Patterned photo-alignment and surface topography for chiral liquid crystal superstructures with unique electro-optic properties

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***Abstract*— The combination of long-pitch and short-pitch chiral liquid crystals (CLCs) with patterned surface anchoring or surface topography is investigated with the aim to develop new electro-optic components. Highly efficient large-angle 1D diffraction gratings and metastable 2D gratings with hysteresis switching are demonstrated as well as electro-optic components with a uniform lying helix-like structure at intermediate voltages.**

Keywords—chiral liquid crystal; photo-alignment; surface topography; electro-optic components

I. INTRODUCTION

Liquid crystals (LCs) are soft materials that can self-organize into complex hierarchical superstructures and are strongly responsive to different external stimuli (electric field, heat, etc.). This makes them interesting for integration in tunable electro-optic devices such as diffraction gratings, smart windows, lasers and light modulators. Chiral nematic liquid crystals (CLCs), in which the constituent mesogens are chiral and tend to twist with respect to each other, nowadays attract significant attention. The self-assembly of CLC into helical superstructures gives rise to unique optical properties that are unachievable with achiral LC. Moreover, geometric frustration can lead to the formation of fascinating structures when CLC is infiltrated in confined geometries. Depending on the applied electric field, device geometry and chiral pitch, cholesteric fingers and particle-like CLC structures can be observed.

Previous work focused on CLC in confined geometries with uniform anchoring but an even richer behavior is observed in cells with patterned anchoring as discussed here. We study how the combination of patterned surface anchoring with long- and short-pitch CLCs leads to the formation of complex and electrically tunable LC structures with different functionalities. The interplay between the LC elasticity, chirality, surface anchoring and applied electric field is investigated. Both patterning of the azimuthal anchoring (by photo-alignment) and modulation of the surface topography (by e-beam lithography) is used to steer the CLC self-assembly. Experimental work is combined with numerical simulations of the director configuration and the optical properties. Fundamental insights in LC self-assembly are provided and different electro-optical devices are characterized.

II. CLC GRATINGS BY PHOTO-ALIGNMENT

1D and 2D diffraction gratings are demonstrated by combining CLC with periodically patterned planar photo-alignment at the substrates. A highly efficient (~88%), polarization-sensitive, large-angle (~47°), 1D diffraction grating is created by infiltrating short-pitch (~400 nm) CLC in a cell with the same 1D rotating planar anchoring at both substrates. This grating is working in reflection and makes use of the photonic bandgap for visible light in short-pitch CLC (Fig 1). By rotating the photo-aligned substrates over 90° with respect to each other, so that the alignment is varying along the x- and y-direction at the top and bottom substrate, a 2D diffraction grating with hysteresis switching is demonstrated with the help of long-pitch (~10 µm) CLC. This grating is operating in transmission and metastability of different topological states is observed as a function of the voltage.

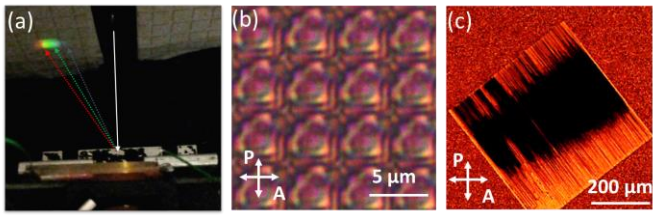

Fig. 1 (a) 1D diffraction grating; (b) low-voltage structure 2D grating; (c) directional CLC growth on surface topography.

III. CLC STRUCTURES BY SURFACE TOPOGRAPHY

As an alternative patterning technique, e-beam lithography is used to produce a periodic surface structure. The periodicity of the topographical pattern, the cell thickness and the voltage treatment are varied and both short-pitch (~335 nm) and long-pitch (~5 µm) CLC are tested (NYS. ET AL., ADV. OPT. MATER. 6(13), 1800070, 2018; NYS ET AL., OPT. EXPRESS 27(8), 11492, 2019). Directional growth of chiral structures along the surface grating is observed for voltages below the CLC unwinding threshold (Fig. 1(c)). In the cell with short-pitch CLC, a uniform lying helix-like structure is formed at intermediate voltages and a chiral configuration with periodic undulations of the helical axis is observed at low voltages. The director configuration in the bulk of the device is revealed with the help of finite element Q-tensor simulations.