked operation of an all-fiber, all-normal dispersion Yb-fiber ring laser, or any other laser of a similar kind.

2. Experimental setup

The laser setup is shown in Fig. 1. A highly doped ytterbium fiber (Yb) is used as the gain media, which is pumped by a 980 nm laser diode (LD) via a 980/1030 nm wavelength-division multiplexer (WDM). The Yb-doped fiber is followed by an isolator (ISO) realizing the unidirectional cavity. The initiation and stabilization of mode-locking is obtained by application of a semiconductor saturable absorber (SA). Between the SA and the polarizing beam splitter (PBS), we placed the new, electronically adjustable polarization controller (PC, Type: PolaRITE III - Mini dynamic polarization controller, product of General Photonics). The rest of the components are the same that were reported in [2].

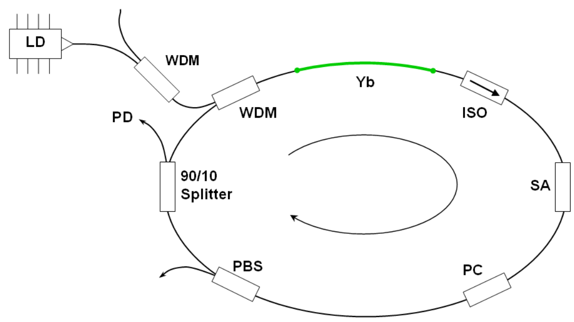

Fig. 1 Laser setup

The nonlinear polarization evolution of the optical pulses results in a variation of the polarization state along the pulse spectrum, leading to a strong spectral filtering effect by the PBS [2]. The PBS is followed by a 90%-10% splitter, where the 10% output port is directed to a fast photodiode (PD, Type: DET10C/M, product of Thorlabs).

3. Results

The laser output detected by the fast photodiode (PD) is analysed by a radio-frequency spectrum analyser (FSV3, product of Rohde&Schwarz). Depending on the contol voltage values of the polarization controller (PC), we can obtain cw mode-locked, Q-switched or noise-like pulse, as shown in Fig. 2. The laser repetition rate is 26.267 MHz, the radio-frequency spectrum is measured over a 2 MHz bandwidth around the laser central frequency.

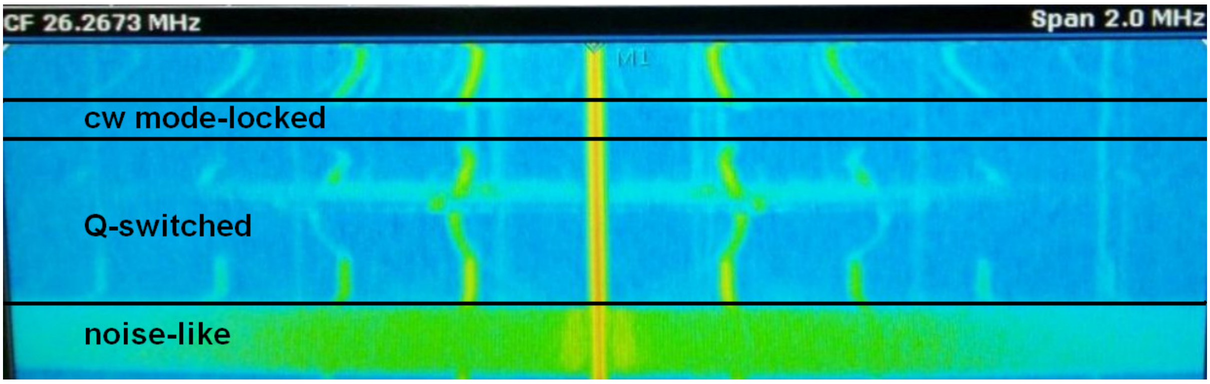

Fig. 2 Measured radio-frequency power spectrum at around the central frequency of the all-fiber, all-normal-dispersion Yb-fiber ring laser

Unfortunately, the radio-frequency spectra measured by the spectrum analyser can not be directly used for optimiziation of the cw mode-locked performance of the laser by setting the contol voltages of the polarization controller by a computer or a microcontroller. In order to solve this problem, we have developed high sensitivity, radio-frequency amplifiers and filters providing electronic signals proportional to the measured signal power (P_{signal}) and the measured single sideband noise power (P_{noise}). Taking the advantage of this new electronics, we could easily measure P_{signal} and P_{noise} as the function of the control voltages applied on the polarization controller device, as shown in Fig. 3. Please note that this function is periodic for both the Quarter-Wave Plate Control Voltage (horizontal axis) and the Half-Wave Plate Control Voltage (vertical axis), and only one period is displayed in Fig. 3.

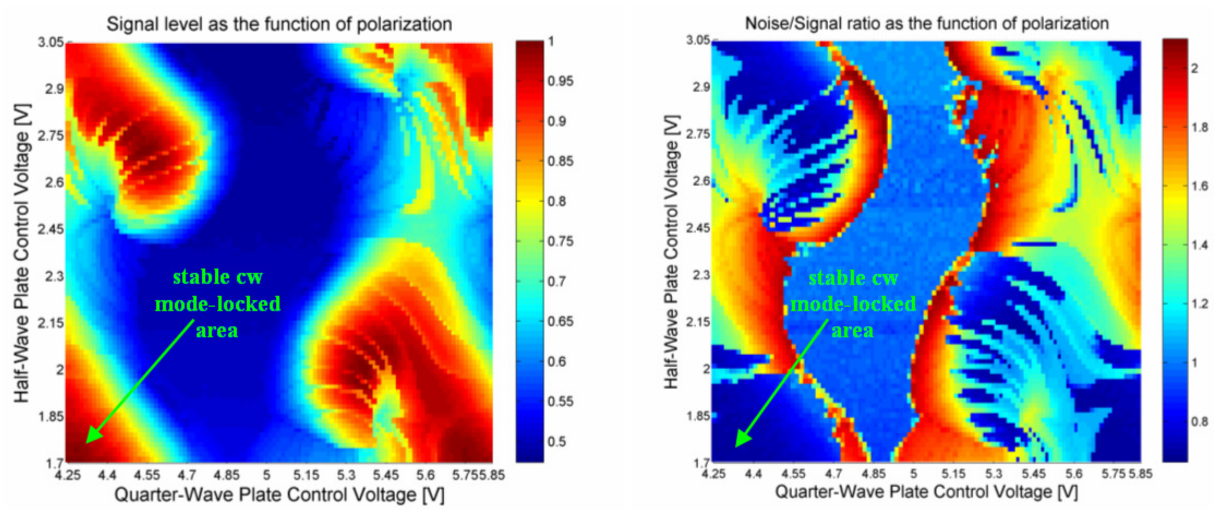

Fig. 3 Measured signal power (left) and normalized noise power (right) as the function of control voltage on the polarization controllers.

For stable cw mode-locked operation of the Yb-fiber laser, we require high signal levels (high P_{signal} values) and low rms noise (low P_{noise}) values. This requirement can be easily visualized if we plot the normalized noise power (P_{noise} /P_{signal}) as the function of control voltage values (see Fig. 3, right). The stable cw mode-locked operation area is indicated by a dark blue color in this Figure. During the experiments with our new laser setup and electronics, we had several interesting findings, which are summarized as follows: first of all, the shape of the "stability maps" that are shown in Fig. 3 were significantly different depending on the pump power, length of the SM fiber in front of the PBS, the round-trip time of the laser and other parameters, such as the method of rolling up of the fiber onto the holder mechanics. Without going into details, it is important to note that large stable cw-mode locked areas could be obtained only if we rolled up the optical fiber in a figure-8 configuration and provided sufficiently high pump power for the Yb-oscillator. In order to come to a stable laser configuration, such as demonstrated in Fig. 3, we preferred to take several "stability maps" during the different stages of the mechanical fixing of the optical fibers and components, and correct the configuration accordingly. Having the laser configuration fixed and the final "stability maps" recorded, we could easily find the optimum control voltage values of the polarization controller, for which the laser operated in the cw mode-locked regime at the highest average signal and the lowest noise power levels (shown in Fig. 3 by arrows).

There are two additional issues that should be mentioned before using the method introduced for computer or microcontroller control of an all-fiber, all-normal dispersion Yb-fiber ring oscillator for everyday use. Firstly, the Yb-fiber laser tested (and the corresponding stability map) had some thermal drift according to the temperature change in the laboratory, even if all of the optical components and fibers were fixed in the housing. This fact requires a continuous, fine re-adjustment of the polarization control voltages during the operation of the laser in order to keep the highest signal to noise ratios. Secondly, the all-fiber, all-normal dispersion Yb-fiber ring oscillator reported here had some inherent nonlinearity, which resulted in an optically bistable behaviour [3], as demonstrated in Fig. 4. For recording the „stability maps" shown in Fig. 4, the quarter-wave plate control voltage values (horizontal axis) were increased and reduced for the even and odd rows, respectively. It is clearly seen that the cw mode-locked status of the laser had a feedback to the stability maps (the stable/unstable borders were slightly shifted), which fact arises additional challenges when writing a computer code for laser control.

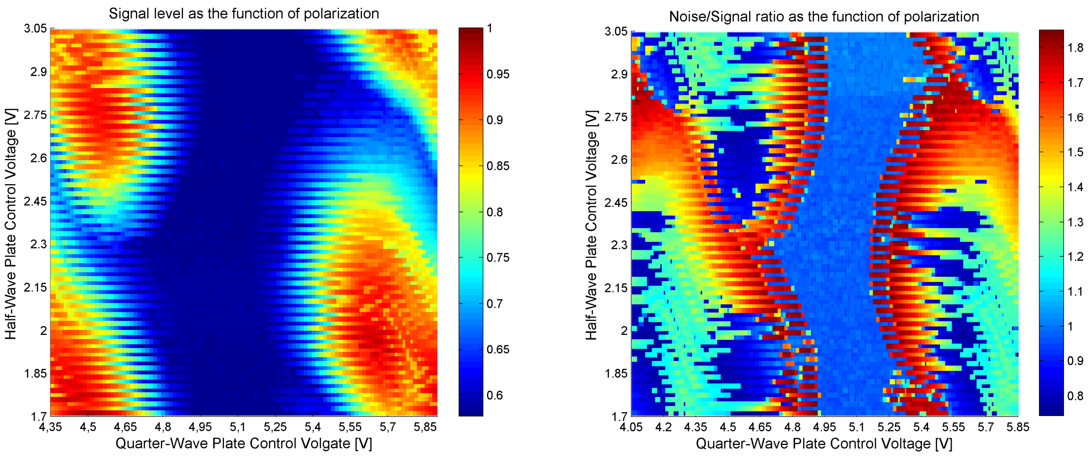

Fig. 4 Demonstration of optical bistability of the all-fiber, all-normal dispersion Yb-fiber ring oscillator. Parameters are the same than in Fig. 3, but the data plotted were recorded for increasing and reducing quarter-wave plate control voltages for even and odd rows, respectively.

In spite of the difficulties mentioned above, we are convinced that the information obtained by the application of our newly developed electro-optic and electronic devices can be well suited for active polarization control of Yb-fiber oscillators to assure drop-out-free, stable, cw mode-locked operation at low RMS noise levels, which might be a critical issue in different applications such as nonlinear microscopy.

4. References

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