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Microarticle

Self-injection locking of the DFB laser through an external ring fiber cavity: Polarization behavior

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ABSTRACT

We study stability of self-injection locking realized with DFB laser coupled with an external fiber optic ring cavity. Polarization behavior of the radiation circulating in the feedback loop is reported. Two regimes of mode hopping have been observed; one of them is accompanied by polarization bistability involving two orthogonal polarization states.

Self-injection locking is an efficient technique used to improve the spectral and polarization performance of semiconductor lasers attractive for many applications in optical communication and sensing [1,2]. Recently, we have demonstrated significant line-narrowing (more than 1000 times) of the DFB laser locked to an external fiber optic ring resonator (FORR) [3]. In particular, such configurations are of great interest for narrow-band Brillouin lasers based on the cavities simultaneously resonant for pump and Stokes waves [4–6]. Although it is commonly accepted that the polarization behavior could significantly affect the stability of lasing, the effect of polarization mode-hopping taking place in the external cavity has not been reported in previous works. Here, we demonstrate specific features of the polarization evolution of the light circulating in the feedback loop used for injection locking of the DFB laser [3].

Fig. 1 presents the experimental configuration of the DFB laser coupled with an external fiber optic ring cavity. Light emitted by DFB laser operating power of 1.5 mw at 1535 nm passes an optical circulator (OC) and is introduced through the coupler C1 into the FORR. The FORR comprises a variable ratio coupler (VRC), coupler C2, and ~4 m length of standard telecommunication SMF-28 fiber. The coupler C2 is used to redirect a part of the power circulating in the FORR through coupler C3 and circulator OC back into the DFB laser providing a feedback to DFB laser operation. When the optical switcher (OS) is open the DFB laser gets locked with the FORR resonant frequency. The variable rate coupler VRC is adjusted (~96/4) to provide this operation in the critical coupling regime [3].

Fig. 2 presents oscilloscope traces recorded with the laser configuration intentionally unprotected from environment noise to observe laser instabilities in a shorter time scale. They are similar to those already discussed in [3]. The signals at port A, B, C reproduce the laser output power, reflected power (i.e. the part of the laser power that is out of resonance with the FORR) and transmitted power (used for DFB laser feedback), respectively. Usually, a stable self-injection locking regime is observed during 1–100 s (depending on environment noise level) and periodically interrupted by mode-hopping events. In this regime the frequency of the DFB laser is locked to the FORR resonance frequency, so the level of the reflected power (port B) is minimal and the level of the power circulating inside the FORR (recorded through port C) is maximal. Before mode-hopping occurs, the frequency locking becomes weaker (probably, due to a thermal fluctuation) and so the power inside the FORR recorded in port C decreases. At some moment this decrease is interrupted by a short jump of power to a higher level highlighting the laser mode-hopping. Such behavior of the transmitted pump power is accompanied by an inverse behavior of the reflected power (port B). These are general features. However, we observed two different regimes in this behavior. The difference between two regimes is the significantly different time the system takes to recover steady-state operation during the

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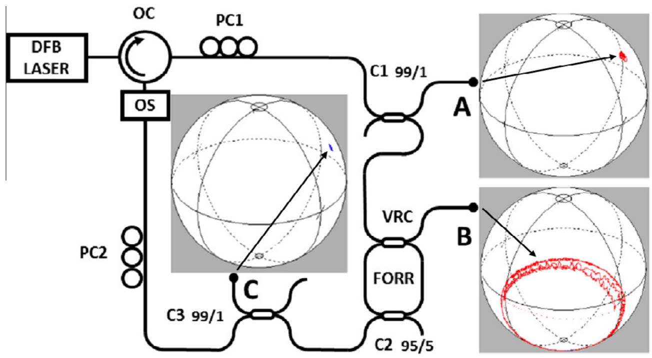

Fig. 1. The experimental configuration and polarization behavior of light circulating in the feedback loop (ports A, B and C); OS – optical switcher, OC – optical circulator, PC – polarization controller, C – coupler, VRC – variable ratio coupler, FORR – fiber-optic ring resonator. Arrows show the measured polarization states.

mode-hopping event. In the first most common regime, this time is rather large, typically ~5 ms. In the second, the typical recovery time is ~100 μs. Besides, in the first regime, the jumps observed from ports B and C are accompanied by a step-like jump of the laser power (~1–5%) recorded in port A, while in the second regime the output laser power does not change remarkably. The traces shown in Fig. 2 have been selected to illustrate two consequent mode-hopping events relating to different regimes, although commonly these two regimes are not mixed.

In order to clarify the physical mechanisms attributed to these regimes the polarization states of light circulating in the DFB laser configuration have been monitored in ports A, B and C synchronously with recording of the oscilloscope traces. The results corresponding to different regimes are shown in Figs. 1 and 2, respectively. First of all, we have to conclude that the state of polarization of the DFB laser does not change in both regimes. It can be seen as a stationary point in Poincare sphere relating to port A. Monitoring of the reflected light polarization state (port B) in both cases shows that the Stokes vector exhibits periodic precession as shown in Fig. 1. The period of precession coincides the period of mode-hopping in the first regime. This feature could be attributed to any slow processes like environment thermal fluctuations affecting birefringence of the fiber and, simultaneously, detuning the FORR resonant frequency. When this FORR frequency deviation becomes large enough, the laser changes its frequency to the nearest resonant mode of the FORR causing mode-hopping events observed in the oscilloscope traces [3]. This explains why the period of polarization state behavior and mode-hopping events are synchronized. Importantly, this dynamics does not affect the polarization of light transmitted through the FORR (that is used as a feedback to the DFB laser operation) represented as a stationary point in Poincare sphere (port C).

In the second regime, the polarization behavior observed in ports A and B are nearly the same as described, but light polarization in the FORR observed from the output C exhibits flip-flop switching between two orthogonal polarization states, i.e. polarization mode-hopping takes place. Surprisingly, this behavior does not affect the laser output power and its polarization state observed in port A. The period of the flip-flop switching between two states coincides with the period of jumps observed in oscilloscope traces recorded in ports B and C. Importantly, the time the system takes to recover steady-state operation during polarization mode-hopping is much less than this time in the case of mode-hopping between FORR modes of nearest orders.

In conclusion, we have presented polarization behavior of light circulating in the feedback loop used for injection-locking operation of the DFB laser. Two regimes of mode hopping have been observed. We suggest that one of them is attributed to hopping between FORR modes of nearest orders, but of the same polarization, while the second is between different polarization modes of the same order. The difference between them is the recovery time the system gets the steady-state operation after mode-hopping events. We believe the reported experimental results will contribute to better understanding of the physical mechanisms responsible for instabilities in such kinds of laser systems.

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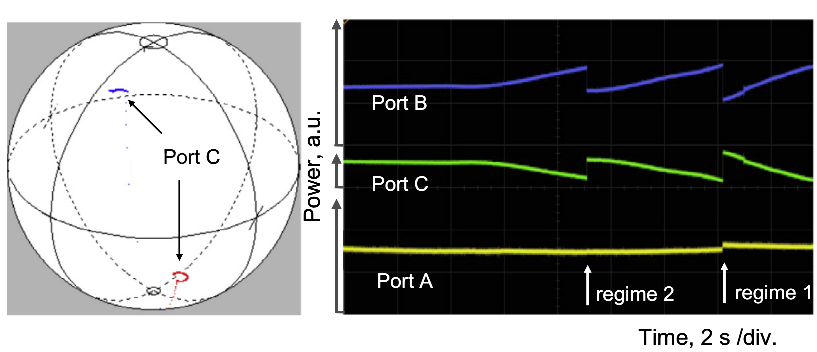

Fig. 2. Flip-flop behavior of the polarization state of the transmitted power (port C) in the second regime and oscilloscope traces recorded in ports A, B, and C. The traces have been selected to illustrate two different mode-hopping regimes, although commonly these two regimes are not mixed. Arrows show the measured polarization states (left) and mode-hopping events (right).