Cavity solitons in GaN waveguide polariton lasers: mode-locking and instabilities

T. Guillet[1,*], V. Develay[1], O. Bahrova[2], H. Souissi[3], C. Brimont[1], L. Doyennette[1], E. Cambril[3], S. Bouchoule[3], B. Alloing[4], J. Zuniga-Perez[4,5], T. Ackemann[6], D. Solnyshkov[2,7], G. Malpuech[2]

[1] Laboratoire Charles Coulomb (L2C), Université de Montpellier, CNRS, France
[2] Université Clermont Auvergne, CNRS, Institut Pascal, Clermont-Ferrand, France
[3] Centre de Nanosciences et de technologies, CNRS, Université Paris-Saclay, France
[4] UCA, CRHEA-CNRS, Rue Bernard Gregory, 06560 Valbonne, France
[5] SUPA and Department of Physics, University of Strathclyde, Glasgow G4 ONG, Scotland, UK
[6] MajuLab, International Research Laboratory IRL 3654, CNRS, UCA, Sorbonne Université
National University of Singapore, Nanyang Technological University, Singapore 117543, Singapore
[6] Institut Universitaire de France (IUF), 75231 Paris, France

The large nonlinearities of exciton-polaritons have been widely exploited in order to control the formation of temporal solitons, initially in microcavities and more recently in waveguides [1]. Within a GaN ridge waveguide forming a Fabry-Perot cavity, with a length of a few tens of microns, we have recently demonstrated a mode-locked polariton laser based on cavity solitons [2], with a very low energy per pulse (5 fJ).

Such waveguide polariton lasers can be optically pumped on a length much shorter than the cavity length since the polariton absorption along the unpumped sections is much smaller than the polaritonic gain arising from the stimulated relaxation of excitons towards the polariton branch in the pumped section (Fig. 1.a,b). During this polariton condensation process, the solitons then form spontaneously as the third order polariton nonlinearity compensates the group velocity dispersion. Figure 1.c presents the emission spectrum of the pulsed polariton laser in a 40 µm-long cavity pumped over 6.5 µm with a line-shaped spot (4 ns pulses at 355 nm): the envelope of the Fabry-Perot modes follows a characteristic secant-hyperbolic lineshape. The pump is resonant with the GaN excitons, which large binding energy and Rabi splitting allow for a stable operation in the strong coupling regime up to 300 K [2]. Interestingly, the cavity soliton becomes instable when the excitation spot is moved away from the cavity center, leading to the simultaneous propagation of two cavity solitons (Fig. 1.d). Longer cavity even lead to the observation of more than 2 solitons. This soliton dynamics can be modeled and understood when solving the Gross-Pitaevskii equations for the coupled exciton-photon system within the waveguide cavity (Fig. 1.e,f).

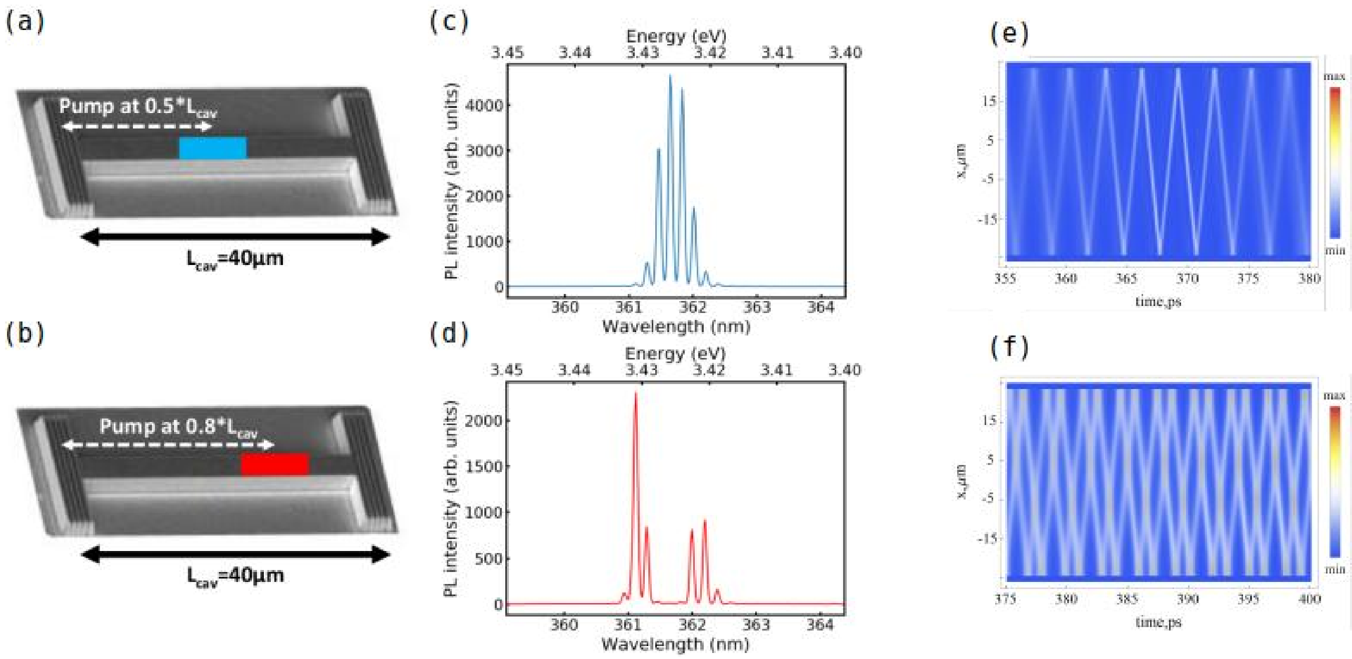

Figure 1: (a,b) Sketch of the optical pumping scheme overlayed on the scanning electron microscopy image of a GaN waveguide polariton laser. The GaN core waveguide stands over an (Al,Ga)N cladding; it is etched into a 1 µm-wide ridge ending with distributed Bragg reflectors. (c,d) Laser emission spectrum at T = 150 K when the 6.5 µm pump is positioned at the center (c) or at 0.8 L_{cav} (d); (e,f) corresponding GPE simulations.

Acknowledgments
Fundings: Horizon 2020 (FET 964770 TopoLight), ANR-21-CE24-0019-01 IDEX-ISITE, 16-IDEX-0001, RENATECH-CNRS

References

[1] P.M. Walker *et al.*, “Ultra-low-power hybrid light–matter solitons”, Nat. Comm. **6**, 8317 (2015)
[2] H. Souissi *et al.*, “Mode-locked waveguide polariton laser”, Optica **11**, 962–970, (2024)

*Email: thierry.guillet@umontpellier.fr