膽固醇液晶盒中液晶結構轉換機制的研究

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摘　　要

不論在基礎科學或應用層面上，膽固醇液晶的結構轉換都很引人入勝。為了設計膽固醇液晶元件的驅動方式，對於液晶結構轉換機制的了解有其必要性。

在本論文中，我們主要探討水平配向膽固醇液晶盒中，三種液晶結構轉換的機制，其分別為 homeotropic-planar 液晶結構轉換、homogeneous-planar 液晶結構轉換以及 planar-focal conic 液晶結構轉換。另外，我們也探討了垂直配向膽固醇液晶盒中，homeotropic-fingerprint 液晶結構轉換的機制。為了了解液晶結構轉換的動態過程，我們根據有限原素法開發了一個三維指向矢模擬程式。

藉由上述的模擬程式，我們模擬了水平配向液晶盒中，當電場被瞬間關掉後，homeotropic-planar 液晶結構轉換的動態過程。此模擬結果已由實驗得到驗證。更進一步地，我們討論偏壓波形對 homeotropic-planar 液晶結構轉換

的影響。根據模擬與實驗所得到的結果，我們設計了一個偏壓波形，藉以縮短 homeotropic-planar 液晶結構轉換的時間。同樣地，我們也模擬當電場被瞬間關掉後，homogeneous-planar 液晶結構轉換的動態過程。模擬的結果符合了之前的實驗觀察。同時，我們也發現 Helfrich 形變不僅可藉由電場誘發，同時也可藉由彈性力誘發。因此我們比較了 homeotropic-planar 和 homogeneous-planar 液晶結構轉換過程中，彈性力所誘發的 Helfrich 形變與 planar-focal conic 轉換過程中，電場所誘發的 Helfrich 形變。另一方面，我們藉由改變電場來觀察 planar-focal conic 液晶結構轉換過程中所出現的週期性液晶結構。我們發現這些液晶結構要不是週期性的條紋液晶結構，不然就是週期性的六角形液晶結構，其中週期性的六角形液晶結構是第一次被實驗觀察到。

最後我們在具有圖案電極的垂直配向液晶盒中，觀察當電場被瞬間關掉後，homeotropic-fingerprint 轉換過程中所出現的條紋液晶結構。我們發現條紋的方向不僅和液晶盒厚度有關同時也和外加電場有關。在此實驗中，我們製作出可隨操作電場調變條紋方向的膽固醇液晶相位光柵，並可利用偏壓來調變此相位光柵的間距。此外我們也提出了該元件的操作機制。

Study on the Mechanisms of Texture Transitions in Cholesteric Liquid Crystal Cells

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ABSTRACT

The texture transitions in cholesteric liquid crystals are very interesting and are of importance for both fundamental science and applications. It is essential to understand the mechanisms of texture transitions in ordr to design driving schemes for cholesteric devices.

In this thesis, we investigated the mechanisms of three types of texture transitions in planar-aligned cholesteric liquid crystal cells: homeotropic-planar texture transition, homogeneous-planar texture transition and planar-focal conic texture transition. In addition, the mechanism of homeotropic-fingerprint texture transition was discussed in homeotropic-aligned cholesteric liquid crystal cells. In order to understand the dynamics of texture transitions, a computer program for three-dimensional simulation based on the finite element method was developed.

When the applied electric field was turned off abruptly, the dynamics of homeotropic-planar texture transition was numerically analyzed and experimentally confirmed in a planar-aligned cholesteric liquid crystal cell. Furthermore, the effect of bias waveform on the homeotropic-planar relaxation process was also studied. On the basis of this knowledge, a bias waveform was designed to reduce the long relaxation time. Similarly, we also numerically investigated the dynamics of the homogeneous-planar texture transition when the unwound electric field was removed abruptly. The simulation results agreed well with the previous experimental observations. Moreover, we found that the Helfrich deformation can be induced not only by an electric field but also by an elastic force. Therefore, we compared the elastic-induced Helfrich deformation during the homeotropic-planar and homogeneous-planar texture transitions with the electric-induced Helfrich deformation during the planar-focal conic texture transition. On the other hand, we observed the modulated textures during the planar-focal conic texture transition by changing the applied electric field. It was found that the modulated textures exhibit either an ordered striped texture or an ordered hexagonal texture depending on the applied electric-field strength. Of these textures, the ordered hexagonal texture was experimentally observed for the first time.

Finally, we observed the stripe formation during the homeotropic-fingerprint texture transition when the applied electric field was turned off abruptly in homeotropic-aligned cholesteric liquid crystal cells with patterned electrode configurations. The striped direction depended not only on the thickness-to-pitch ratio, but also on the applied electric field. In this work, the cholesteric liquid crystal phase grating with the field-controllable grating orientation and grating period was realized and the operational mechanism of this device was presented.

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Ec : critical field necessary to unwind the helix of cholesteric liquid crystals

n_o : ordinary refractive index of liquid crystals

n_e : extraordinary refractive index of liquid crystals

n_{eff} : effective refractive index of liquid crystals

m : diffraction order

d : thickness of the liquid crystal cell gap

$<n>$: the average refractive index of the medium

$\Delta\lambda$: spectral width of the selective reflection band

Δn : birefringence of a nematic layer perpendicular to the helical axis

Δn_{eff} : effective birefringence $\Delta n_{eff} = n_{eff} - n_o$

Λ : grating period

θ_B : Bragg angle

ϕ : angle between the rubbing directions of two plates

f_{lc} : elastic free energy density of a liquid crystal system

F_{lc} : elastic free energy of a liquid crystal system

K_{11} : splay elastic constant of liquid crystals

K_{22} : twist elastic constant of liquid crystals

K_{33} : bend elastic constant of liquid crystals

K_{13} : splay-bend elastic constant of liquid crystals

K_{24} : saddle-splay elastic constant of liquid crystals

P_0 : natural pitch of cholesteric liquid crystals

q_0 : chiral parameter ($=2\pi/P_0$)

d/P_0 : thickness to natural pitch ratio

$\vec{n}$: director of liquid crystals

$\varepsilon_{\parallel}$: dielectric constant measured under the electric field parallel to the director

$\varepsilon_{\perp}$: dielectric constant measured under the electric field perpendicular to the director

$\Delta\varepsilon$: dielectric anisotropy of liquid crystals ($=\varepsilon_{\parallel}-\varepsilon_{\perp}$)

ε : dielectric constant of the material

χ_e : electric susceptibility of the medium

$\vec{D}$: electric displacement

f_e : electric free energy density of a liquid crystal system

F_e : electric free energy of a liquid crystal system

λ_s : dimensionless surface parameter

A : anchoring strength of the director at the surface

f_s : surface free energy density of a liquid crystal system

$\Delta\alpha$: deviation angle of the director at the surface from the easy axis at the polar direction

$\Delta\phi$: deviation angle of the director at the surface from the easy axis at the azimuthal direction

α : pretilt angle of the director at the surface

f_g : Gibbs free energy density of a liquid crystal system

F_g : Gibbs free energy of a liquid crystal system

F : total free energy of the liquid crystal system

Γ : Lagrange multiplier

n_i : projection of the director on x_i axis (i=x,y,z)

γ_1 : rotational viscosity of liquid crystals

S_i : interpolation functions or shape functions (i=1~4)

P^* : effective pitch of the transient planar texture [$P^*=(K_{33}/K_{22})P_0$]