Orbital angular momentum lasing with an optically-controlled chirality

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Abstract: We propose and experimentally demonstrate a novel scheme, based on a fully integrated device, for generating lasing in a mode carrying orbital angular momentum with a chirality that can be optically controlled (i.e. from a clockwise to a counter-clockwise phase twist). Furthermore, we show that nonlinear contributions to the gain can lead to a bistable regime involving modes presenting distinct topological charges and polarization patterns.

The orbital angular momentum (OAM) of light, emerging in helical light beams, is an unbounded degree of freedom that appears very advantageous for applications ranging from optical manipulation to classical and quantum information multiplexing. In this context, coherent sources of light carrying OAM are extremely appealing. Right now, one of the main limitations of integrated lasers generating OAM is their lack of versatility, as they rely on engineering chiral resonators [1], thus imposing a unique, non-tailorable chirality of the emission, i.e. clockwise (+|L|) or counter-clockwise (-|L|). Here, we propose and demonstrate, using a fully integrated device, a novel scheme where the chirality of a lasing mode carrying OAM can be optically controlled.

To do this, we use a semiconductor planar microcavity embedding a single quantum well (i.e. a VCSEL), where we etch a hexagonal ring of overlapping micropillars (see Fig. 1a). In such resonators exhibiting discrete rotational symmetry, the angular momentum of photons, associated to the evolution of their phase around the device, couples to their spin [2]. Thanks to this spin-orbit interaction, it is possible to trigger lasing in a mode carrying a net OAM by spin-polarizing the gain medium with a circularly polarized optical pump. This allows optically breaking time-reversal symmetry and thus controlling the chirality of the emission solely by changing the polarization of the pump (see self-interferograms of the beam for a L = ± 1 lasing mode in Fig. 1 b and c, respectively obtained with $\sigma_{\pm}$ polarized pumps; similar results were obtained for L = ± 2 modes) [3]. Furthermore, far above the lasing threshold, nonlinear contributions to the gain lead to a bistable regime involving photonic modes presenting distinct topological charges (here, L = 0 and L = + 2; see Fig. 1d); as well, thanks to the engineered spin-orbit coupling, these modes exhibit distinct different polarization textures (circular and azimuthal polarizations) [4].

Importantly, these schemes are very general and can be extended to devices presenting higher values of OAM, thus paving the way to the engineering of novel laser sources with optically tunable OAM.

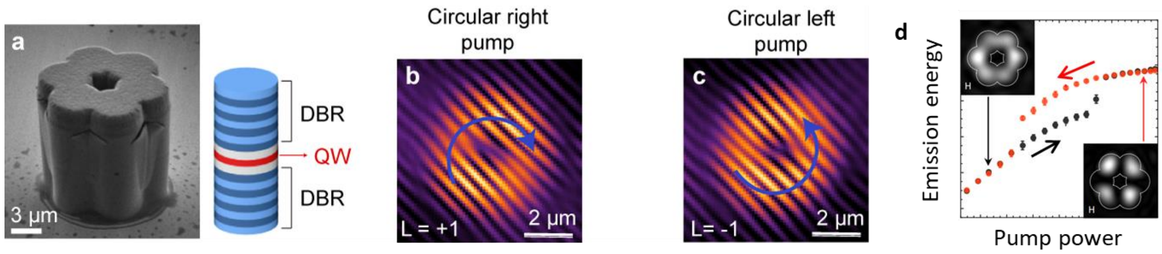

Figure 1 a. *Left*. SEM image of a device. *Right*. Schematic representation of a single pillar where a quantum well (QW) is embedded between distributed Bragg mirrors (DBR). **b,c** Self-interferograms of the lasing beam for circular right (**b**) and left (**c**) pumps reveal vortices with +1 and -1 topological charges respectively. **e**. In the saturation regime, observation of a hysteresis cycle evidences an optical bistability between modes presenting distinct topological charges (top left, L=+2; bottom right, L=0).

[1] P. Miao et al., Science 353, 464 (2016)
[2] V. Sala et al., Phys. Rev. X 5, 011034 (2015)
[3] N. Carlon Zambon, P. St-Jean et al. arXiv: 1806.04590 (2018) (to appear in *Nat. Photon.*)
[4] N. Carlon Zambon, P. St-Jean et al. arXiv: 1812.06163 (2018) (under review)