색깔 변환이 가능한 삼차원 포토닉 액추에이터

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Abstract

By combining the multi-faceted environmental responsiveness of polymer hydrogels with photonically active structures, there has been a significant effort to create color-tunable photonic crystal sensors by changing either the periodic spacing of the structure or the dielectric constants of the materials. Here, we show that reversible spiral and helical opal switches with both dimensional and optical functionalities that respond to environmental chemistry can be constructed. When the transparent opal switch is swollen in hydrophilic acetic acid, right-handed spirals and helices that exhibit angularly dependent colors from Bragg diffraction are formed. When the transparent opal switch is swollen in hydrophobic hexane, left-handed spirals which exhibit angularly dependent colors from Bragg diffraction are formed. When the transparent opal switch is swollen in hydrophobic hexane solvent, a left-handed spiral and helix with an angularly independent bluish color is formed. After deswelling, all switches returned back to the transparent planar state. These color-tunable, reversible spiral and helical opal switches can be useful as mechanical actuators, and electrical devices as well as optical components.

1. Photonic Crystals

Photonic crystals are periodic structures that are designed to affect the propagation of electromagnetic

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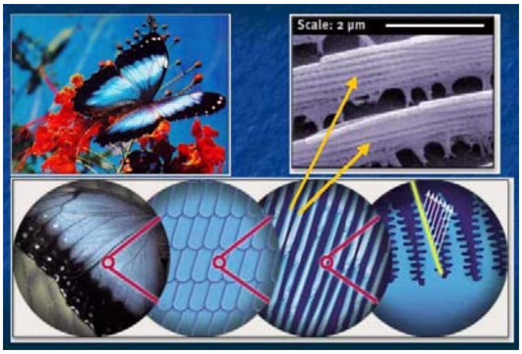

Figure 1. Morphology and structure of the natural butterfly wing photonic crystals (Peleides Morpho).[1,2]

waves in the same way as the periodic potential in a semiconductor crystal affects the motion of electrons, by defining allowed and forbidden electronic energy bands. Nature provides an abundant selection of micro- to nanostructures that can be used as templates for fabricating a wide range of photonic related structures. One of the best examples of photonic crystals is the butterfly wing photonic crystal (Figure 1).[1,2]

In photonic crystals, the periodic potential is due to a lattice of macroscopic dielectric media. If the dielectric constants of the materials in the crystal are different enough, and the absorption of light by the material is minimal, then scattering at the interfaces can produce many of the same phenomena for photons as the atomic potential does for electrons. The absence of allowed propagating modes for a range of wavelengths inside the structures gives rise to distinct optical phenomena such as inhibited spontaneous emission, and lossless reflection enabling low-loss-waveguiding. In particular, we can design and construct photonic crystals with photonic band gaps, preventing light from propagating in certain directions with specified energies.[3] In order to prevent the propagation of light in all directions, a three-dimensional photonic crystal with an omni-directional,

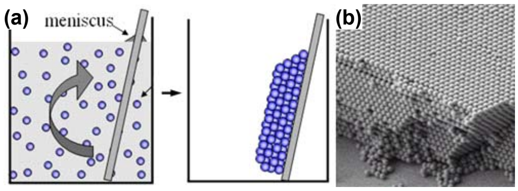

Figure 2. (a) Schematic diagram of Colvin's colloidal crystallization. (b) Typical scanning electron micrograph image of colloidal single-crystal.[4]

or complete photonic band gap is required. One of the most common ways to fabricate three-dimensional photonic crystal fabrications the self assembly of colloidal particles (Figure 2).[4] Recently, by combining the multi-faceted environmental responsiveness of polymer hydrogels with photonically active structures, there has been significant effort to create color-tunable photonic crystal sensors by changing either the periodic spacing of the structure or the dielectric constants of the materials.[5-8]

2. Helical Structures

Natural materials, such as polypeptides, proteins, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) have been a key inspiration to chemists and physicists in designing and synthesizing programmed molecular structures that organize them into superstructures (Figure 3).[9-12] One of the most important interactions in natural materials and synthesized bio-mimetic materials is the chiral interactions and the chirality transfer between different length scales from sub-nanometer to micrometer. Even though many scientists have devoted their studies to recognizing the different levels of chirality and the chirality transfer between levels, we do not yet have a complete understanding of these processes. There are two types of helices in nature: one is a polypeptide-like spring helix and the other is DNA-like double helix (Figure 3).

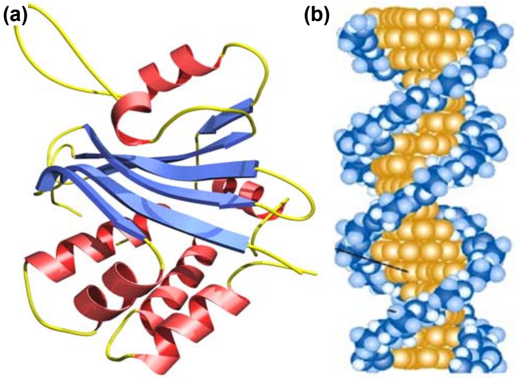

Figure 3. (a) Polypeptide spring helix.[13] (b) DNA double helix.[14]

Scientists have successfully constructed those two types of helical structures by breaking symmetry (Figure 4).[15,16] Wang, et. al. created the polypeptide-like zinc oxide helix by introducing a rigid lattice twisting (Figure 4a) perpendicular to helical axis.[15] Cheng, et. al. constructed the DNA-like polyester double twisted single crystals by introducing the molecular chirality. In this system, they found that the handedness of the helical sense is not only determined by the configurational chirality, but also by the number of methylene units.[16] In mathematics, a polypeptide-like spring helix is a curve in three-dimensional space, which can be expressed in rectangular coordinates: $x = \cos(\theta)$, $y = \sin(\theta)$, $z = \theta$. As twisting power (θ) increases, the point (x,y,z) traces a right-handed helix of pitch 2π about the z-axis (helical axis), in a right-handed coordinate system. The equivalent left-handed helix can be constructed in a number of ways, the simplest being to negate either the x, y or z component. A DNA-type double helix typically consists geometrically of two congruent helices with the same axis, differing by a translation along the axis. It is worthwhile to note that the construction of DNA-like double helix requires lower symmetries than those of polypeptide-like spring helix.

3. Environmentally Responsive, Color-Tunable Photonic Actuators.

Photonic crystals are periodic nano-structures that are designed to affect the propagation of electromagnetic waves. Recently, there has between significant effort to create color-tunable photonic crystal sensors by changing either the periodic spacing of the structure or the dielectric constants of the materials. In this research, by combining the multi-faceted environmental responsiveness of polymer hydrogels, the sensitivity of helical geometric structures, and the diffractive power of three-dimensional colloidal arrays, we can develop color-tunable heli-

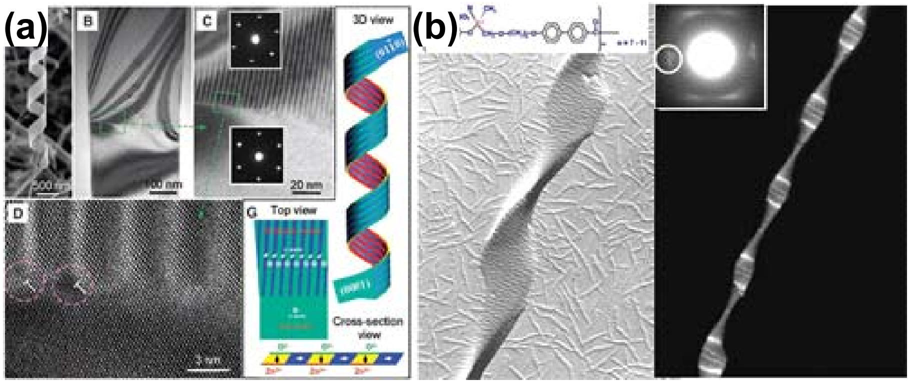

Figure 4. (a) Zinc oxide nanohelix (polypeptide- like spring helix).[15] (b) Polyester double-twisted single crystal (DNA-like double helix).[16]

cal photonic crystal actuators which respond to external stimuli, such as stress, temperature, moisture, pH, electric or magnetic fields by changing shape and color. These color-tunable helical photonic crystal actuators can be useful as chemical and biological sensors, mechanical actuators, and electrical and photonic devices.

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