Spontaneously Appearing Vector Vortex Beams in Vertical-Cavity Surface-Emitting Lasers with Feedback

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Beams with a spatially non-uniform distribution of polarization attracted considerable recent interest due to their intrinsic beauty, novel functionalities in quantum optics and newly enabled applications [1]. Typical realizations investigated possess a circular symmetric intensity structure, most often in form of a doughnut, combined with a spatially non-uniform polarization field containing polarization singularities and are referred to as `vector vortex beams'. Typically, considerable engineering effort is necessary to create these non-trivial polarization configurations. In contrast, we report on the spontaneous formation of vector vortex beams in a broad-area vertical-cavity surface-emitting laser (VCSEL) with frequency-selective feedback [2]. In particular, an anti-vortex state with a hyperbolic polarization structure is observed. The relation to vectorial high-order solitons is discussed.

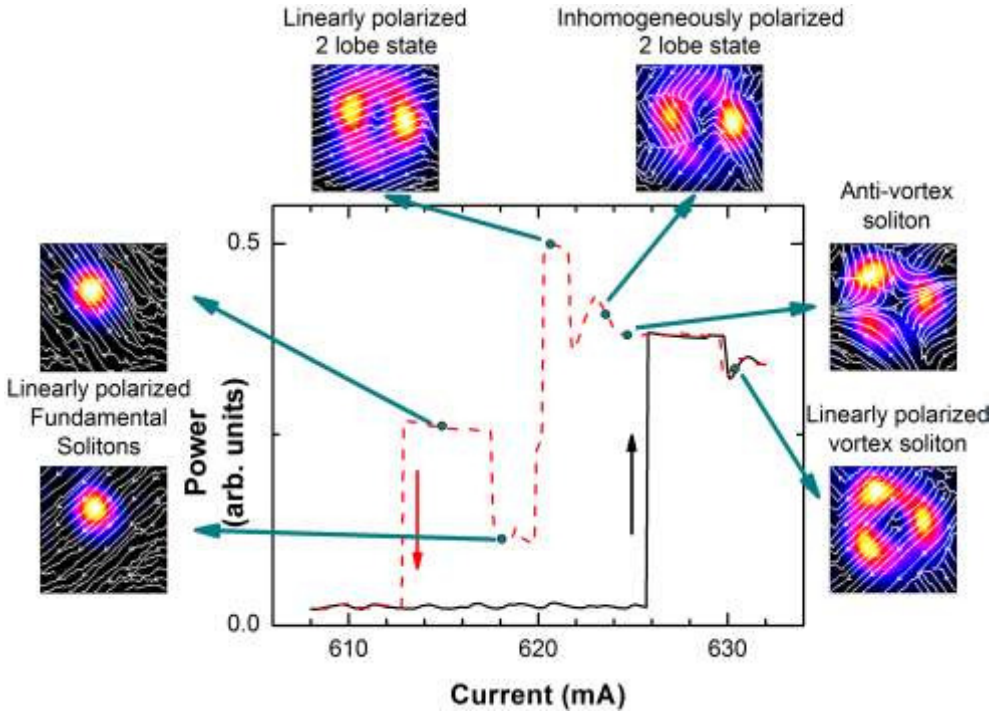

Fig. 1 Light-current characteristic of a VCSEL with frequency selective feedback monitored through a linear polarizer: Up-scan (black) and down scan (red) are very different demonstrating coexistence of structures with the non-lasing solution. The insets depict intensity distributions (S0) in pseudo-colour with the streamlines of local polarization direction underlayed in white. On the left: polarization switching of fundamental soliton. On the right: linearly polarized vortex soliton and anti-vortex soliton with hyperbolic polarization structure.

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. At high substrate temperatures (40°C) the fundamental solitons and high-order solitons (vortices or better azimuthons as the intensity structure is not strictly circularly symmetric but contains three humps) observed are linearly polarized and behave in a quasi-scalar way. Dropping the temperature (20°C) increases the initial detuning between VCSEL resonance and VBG resonance and hence enhances the threshold current (roughly three times). As a result the gain available is much higher and the small polarization anisotropies in VCSEL and setup cannot pin the polarization state any more.

We observe polarization switching between fundamental solitons (Fig. 1, left) and the appearance of vortex states with non-trivial polarization structure, in particular the anti-vortex with a hyperbolic polarization distribution (Fig. 1 right). The scalar vortices (and azimuthons) are known to be soliton solutions of the system in quasi-scalar approximation [2], hence we conjecture that the anti-vortex has also solitonic character. Further states with an irregular but roughly four-domain polarization configuration exist also with either two lobes (Fig.1 top) or three lobes (i.e. azimuthons) and are under current investigation.

References

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[2] J. Jimenez et al., "Observation of laser vortex Solitons in a self-focusing semiconductor laser", J. Opt **15**, 044011 (2013)