Linked topological colloids in a nematic host

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r s rfl s. fl s r l s r d m

s r n n s n s =

r -rd r ln s fl n d l s fl s d ll d l r l s n LCs, s r s n n l s m l s m l s fl s r d l- l d l nd d r r sr r sd S l m n ln s (F . 8 nd SI A , F . S4).

ln s r l fl ln d r l m n n s n sd r l nr s r s l r. n l n n n n l ll d s, m n -d n r n s n s m n ln d m n n s l n n s m m s r l , n sr n d s l ln n , r d fl r n m l m n n r l s. LC l s -md d n r n s n ln d r n s fl s m r l nd s rr nd n LC m r r d fl r n f m n d fl r n ln d r n s s m l r n- d d d fl s. F r m l , n ln n fl r n ss n n F . 2, fl r nd d ms r r n , s d r s l n dr l r n r n s nd s fl- ss m l s m l r s d d r sl (19, 20), r d fl r n f m l r m nd m s l m l rr n m n s fl m n n r n s fl ln d r (F s. 2 nd 3). n l n ln d ll d l r n s r nd l r nd r nd n s, n r n -l nd n d fl s (19), r ln d n r r s n n s r d nd n sn l r s. n ln d l s fl fl-n r d fl ln s (F . 9) n l ll - l n n d fl s fl d r ±1, nd dd n l s fl- m n s n ±1 n d fl r s n l s n r d d

l n l l r n s r n (19). r, f n r mn m n fl l s d s r n s nd d m l -s d r l s l fl ln s ll s f n r mn m fl r fl ll nfl r n s ln r d fl l s (s m fl r ln d r nd r- l s). S r n r ln n fl d fl l s nd d ln d r n s r d s n dd n l n r n m n s md d fl ln n s n (F . 4), s fl d r fl 50–70 fl r sn l r fl-n r d fl ln s (26, 30). D fl -n n l d l- l d l nfl r n s, l n s n n F . 4, n ll d l m n n r n s n r r (m s m- m n l) n , d nd n n m n fl d fl ln n s n nd r ls l s fl r sd sr n d r r d s- r n s n s r n s r r. n m n n r n s , ll d nd r s B n n m n s n fl n s = 2 nd l d , s fl l d s n f m fl s r r n s. B nd LC ll d s, ln n n l r n r n s n ll d l m n n s n, fl r m l , n r n s r n f m l r s r d l n fl r s, n n n fl r d s n n m l ll d l s fl- ss m l r r s nd fl n n l . n r nd , r s s m l s l s d l s fl d fl ln s m r d n r m n l l fl r m fl r s n r d n s fl m m l m d ls fl r mn m mr l n fl ln d nd n d l l

r mn n n r n , nd n m n n s. In s ,
l n -l n r ns (33) h m n n s fl l-
l d l dl n l s dl m r . E r m n l s d fl
m l ns fl ln n fl r l s nd d fl l s n r ms fl
l e d r n fl dd n ld fl s dl ls l-
l fl r n m n s fl r n s mm r fl LC s s, . .,d s-
n s n n n l nd l n m s (34), s ll s
nd d r s fl s fl m r s s ms n r n l ll
n n r l nfl r ns (3, 7, 8, 19, 35–37). r n d d fl r
l r ns n l d s l n l s s nd s d fl sr r l s
d r ms, s ll s ll nfl n m n , n r ss s, -
r l , s rfl n n r n l fl ln d ll d l m n n s, nd
rn l fl dl s n r l m (35–37). Ln d m l m n n r -

a 170-μm-thick coverslip, spaced by 50-μm-thick Mylar strips. As the beam focus was translated through the monomeric fluid, we always began polymerization at the substrate-fluid interface to effectively anchor the structure while it is being drawn. Arrays of particles were then detached from substrates by gentle sonication and dispersed into LCs. As-manufactured particles impose tangential boundary conditions for ( ), but some of them were treated with DMOAP for perpendicular ones (8).

Optical Imaging and Laser Manipulation. Director structures are studied using a combination of conventional polarizing optical microscopy and a 3D nonlinear imaging technique dubbed "three-photon excitation fluorescence polarizing microscopy" (3PEF-PM) (25), which is based on fluorescence of LC molecules excited through three-photon absorption of femtosecond infrared laser light. The 3PEF-PM fluorescence intensity exhibits a strong well-defined dependence (25) on the orientation of linear polarization of the excitation beam relative to ( ). 3PEF-PM images, comprised of 3D stacks of optical slices, such as the ones shown in the SI Appendix, Figs. S12 and S13 and Movies S3–S5, reveal orientations and relative positions of linked rings as well as the corresponding locations and configurations of topological defects accompanying them. Close analysis of 3PEF-PM stacks reveals dependence of 3D ( )-structures on boundary conditions and topology of colloids. Optical videomicroscopy and holographic laser tweezers (25) probe elastic interactions between the linked rings. Additionally, high-power beams of laser tweezers allow for locally meltin8(d)TJ(ee3inS9m)15.tw33o8.8f.efponaperticpandmeatid