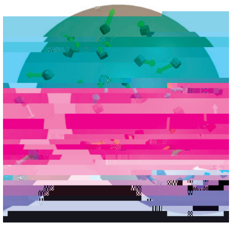
otherwise possessing properties that render optical trapping impractical.

In this paper, we describe a robust method for magnetic and optical manipulations of topological defects using magnetic and optical colloidal handles (MOCH) in various LC hosts. This method allows us to manipulate the MOCHs and topological LC defects attached to them in a fully holonomic manner,



the epi-detection mode being the primary con guration when implementing full three-axis holonomic manipulation.

B. Sample preparation

We use a commercial nematic mixture E-31 (from EM Chemicals) and a single-compound nematic LC pentylcyanobiphenyl (5CB, obtained from Frinton Laboratories). Cholesteric LC hosts are formed using one of these nematics doped with a small volume fraction of chiral agent (cholesteryl pelargonate obtained from Sigma-Aldrich Chemistry) to obtain chiral nematics with a cholesteric pitch in the range of 5–10 μ

defects induced by their rotation and with various types of laser-induced local melting of the LC, one may be able to control twist and writhe [38–40] of defect lines forming loops, and thus, one may be able to generate defect loops with nonzero topological hedgehog charges. This potentially can be performed for individual or multiple defect loops that may or may not be linked with each other. Another interesting direction of extending the present work may involve generation of topologically nontrivial con gurations of defect lines in the forms of various free-standing knots, links, etc. Although our manipulation method is geometrically unrestricted in terms of the defect manipulation, such restrictions will be self-imposed naturally by topological constraints inherent in various LC systems, which, therefore, may allow one to explore the interplay of topologies of nematic director elds, defects, various loops, surfaces, etc. With careful calibration of magnetic forces and torques exerted on SPMBs, MOCHs may also allow for experimental exploration of mechanical properties of defect lines and wall defects, which remain poorly understood. By using nanoparticles instead of relatively large SPMB microbeads, one can potentially probe the core structure of defects and can explore variations in rheological properties within LC samples containing defects, etc.

V. CONCLUSION

We have developed an integrated magnetic and optical manipulation system for full holonomic control of topological defect lines in nematic and cholesteric liquid crystals. The rotational manipulation of colloidal chains and pinning of defects to colloidal particles allows us to form complex 3D patterns of defects not found naturally in liquid crystal systems, such as spirals in cholesteric ngers of the rst kind. Furthermore, we have been able to integrate this magnetic rotational manipulation with linear holographic optical trapping in such a way as to enhance the strengths of each while ameliorating the inherent weaknesses in either method alone. Using speci c examples, we demonstrated that our method provides powerful new tools for the study of topological defects as well as potentially allowing one to create fascinating topological defect con gurations, such as free-standing knots and links of defects. Such exploration may be of interest not only from the standpoint of a general understanding of defects in condensed matter, but also for their use in modeling topological defects in early universe cosmology, string theory, high energy physics, and other physical systems.

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