Panoscopic Structures of Colloidal Liquid Crystals of Inorganic Nanosheets Prepared from a Crystalline Layered Oxide

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Hierarchical soft structure is a key concept for novel intelligent materials, and such structures have been well realized in various organic systems using liquid crystals (LCs). However, panoscopic organization, the term which means structural control over all length-scale from micro-, meso-, to macroscopic, of soft matter has still insufficiently been developed because its building blocks are usually organic moieties which lack robustness for the retention of defined structures up to macroscopic scales. If we can use inorganic building blocks, panoscopic structures will be constructed in soft matter rather easily. We expect that colloidal LCs of inorganic particles are promising systems for organizing inorganic panoscopic soft structures. Colloidal LCs are lyotropic systems giving ordered structures of anisotropic particles like rods and plates based on the excluded volume effect. Because of the robustness of the inorganic crystallites and the mesogen size much larger than that of conventional organic molecules, the inorganic colloidal LCs can construct large-scale structures, being impossible with the organic LCs, with characteristic lengths of sub-mm to mm through panoscopic organization of the nanosheets.

In the present study, we have organized panoscopic structures of inorganic colloidal LCs using inorganic nanosheets with thickness of around 1 nm and lateral dimension of several micrometers prepared by exfoliation of a layered oxide [1]. Highly anisotropic shape of the nanosheets allows the emergence of the LC phase at low particle concentrations (< 1 mass%), where the particles maintain high mobility required for structural transformation of the colloid. Nanosheet LCs of a layered niobium oxide are converted to hierarchically organized arrays whose structures are controlled from nano to macroscopic length scale. The panoscopic organization is attained through a two-stage process that is the growth of LC domains called tactoids as the secondary building blocks followed by orientational change of the tactoids under controlled application of external fields, as schematically shown in Fig. 1. The tactoids is formed by incubation of the liquid crystals at room temperature. The grown tactoids are then assembled to higher-order structures with characteristic length of sub-mm to mm under the simultaneous application of an ac electric field and gravity, whose directions determine the final textural motif of the panoscopic arrays. Whereas a net-like texture is observed with applying the electric and gravitational forces in the same direction, a stripe texture where the nanosheets are unidirectionally aligned is observed when the electric field is applied in the direction perpendicular to gravity.

The use of well-grown tactoids is the key to the macroscopic structural control. The tactoid size is governed by concentration of the nanosheets as well as the incubation time for the tactoid growth. The tactoid area increases from 100 – 10,000 µm² with the increase of the nanosheet concentration from 2.5 to 10 g L⁻¹ and/or the incubation time from 0 to 180 min for the nanosheets with the lateral size of around 2 µm, whereas the tactoid thickness is principally determined by the nanosheet concentration. The final structures of the nanosheet liquid crystals are influenced by both of the area and thickness of the tactoids.