Super-resolution stimulated emission depletion microscopy of director structures in liquid crystals

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by photobleaching and realignment of the director field due to the optical Frederiks transition [2–5]. Details of the STED imaging design are presented in Fig. 1, with the simplified schematic of a STED microscope [16] (modified to enable polarization sensitivity) shown in Fig. 1(d).

LC samples were prepared between two glass substrates, treated with 2 wt% aqueous solution of N,N-dimethyl-N-octadecyl-3-aminopropyltrimethoxysilyl chloride or polyimide (PI-2555, HD Microsystems) to set perpendicular (homeotropic) or tangential (planar) boundary conditions on the surfaces, respectively. The substrates were assembled into thin wedge

STED-PM and FCPM fluorescence signals from the dye-doped LC with the director oriented out of the focal plane vary as $\propto \cos^4$ (which is because the absorption and fluorescence both exhibit $\propto \cos^2$ dependencies), where is the polar angle between the dye's molecular transition dipole and the focal plane. Therefore, both polarized luminescence images reveal that $\boldsymbol{n}(\boldsymbol{r})$ is in-plane in the central regions of the stripes and vertical in the LC background surrounding them, though STED-PM exhibits spatial resolution superior to that of FCPM. The normalized line profiles between the arrows in Figs. 2(a) and 2(b), obtained after subtracting the background, show substantial improvement in resolution, with the full width at half maximum (FWHM) of features reduced from 350 nm to 131 nm and features with a maximum and minimum separated by $\leq 100\ \mathrm{nm}$ distance resolved. This indicates imaging resolution better than 100 nm when accounting for the finite width of the actual fluorescent pattern due to the continuous rotation of the director within it. To compare the resolution between confocal and STED imaging of the LC director, we performed Fourier ring correlation analysis [19] on confocal images of the same field of view and obtained a resolution of $(288 \pm 3)\ \mathrm{nm}$. Therefore, at 5 mW STED power, an approximately threefold

accompanied by singular line defects near the substrates while forming one type of cholesteric fingers [22], while skyrmions can terminate on singular point defects near confining substrates to form the so-called “torons” [23]. The study of such three-dimensional structures with nanoscale super-resolution will require super-resolution PSF for not only the lateral directions, but also along the microscope’s optical axis. This can be achieved using the so-called “z-donut” or “bottle” STED beams [8], but is beyond the scope of our present study.