minimization of the Landau–de Gennes free energy [49,50]. Our findings may provide the means of generating and controlling nonsingular topological defect lines and their loops; in addition they may lead to alternative approaches for the design and realization of LC-colloidal composite materials with preengineered properties and response to external stimuli such as electric fields [51–54].

II. EXPERIMENTAL METHODS, TECHNIQUE, AND MATERIALS

Cholesteric LCs are prepared by mixing the room-temperature nematic hosts 4-cyano-4′-pentylbiphenyl (5CB) or ZLI2806 with a chiral dopant CB15 (all from EM Chemicals). The helicoidal pitch p value is set by controlling the volume fraction of the chiral additive (C_{chiral}) of known helical twisting power for a given nematic host, h_{HTP} [30] according to the relation $p = (h_{HTP}C_{chiral})^{-1}$, which works well for relatively small volume fractions of the chiral additive (≤ 0.01) used in this study [30,45]. For the mixtures obtained by doping CB15 into the 5CB nematic host, $h_{HTP} = 7.3\,\mu m^{-1}$, whereas $h_{HTP} = 5.9\,\mu m^{-1}$ for the cholesteric mixtures prepared by doping CB15 into the ZLI2806 nematic host [30]. These h_{HTP} values were used to calculate C_{chiral} for the values of pitch in the range $p = 5–25\,\mu m$, as presented for particular experiments in the captions of the corresponding figures. Additionally, the values of p were measured separately using the Grandjean-Cano method [30,44–46], showing a good agreement with the values estimated based on the chiral additive volume fractions during the LC sample preparation. We have utilized solid silica particles of known nominal diameter [18]. These particles were treated with *N*,*N*-dimethyl-

FIG. 1. Optical imaging of defects around a spherical colloidal particle in a cholesteric LC. (a) After the LC around a particle is locally

large variety of defect structures around spherical inclusions in cholesteric LCs and interactions between them, mediated by sharing defects and elastic deformations surrounding the particles. The type of desired assembly can be selected and assembled optically with the help of laser tweezers. Since nanoparticles are known to get elastically trapped inside the hedgehog point defect and other singularities [12,18] in a nematic LC, the chiral dipolar particles and their assemblies can act as templates for 3D self-assembly of nanoparticles inside the matrix created by the micrometer-sized colloidal particles and the cholesteric LC host.

ACKNOWLEDGMENT

We thank P. Ackerman, T. Lee, and B. Senyuk for discussions. This work was supported by the NSF Grant No. DMR-1410735.

[1] P. Poulin, H. Stark, T. C. Lubensky, and D. A. Weitz, Science 275, 1770 (1997).
[2] R. W. Ruhwandl and E. M. Terentjev, Phys. Rev. E 55, 2958 (1997).
[3] Y. Gu and N. L. Abbott, Phys. Rev. Lett. 85, 4719 (2000).
[4] S. Ramaswamy, R. Nityananda, V. A. Raghunathan, and J. Prost, Mol. Cryst. Liq. Cryst. Sci. Technol., Sect. A 288, 175 (1996).
[5] F. Brochard and P. G. de Gennes, J. Phys. (Paris) 31, 691 (1970).
[6] D. Andrienko, M. P. Allen, G. Skačej, and S. Žumer, Phys. Rev. E 65, 041702 (2002).
[7] C. P. Lapointe, T. G. Mason, and I. I. Smalyukh, Science 326, 1083 (2009).
[8] B. Senyuk, Q. Liu, S. He, R. D. Kamien, R. B. Kusner, T. C. Lubensky, and I. I. Smalyukh, Nature 493, 200 (2013).
[9] T. A. Wood, J. S. Lintuvuori, A. B. Schofield, D. Marenduzzo, and W. C. K. Poon, Science

[48] T. Lee, R. P. Trivedi, and I. I. Smalyukh, Opt. Lett. 35, 3447 (2010).
[49] P. M. Chaikin and T. C. Lubensky, Principles of Condensed Matter Physics (Cambridge University Press, Cambridge, 1995).
[50] H. Stark, Phys. Rep. 351, 387 (2001).
[51] V. N. Manoharan, Science 349, 1253751 (2015).
[52] V. J. Anderson and H. N. W. Lekkerkerker, Nature 416, 811 (2002).
[53] S. Sacanna, W. T. M. Irvine, P. M. Chaikin, and D. J. Pine, Nature 464, 575 (2010).
[54] Q. Liu, Y. Yuan, and I. I. Smalyukh, Nano Lett. 14, 4071 (2014).
[55] P. Oswald and P. Pieranski, Nematic and Cholesteric Liquid Crystals: Concepts and Physical Properties Illustrated by Experiments (Taylor & Francis/CRC Press, Boca Raton, FL, 2005).
[56] S. Kralj, S. Žumer, and D. W. Allender, Phys. Rev. A 43, 2943 (1991).
[57] P. G. de Gennes and J. Prost, The Physics of Liquid Crystals,