Spontaneously Appearing Polarization Singularities in Vertical-Cavity Lasers with Feedback

Thorsten Ackemann[1], **Thierry Guillet**[2]

1. SUPA and Department of Physics, University of Strathclyde, Glasgow G4 0NG, Scotland, UK

2. Laboratoire Charles Coulomb (L2C), Univ. Montpellier, CNRS, Montpellier, France

Topological states of fluids of light in nonlinear optical devices are attracting a lot of attention. Interest shifts to “fully structured light” with complex intensity, phase and polarization structure [1]. Vector vortex beams (VVB) have singularities in their director field leading to a spatially inhomogeneous polarization structure. As the simultaneous presence of different polarization states demands a high isotropy of the optical setup, their spontaneous emergence is very uncommon but they have been predicted [2] and observed [3] in vertical-cavity surface-emitting lasers (VCSEL). In Ref. [3] it was concluded that many (potentially all) different VVB exist but their mutual stability is dictated by small residual anisotropies. In this contribution, we are investigating this by introducing a controlled anisotropy via a half-wave plate (HWP).

The experimental setup consists of a VCSEL with a 200 µm diameter aperture and feedback from a volume Bragg grating (VBG) in a self-imaging external cavity. The self-focusing nature of the semiconductor nonlinearity leads to the formation of spatial solitons, single-humped fundamental solitons with two orthogonal polarization states at lowest currents and different VVB interpreted as high-order solitons at higher currents.

Turning the HWP introduced into the external cavity, it is apparent that the direction of polarization of the fundamental solitons is rotated in the same way as the HWP is rotated (Fig. 1b). Over most of the range both polarization states can be obtained indicating good isotropy. The exception is a small region centred around a polarization angle $\Psi \approx$ -20° to +20°, which seems to be the least favourable orientation with only the intrinsic anisotropies.

Fig.1a summarizes at what angle of the HWP which type of VVB is observed. Apart from linearly polarized vortex beams, there are VVB with hyperbolic and spiral polarization structure and a state with a spatially inhomogeneous polarization domain structure which is not a VVB. There is no obvious pattern behind the selection but it is interesting to note that only a single type of VVB was found for each angle. The spiral vortex is a robust feature at the appropriate anisotropy, whereas it had been very difficult to obtain in [3] before. At the angles where no VVB or domain structure is reported, the linearly polarized vortex has a vertical polarization. This reenforces the impression that vertical/horizontal polarization corresponds to some maximum polarization anisotropy, and the introduction of the intra-cavity HWP is an efficient way to minimize the effective anisotropy, favorizing the observation of VVBs .

These observations support the notion that all or at least many kind of VVB exist in the system and the anisotropies decide whether are stable and accessible via current ramps. It will be interesting to explore optical pumping where anisotropies should be even lower and to investigate the connection to spin-orbit coupling present in the microcavity and semiconductor spin dynamics.

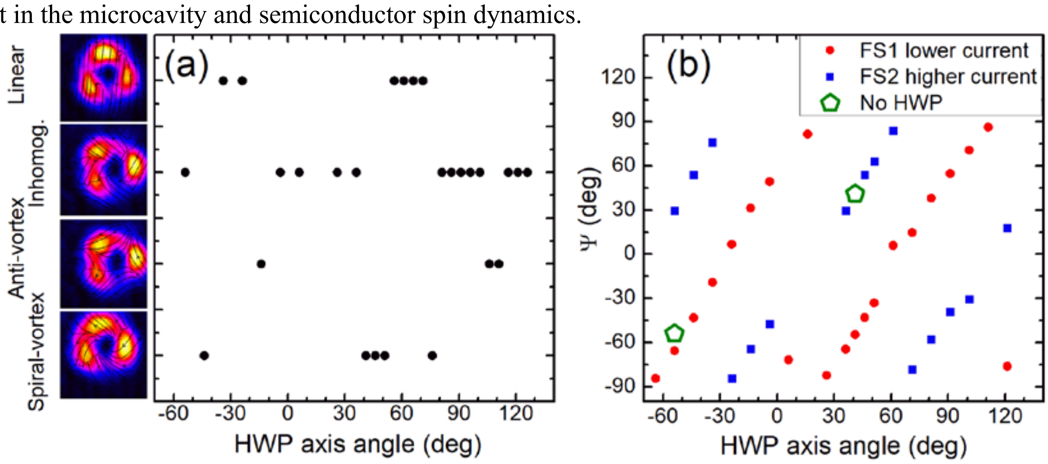

Fig. 1 Influence of an intra-cavity HWP on polarization states. The reference axis for the angles is vertical. a) Indication of which type of VVB is observed, insets show S_0 Stokes parameter and polarization streamlines. b) Red dots denote the main polarization direction Ψ of the fundamental soliton occurring at lower currents, blue of the one at higher current. The green rhombus indicates the selected polarization without HWP.

[1] A. Forbes, “Structured Light from Lasers”, Laser Photonics Rev. **13**, 1900140 (2019)
[2] J. Jimenez, P. Rodriguez, T. Guillet, T. Ackemann, Phys. Rev. Lett. **119**, 113902 (2017)
[3] F. Prati, G. Tissoni, M.S. Miguel, N.B. Abraham, Opt. Commun. **143**, 133 (1997)

This is an accepted author manuscript of the following conference contribution: Ackemann, T., & Guillet, T. (2021). Spontaneously appearing polarization singularities in vertical-cavity lasers with feedback. In 2021 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC) [9541680] (IEEE Explore). IEEE. https://doi.org/10.1109/CLEO/Europe-EQEC52157.2021.9541680