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Electrical control of nanoparticles arrays created via topological defect lines design in anisotropic fluids

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ABSTRACT

Soft material templating is a promising approach for assembling and manipulating nanoparticles structures. Due to the high sensitivity of soft matter systems to external stimuli, such composite materials exploit the soft surrounding medium to move or to reconfigure nano-structures or nano-objects as well as to tune their own properties. The use of topological defects in anisotropic fluids has been recently reported. Here, arrays of defect lines are created in planar-periodic nematic liquid crystal cells, wherein the nematic director undergoes static twist deformations separated by topological defects. Trapping and manipulation of the nanoparticles in disclinations are demonstrated and investigated by confocal fluorescence microscopy exploiting quantum dots. Nanoparticles gathering is observed during electrically controlled switching from orientational topological walls to disclinations. The external field is also used to perform displacement and deformation of the nanoparticles arrays, as well as their dynamical assembling and disassembling. The reported results substantiate the opportunities offered by defects architectures in anisotropic fluids as a successful bottom-up approach that enables versatile assembling and remote control of nanoparticles.

1. Introduction

Control of the spatial positioning of nano-objects is still a challenging research area because of the huge added value that it could introduce in several branches of science. Spatial patterning and manipulation of nanoparticles (NPs) is very promising for new and more efficient nanotechnologies involving the field of material science and enabling lab-on-a-chip solutions for sensing, imaging, drug delivering, etc. [1–4]. Moreover, the capability to perform a remote control of the designed architectures can be of high impact in tuning photonic, electronic or magnetic properties of the nanocomposite materials and to develop switchable and tunable devices [5–7]. In fact, nanocomposite structures exhibit collective phenomena and high sensitivity to external stimuli. Recently, great attention has been addressed towards soft matter based templates due to the ability to assemble NPs and manipulate their properties. To this aim, condensed matter structures with nanoscale dimensions have been investigated as fine instruments for the task. An explored approach is to exploit the nanoscopic structures of the cores of topological defects (TDs) in anisotropic soft materials. The existence of TDs is a consequence of violations in the orientational order which happen in many soft materials (e.g. biological membranes, lipid monolayers, liquid crystals (LCs)) [8–10]. An emerging class of systems for direct assembling of NPs, relies on TDs networks in liquid crystals demonstrating that nano-objects can be trapped and accumulated in the TDs core [11,12]. Structures stabilized by TDs are extremely robust among various structures in soft matter, since the energy required to destroy them is far beyond the thermal energy [13]. However the sensitivity of LCs to external stimuli enables to modify position and shape of these nanostructures with moderate variations of control parameters as temperature, electric, magnetic or optical fields, addressing methods to perform remote and contactless control for reconfigurable and tunable systems at the nanoscale [14,15].

Mechanism of NPs trapping by TDs is still under investigation and some models have been proposed [16,17]. Differently to micron-sized particles which move to the TDs in the gradient of the distorted director field [18,19], NPs slightly affect the LC director configuration. Moreover, NPs locally change (typically reduce) the order parameter S of the LC, increasing in this way the free energy of the system. Since disclination lines (DLs) in LCs have an isotropic core with $S = 0$, NPs move towards them in a gradient of the order parameter minimizing the total free

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