Soliton Patterns Formation in Fiber Lasers

F. Sanchez[1]*, M. Salhi[1], A. Komarov[1,2], F. Amrani[1], A. Niang[1]
[1]Laboratoire de Photonique E.A. 4644, Université d'Angers, Angers, France
[2]Institute of Automation and Electrometry SB RAS, Novosibirsk, Russia
**e-mail address: francois.sanchez@univ-angers.fr*

The history of the interaction of dissipative solitons started in 1991 when it was predicted the existence of bound solitons as a consequence of a direct interaction between solitons [1]. In its simplest form, a bound state of solitons consists in a couple of identical solitons with constant temporal delay and with constant phase difference. Further works mainly concerned theoretical results on bound states of two or a few solitons (about 10), using several versions of the complex Ginzburg–Landau equation and coupled nonlinear Schrödinger equations. The scaling up of the power in fiber lasers has recently permitted the experimental observation of a soliton crystal which is a bound state of hundreds of solitons filling a small part of the cavity [2]. Because standard models fail to describe such large number of bounded pulses, alternative models have been recently proposed. New fascinating states involving hundreds of solitons have been recently reported [3]. Such states have been classified using a formal analogy with the state of the matter. It has been introduced the notion of soliton liquid, soliton polycristal and soliton crystal. These results open a new field of investigation which concerns the interaction of a large number of ultrashort pulses including the understanding of the dynamics of birth and collapse of solitons.

In this communication I will present spectacular soliton patterns that we have experimentally obtained in passively mode-locked erbium-doped double-clad fiber lasers. In a first part I will consider the case of a 1 W fiber amplifier passively mode-locked through nonlinear polarization rotation (NLPR) where a soliton crystal, a soliton polycristal and a soliton liquid have been observed. Examples of the temporal traces are given in Fig. 1. Figure 1(a) corresponds to a soliton crystal which consists in a bound-state of hundreds of solitons. The resolution of the oscilloscope allows only visualizing the envelope of the signal. The inset shows the autocorrelation trace which reveals the internal structure. Figure 1(b) shows the case of a polycristal which consists in an incoherent and disordered juxtaposition of small soliton crystals. Similar patterns have been obtained in the figure-of-eight configuration where the mode-locking is obtained thanks to a nonlinear amplifying loop mirror [4]. These results suggest that the soliton patterns we have observed could be an intrinsic feature of high-power fiber laser independently of the exact mode-locking mechanism. I will finally consider the case of a 10 W fiber amplifier passively mode-locked through NLPR. We have realized the harmonic passive mode-locking of soliton crystals [5].

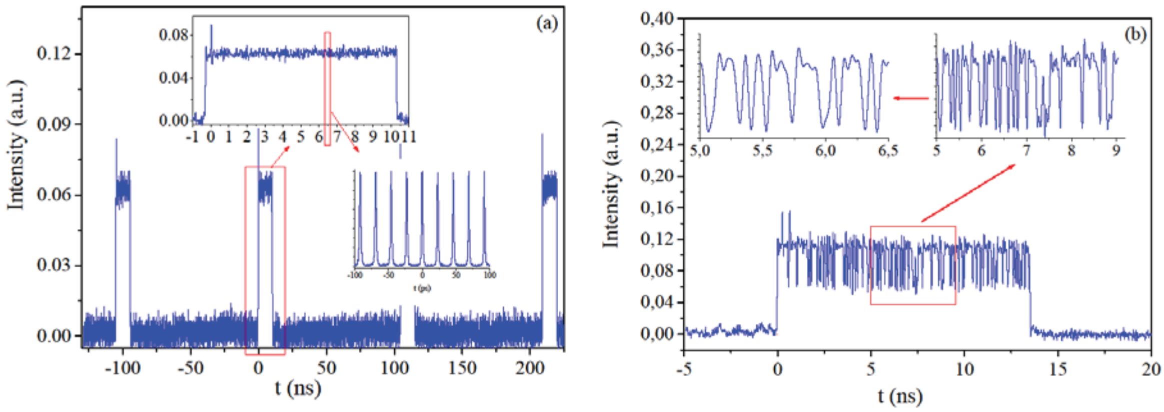

Fig. 1. (a) A soliton crystal with the autocorrelation trace revealing the internal structure of the square signal. (b) A soliton polycristal.

References

[1] B.A. Malomed, “Bound solitons in the nonlinear Schrödinger-Ginzburg-Landau equation”, Phys. Rev. A **44**, 6954 (1991).

[2] A. Haboucha, H. Leblond, M. Salhi, A. Komarov and F. Sanchez, “Analysis of soliton pattern formation in passively mode-locked fiber laser”, Phys. Rev. A **78**, 043806 (2008).

[3] F. Amrani, A. Haboucha, M. Salhi, H. Leblond, A. Komarov and F. Sanchez, “Dissipative solitons compounds in a fiber laser: analogy with the states of the matter”, Appl. Phys. B **99**, 107 (2010).

[4] F. Amrani, M. Salhi, H. Leblond, Ph. Grelu and F. Sanchez, “Universal soliton pattern formation in passively mode-locked fiber lasers”, Opt. Lett. **36**, 1545 (2011).

[5] F. Amrani, A. Niang, M. Salhi, H. Leblond and F. Sanchez, “Passive harmonic mode locking of soliton crystals”, Opt. Lett. **36**, 4239 (2011).