Circularly Polarized and Directional Lasing in Blue Phase Liquid Crystal

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Polarized directional emission can be achieved in semiconductor lasers though complex and costly nanopatterning [1]. Here, we propose alternative self-organizing platform for directional and chiral lasing based on blue-phase liquid crystals (BPs). BPs are chiral liquid crystal phases that manifest when doubly twisted cylinders arrange themselves into cubic lattices, typically on the scale of hundreds of nanometers. This unique structural configuration grants BPs distinct optical properties, notably circularly polarized Bragg reflections in the visible energy range. Thus, BPs offer potential as chiral three-dimensional photonic structures with promising applications in displays, biosensors, optical filters, and lasers [2]. Although previous studies have shown lasing capabilities in dye-doped BPs [3], the investigation into their directionality and polarization characteristics has been somewhat limited.

In our study, we demonstrate that lasing in dye-doped blue-phase structure BPI can be induced by the presence of Kossel lines – traditionally observed in the X-ray Bragg diffraction patterns of crystals – within the visible spectrum. Kossel lines form stop bands, characterized by a high density of states at their edges. This phenomenon manifests itself in the lack of transmission of right-hand circularly polarized light through Kossel lines and the enhanced photoluminescence in the same polarization, matching the Bragg diffraction lines' dispersion.

This unique characteristic leads to highly directional lasing, with the emission direction dictated by the overlap between the lasing wavelength of the employed dye and the dispersion of the Kossel line. Given the chiral nature of BPs, the emitted light is anticipated to be circularly polarized. However, our findings reveal two distinct lasing types. One's helicity is determined by the polarization of the Bragg diffraction, and its emission direction closely correlates with the cubic symmetry and the orientation of the sample. Conversely, the other type exhibits opposite circular polarization, and its emission direction is primarily dictated by the experimental geometry.

[1] K. Rong, X. Duan, B. Wang, et al. *Nat. Mater.* **22**, 1085–1093 (2023).
[2] K. Bagchi, T. Emersic, J.A. Martinez-Gonzalez, et al. *Sci. Adv.* **9**, eadh9393 (2023).
[3] W. Cao, A. Muñoz, P. Palffy-Muhoray, et al. *Nat. Mater.* **1**, 111–113 (2002).