



### Article Optical Response Associated with the Orientation and Structure of Liquid Crystals with Respect to Phosphatidylcholine Concentration

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Abstract: Based on the anchoring effect due to the self-assembling behavior of the phospholipid molecules at the interface between the liquid crystal and water phases on the orientation of liquid crystals, the optical response associated with the orientation and structure of liquid crystals with respect to the concentration of 1,2-didodecanoyl-sn-glycero-3-phosphocholine solution has been investigated. The optical response owing to changes in the orientation and structure of the mixed cholesteric liquid crystals with respect to the change in the concentration of phosphatidylcholine has been obtained. Moreover, the feasibility of using as-prepared mixed cholesteric liquid crystals to measure the phosphatidylcholine concentration has been verified. A methodology to measure the reflectance spectrum by using mixed cholesteric liquid crystals to sensitize the phosphatidylcholine concentration has been further realized. The sensitization effect of the mixed cholesteric liquid crystals on the measurement of phosphatidylcholine concentration was also verified.

**Keywords:** liquid crystals; cholesteric liquid crystals; nematic liquid crystal; phosphatidylcholine; optical fiber; sensor

### 1. Introduction

Plenty of liquid-crystal-state biological tissue primitives, such as proteins, lipids, polysaccharides, etc., are available in the biological systems. These substances exhibit either a rod or a flat shape in solutions, with benzene rings and polar groups forming hydrogen bonds, which is the condition for the formation of the liquid crystal phases. Therefore, studies on the liquid-crystal-state conformation of the biological tissue primitives have attracted significant research attention for bio-sensing. These studies include the verification of the presence of the liquid crystal phase in the biological systems via novel physical and chemical methods as well as investigation of the effect of the biochemical substances on the liquid crystal state of the phases. Based on the changes in the orientation of the liquid crystals, Abbott et al. from the University of Wisconsin-Madison identified the optical enlargement of the interactions between the phospholipids and proteins under a polarizing microscope. The authors proposed a novel method with no requirement of fluorescence labeling for investigating the self-assembly and membrane formation process of the phospholipids and proteins, thus establishing the application of liquid crystals for bio-sensing [1]. Based on the findings of Abbott et al., bio-sensing technology based on the change in the liquid crystal orientation has been widely applied for protein and DNA analyses, thus becoming the method of choice in the field of bio-sensing [2–7].



**Citation:** Han, Y.; Jiang, Y.; Guo, W.; Li, B.; Zhang, L.; Liang, T.; Wu, J.; Wei, H. Optical Response Associated with the Orientation and Structure of Liquid Crystals with Respect to Phosphatidylcholine Concentration. *Crystals* **2021**, *11*, 678. https:// doi.org/10.3390/cryst11060678

Academic Editor: Charles Rosenblatt

Received: 17 May 2021 Accepted: 9 June 2021 Published: 12 June 2021

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Optical fiber sensors, especially the ones based on evanescent fields, have been gradually applied for sensing in the biological and medical fields due to their small size, low cost, resistance to electromagnetic interference, simple networking, and reuse, among other advantages. In our previous study, it has been reported that the power of the light transmitted in the side-polished optical fiber can be used to characterize the changes in the orientation of the nematic liquid crystals [8]. Furthermore, it has also been proved that the changes in the helical structures of the cholesteric liquid crystals can be characterized by using the transmittance spectrum of the side-polished optical fiber [9]. However, the characterization of the orientation and structure of the liquid crystals with respect to the interaction between the biomolecules is still needed so as to construct optical fiber bio-sensors based on the liquid crystal media. Therefore, this study investigates the characteristics of the response associated with the orientation and structure of the liquid crystals with respect to the concentration of 1,2-didodecanoyl-sn-glycero-3-phosphocholine, based on the anchoring effect due to the self-assembly behavior of the phospholipids at the interface between the liquid crystal and water phases on the orientation of the liquid crystals. Sensitization of the phosphatidylcholine concentration measurement with its reflectance spectrum was obtained by using mixed cholesteric liquid crystals. The sensitization effect of the mixed cholesteric liquid crystals on the measurement of phosphatidylcholine concentration was subsequently verified. The findings obtained in this study lay the foundation for the development of a side-polished fiber optic biosensors based on the liquid crystal media.

#### 2. Experimental Design and Principles

In a previous study [9], the feasibility of characterizing the changes in the helical structures of cholesteric liquid crystals via the transmittance spectrum of the side-polished optical fiber has been verified. Moreover, the hydrophobic groups in the phospholipid molecules at the interface between the liquid crystal and water phases undergo hydrophobic association with the nematic liquid crystal, thus leading to changes in the orientation of the liquid crystal molecules. In this study, the characteristic surface reflectance spectrum of the mixed cholesteric liquid crystals with respect to the phosphatidylcholine concentration has been investigated. Correspondingly, the mixing of nematic liquid crystals with the cholesteric liquid crystals has been proposed and demonstrated. The modulation effect of the phosphatidylcholine concentration on the orientation and structure of cholesteric liquid crystals was sensitized by considering the hydrophobic interaction between the phosphatidylcholine molecules and nematic liquid crystals. The findings from this study lay the foundation for phosphatidylcholine concentration detection using side-polished optical fiber based on liquid crystal media.

## 2.1. The Hydrophobic Association of 1,2-Didodecanoyl-sn-Glycero-3-Phosphocholine with Liquid Crystal Molecules

The self-assembly of the phospholipids and proteins on the surface of bio-membranes is attributed to the liquid-crystal-state conformation of the bio-membranes. The main component of the phospholipids, accounting for 70% (w/w) content of bio-membranes, is phosphatidylcholine. This is an amphiphilic substance and common chemical medium [10]. Additionally, the 1,2-Didodecanoyl-sn-glycero-3-phosphocholine (L-DLPC) used in this study is a commonly used synthetic phosphatidylcholine. Abbott et al. [1] reported that the phospholipid molecules that self-assembled at the interface between the liquid crystal and the water phases underwent hydrophobic association with the 5CB nematic liquid crystals through the hydrophobic ends, thus leading to alterations in the orientation of the liquid crystal molecules. The changes in the light transmission intensity and texture of the polarization signal were studied for characterizing the hydrophobic interaction between 1,2-didodecanoyl-sn-glycero-3-phosphocholine and liquid crystal molecules. However, this detection method is qualitative or semi-quantitative, which requires the use of micropoint probes to achieve the local quantification of the measurement values. Therefore, it is difficult to realize the online monitoring of the biological samples in real time using this method.

In this study, the hydrophobic association between 1,2-didodecanoyl-sn-glycero-3phosphocholine and liquid crystal molecules was characterized by using the surface reflectance spectrum of the mixed cholesteric liquid crystal collected by using a reflective type fiber-optic probe. Thus, this approach makes it feasible to characterize the hydrophobic association between 1,2-didodecanoyl-sn-glycero-3-phosphocholine and liquid crystal molecules by using the side-polished optic fiber.

### 2.2. Experimental Principle for Characterizing the Optical Response Related to the Orientation and Structure of Liquid Crystals with Respect to the Phosphatidylcholine Concentration

Cholesteric liquid crystals demonstrate a periodic intrinsic helical structure. After mixing cholesteric liquid crystals with nematic liquid crystals, the nematic liquid crystal molecules are noted to twist and arrange along the screw axis of the cholesteric liquid crystal, thus resulting in the extension of the intrinsic helical structure of the cholesteric liquid crystal [11]. As shown in Figure 1a, the pitch of the cholesteric liquid crystal is an important structural parameter. The pitch signifies that the cholesteric liquid crystal can reflect the visible light of the same wavelength as its pitch. Due to the fact that the helical structure of the mixed cholesteric liquid crystals contains rod-shaped nematic liquid crystal molecules, the changes in the orientation of the nematic liquid crystal molecules will correspondingly modulate the helical structure of the cholesteric liquid crystals (as shown in Figure 1b). Due to the anchoring effect of the water phase at the interface, the nematic liquid crystal molecules in the vicinity are noted to be parallel to the interface and arrange themselves along the helical axis of the cholesteric liquid crystals (as shown in Figure 1c). In the presence of the self-assembled 1,2-didodecanoyl-sn-glycero-3-phosphocholine molecules at the interface between the liquid crystal and the water phases, the nematic liquid crystal molecules are no longer arranged in a parallel manner along the interface due to the association between the hydrophobic ends of the nematic liquid crystal and the 1,2-Didodecanoyl-sn-glycero-3-phosphocholine molecules. Therefore, modulating the change in the orientation of the nematic liquid crystals is expected to alter the helical structure of the cholesteric liquid crystals, thus, increasing their equivalent pitches (as shown in Figure 1c). Specifically, the equivalent pitch of mixed cholesteric liquid crystals is noted to be sensitive to changes in the orientation of the nematic liquid crystals. The relationship between the equivalent pitch and concentration of 1,2-didodecanoyl-sn-glycero-3-phosphocholine can subsequently be described by a specific function. For the incident light parallel to the helical axis of the liquid crystals, mixed cholesteric liquid crystals exhibit the strongest selective reflection of the incident light. The wavelength of the reflected light can, thus, be expressed via Equation (1).

$$\lambda_0 = n' p_{eff} \tag{1}$$

where, n' is the equivalent refractive index and peff is the equivalent pitch of the mixed cholesteric liquid crystals. It is obvious from Equation (1) that the selective reflection of the incident light by mixed cholesteric liquid crystals is related to their equivalent pitch, along with being sensitive to the orientation change of the nematic liquid crystals. As the concentration of 1,2-didodecanoyl-sn-glycero-3-phosphocholine is varied to different levels, the nematic liquid crystals correspondingly undergo alteration in the orientation to varying degrees [1]. As a result, the selective reflection of the incident light by the mixed cholesteric liquid crystals also changes.

In this study, three solutions with different 1,2-didodecanoyl-sn-glycero-3-phosphocholine concentrations were dropped on the surface of mixed liquid crystals. The wavelength of the light reflected by the mixed cholesteric liquid crystals with respect to the concentration of 1,2-didodecanoyl-sn-glycero-3-phosphocholine was subsequently investigated based on the changes in orientation and structure of the liquid crystals.



**Figure 1.** Schematic diagram of the experimental method and principle of the characterization of the optical response associated with the orientation and structure of liquid crystals with respect to the phosphatidylcholine concentration: (**a**) Schematic diagram of the intrinsic helical structure of cholesteric liquid crystal. (**b**) Schematic diagram of the helical structure of mixed cholesteric liquid crystals in the vicinity of the water phase interface under its anchoring effect. (**c**) Schematic diagram of the changes in the helical structure of mixed cholesteric liquid crystals in the vicinity of the water phase interface under its anchoring effect. (**c**) Schematic diagram of the changes in the helical structure of mixed cholesteric liquid crystals in the vicinity of the water interface in the presence of phosphatidylcholine.

#### 3. Sample Preparation and Experimental Techniques

3.1. Preparation of the Mixed Cholesteric Liquid Crystals

The nematic liquid crystal 5CB (4-cyano-4'-pentylbiphenyl) was first mixed with the as-prepared cholesteric liquid crystal (cholesteryl ester liquid crystals, CLC) [9] at a volume ratio of 15%:85% (v/v). The mixed cholesteric liquid crystals were subsequently prepared according to the following procedure:

- 1. The mixed liquid crystal sample consisting of 15% 5CB nematic liquid crystals and 85% cholesteryl ester liquid crystals (v/v) was heated by using a heating gun until the two liquid crystal phases became isotropic to form a transparent liquid.
- 2. The mixture of the liquid crystals heated to an isotropic state was subsequently placed in an ultrasonic wave generator for agitation by ultrasonic waves at 40 °C to promote the uniform mixing of the two ingredients.
- 3. The mixture was subsequently mounted in a vortex mixer and shaken for 10 min to further promote the mixing of the two ingredients.
- 4. The sample was finally allowed to stand and cool to room temperature. As a result, the mixed cholesteric liquid crystal sample was obtained.

#### 3.2. Preparation of 1,2-Didodecanoyl-sn-Glycero-3-Phosphocholine Solutions

TBS buffer was prepared by mixing 10 mM Tris solution with 100 mM NaCl solution, followed by adjusting the pH of the mixed solution to 8.9. Different amounts of 1,2-didodecanoyl-sn-glycero-3-phosphocholine were dissolved in the as-prepared TBS buffer to prepare solutions with 1,2-didodecanoyl-sn-glycero-3-phosphocholine concentration of 0, 0.025, and 0.1 mM; 4.68 mL of the three solutions was subsequently added separately to three petri dishes.

#### 3.3. Experimental Techniques

The experimental setup is shown in Figure 2. Light source 1 (designated as LS-1) provides the incident light covering the visible wavelength range. The reflectance spectra of the mixed cholesteric liquid crystals were collected using a USB4000 spectrophotometer (Ocean Optics Co., Ltd. Shanghai, China) containing a reflective fiber-optic probe. The characteristics of the reflectance spectra of the samples were compared with respect to the concentration of the solution. The petri dishes were placed on a hot plate, and the ambient temperature in the vicinity of the petri dishes was set to 26 °C by adjusting the heating power of the hot plate at an appropriate level. A 3  $\mu$ L solution of the mixed cholesteric liquid crystals was added to the three petri dishes with a pipette. Subsequently, 4.68 mL of 1,2-didodecanoyl-sn-glycero-3-phosphocholine solutions with concentrations of 0, 0.025, and 0.1 mM were added to the three petri dishes. The liquid heights of the solutions in the petri dishes were maintained at 12.1 mm. The reflective-type fiber-optic probe of

the USB4000 spectrophotometer was mounted in a position vertical to the surface of the mixed liquid crystals so as to guarantee the incident light vertically hitting the surface of the mixed liquid crystals. The reflectance spectra of the mixed cholesteric liquid crystal samples were subsequently scanned with a spectrophotometer.





**Figure 2.** Schematic diagram and image of the experimental set up used for the investigation of the optical response associated with the changes in the orientation and structure of liquid crystals with respect to the phosphatidylcholine concentration.

#### 4. Results and Discussion

## 4.1. Changes in the Reflectance Spectra of Liquid Crystals Caused by the Helical Structure of Mixed Cholesteric Liquid Crystals

In this study, 5CB was mixed with the cholesteryl ester liquid crystals at a volume ratio of 15%:85%. The mixed cholesteric liquid crystals were subsequently prepared by heating and shaking the mixture. As shown in Figure 3a, after mixing the cholesteryl ester liquid crystals with 15% 5CB (v/v), the color of the liquid crystals was observed to shift from blue to red. The reflectance spectra of the mixed cholesteryl ester liquid crystals as well as cholesteryl ester liquid crystals (i.e., 100% cholesteric liquid crystals) were obtained at room temperature (26 °C). Comparison of the reflectance spectra of the two liquid crystal samples (Figure 3b) reveals that the wavelength of the reflection peak in the case of mixed cholesteryl ester liquid crystals red-shifted to 244 nm. According to Equation (1), the red shift indicates that mixing the nematic liquid crystal with the cholesteryl ester liquid crystal changes the helical structure of the mixed cholesteric liquid crystal, along with enhancing its equivalent pitch. The observed changes could be attributed to the fact that mixing with the cholesteryl ester liquid crystals twists the rod-shaped 5CB nematic liquid crystals, along with their arrangement parallel to the helical structure of the cholesteryl ester liquid crystals. The observed helical growth of 5CB weakens the intrinsic helical capability of the cholesteryl ester liquid crystals. As a result, compared with the cholesteryl ester liquid crystals, the equivalent pitch of the mixed cholesteric liquid crystals is increased.

In this study, pure nematic liquid crystal 5CB was mixed with cholesteryl ester liquid crystals. Although the nematic mixtures [12–14] usually have a much higher birefringence than pure nematics, the orientation of the pure nematic liquid crystal molecules are changed due to the association between the hydrophobic ends of the pure nematic liquid crystal and the 1,2-Didodecanoyl-sn-glycero-3-phosphocholine molecules. Therefore, modulating the change in the orientation of the pure nematic liquid crystals is expected to alter the helical structure of the cholesteric liquid crystals, thus increasing their equivalent pitches.



**Figure 3.** The as-prepared mixed cholesteric liquid crystals as well as cholesteryl ester liquid crystals (i.e., 100% cholesteric liquid crystals): (a) Images of the as-prepared mixed cholesteric liquid crystals as well as the cholesteryl ester liquid crystals; (b) reflectance spectra of the mixed cholesteric liquid crystals as well as the cholesteryl ester liquid crystals.

# 4.2. Comparison of the Reflectance Spectra of Mixed Cholesteric Liquid Crystals with Different Mixing Ratios

In this study, 5CB was mixed with cholesteryl ester liquid crystals (100% cholesteric liquid crystals) at a volume ratio of 25%:75%. The mixed cholesteric liquid crystals sample was prepared by heating and shaking the mixture under the same conditions as used earlier. This sample was prepared mainly to explore the mixing ratio suitable for the measurement requirements. The reflectance spectrum of the mixed cholesteric liquid crystals (25%:75%, v/v) sample was measured at room temperature (26 °C) and compared with the reflectance spectrum of the mixed cholesteric liquid crystals sample with a mixing ratio of 15%:85%. As shown in Figure 4, no obvious reflection peak is observed in the reflectance spectrum of the mixed cholesteric liquid crystals with a mixing ratio of 25%:75%. Considering that the wavelength range of the LS-1 light source is 350 nm~1200 nm and the modulation effect of the concentration of the 1,2-didodecanoyl-sn-glycero-3-phosphocholine solution on the helical structure of the mixed liquid crystals during the experiment, the mixed cholesteric liquid crystals sample with a mixing ratio of 15%:85% was selected owing to the superior detection sensitivity for spectral analysis.



**Figure 4.** Reflectance spectra of mixed cholesteric liquid crystals with mixing ratios of 25%:75% and 15%:85%.

### 4.3. Influence of Liquid Surface Pressure on the Surface Reflectance Spectrum of Mixed Cholesteric Liquid Crystals after the Addition of Water

The helical structure of cholesteric liquid crystals results not only due to the material itself, but also has a sensitive functional relationship with factors in the external environment such as temperature, pressure, electromagnetic field, etc. These factors affect

the surface reflectance spectrum of the mixed cholesteric liquid crystals. Therefore, in order to eliminate the interference of the environmental factors with the experimental findings, the effect of the liquid surface pressure on the surface reflectance spectrum of the mixed cholesteric liquid crystals has been discussed in this study. For this purpose, 3 µL droplets of the mixed cholesteric liquid crystals sample were placed in a petri dish at room temperature (26 °C). Subsequently, the correlation between the reflectance spectrum of the mixed cholesteric liquid crystals and height of the water phase, along with the correlation between the reflectance spectrum of the mixed cholesteric liquid crystals and liquid surface pressure, was investigated by continuously enhancing the height of the water phase in the petri dish. The experimental results are presented in Figure 5a. As the height of the water phase exceeded 11.8 mm, the surface reflectance spectrum of the mixed cholesteric liquid crystals did not change significantly with the height of the water phase. Compared with the scenario of no water phase added in the petri dish, the reflection peak of the mixed cholesteric liquid crystal was observed to be more prominent after the addition of water. The observed difference in the reflection peak can be attributed to the fact that the helical axis of the mixed cholesteric liquid crystals is arranged in a direction vertical to the interface under ideal conditions. It can be observed from Equation (1) that a prominent reflection peak appears in the surface reflectance spectrum of the liquid crystals measured under these conditions. If the mixed cholesteric liquid crystals are not subjected to the anchoring treatment, the helical axis of the mixed cholesteric liquid crystals would not be able to uniformly arrange in a direction vertical to the interface. Therefore, a wider reflection peak would appear in the surface reflectance spectrum of the liquid crystal surface. However, on adding the water phase, owing to the fact that the water interface has a certain anchoring effect on 5CB in mixed cholesteric liquid crystals, the helical axis of the mixed cholesteric liquid crystals in the vicinity of the water surface tends to arrange in a direction vertical to the interface. The observed change in the orientation of the liquid crystals leads to the appearance of a prominent reflection peak in the surface reflectance spectrum of the mixed cholesteric liquid crystals, thus, improving the measurement sensitivity.



**Figure 5.** The effect of the water phase height on the surface reflectance spectrum of mixed cholesteric crystals: (**a**) The relationship between the surface reflection spectrum of the cholesteric liquid crystals and height of the water phase. (**b**) The relationship between the reflection peak drift in the surface reflection spectrum of the cholesteric liquid crystals and change in the height of the water phase.

As shown in Figure 5b, as the height of the liquid level is increased from 11.2 mm to 11.8 mm, the wavelength of the reflection peak in the spectrum of the mixed cholesteric liquid crystal is shifted by approximately 36 nm. On the other hand, as the height of the liquid crystal is enhanced from 11.8 mm to 12.1 mm, the wavelength of the reflection peak in the spectrum of the mixed cholesteric liquid crystal is shifted by approximately 2 nm only. Therefore, as the height of the water phase exceeded 11.8 mm, the surface

reflection spectrum of the mixed cholesteric liquid crystals was observed to be stable, and the reflection peak in the surface reflection spectrum of the mixed cholesteric liquid crystals did not shift significantly with the height of the water phase.

## 4.4. Surface Reflectance Spectrum of Mixed Cholesteric Liquid Crystals with Respect to the Phosphatidylcholine Concentration

Cholesteric liquid crystals featuring a periodic helical structure exhibit selective reflectivity. For mixed cholesteric liquid crystals, due to the presence of rod-shaped nematic molecules in their helical structure, the equivalent pitch increases correspondingly, and the change in the pitch depends on the variation in the orientation of the nematic liquid crystals. For the solutions with different concentrations of 1,2-didodecanoyl-sn-glycero-3phosphocholine, the strength of the hydrophobic association between 1,2-didodecanoylsn-glycero-3-phosphocholine molecules and nematic liquid crystals is also observed to be different. This further leads to the differences in the extent of change in the orientation of the nematic liquid crystals. As a result, the selective reflection of light by mixed cholesteric liquid crystals is also noted to be different. In the experiments, the wavelength of the selective reflected light of the mixed cholesteric liquid crystals with respect to the 1,2-didodecanoyl-sn-glycero-3-phosphocholine concentration was studied based on the orientation and structural changes in the liquid crystals.

1. The effect of interaction time between phosphatidylcholine and mixed cholesteric liquid crystal on the surface reflectance spectrum of the mixed cholesteric liquid crystals

The reflectance spectra of the mixed cholesteric liquid crystals were measured at three time durations: the first detection was conducted immediately after the addition of the 1,2-didodecanoyl-sn-glycero-3-phosphocholine solution, while the second and the third analyses were conducted after 2 h and 3 h, respectively. Figure 6a shows the surface reflectance spectra of the mixed cholesteric liquid crystals immediately after the addition of 0.1 mM 1,2-didodecanoyl-sn-glycero-3-phosphocholine solution in the mixed cholesteric liquid crystals as well as standing the mixture for 2 h and 3 h. It can be observed that, as the time of interaction between 1,2-didodecanoyl-sn-glycero-3-phosphocholine solution and mixed cholesteric liquid crystals is increased, the surface reflectance spectrum of the mixed cholesteric liquid crystal gradually becomes stable.



**Figure 6.** The effect of interaction time between the 0.1 mM 1,2-didodecanoyl-sn-glycero-3-phosphocholine solution and mixed cholesteric liquid crystals on the surface reflection spectrum of the mixed cholesteric liquid crystals: (**a**) The relationship between the surface reflection spectrum of the cholesteric liquid crystal and interaction time. (**b**) The relationship between the reflection peak drift in the surface reflectance spectrum of the cholesteric liquid crystals and interaction time.

As shown in Figure 6b, the wavelength of the reflection peak in the surface reflectance spectrum of the mixed cholesteric liquid crystals obtained after immediate addition of 1,2-didodecanoyl-sn-glycero-3-phosphocholine solution is 1035.66 nm, whereas, after standing for 2 h, the wavelength of the reflectance peak in the surface reflectance spectrum of the mixed cholesteric liquid crystals is noted to be 964.8 nm. Thus, compared with the wavelength of the reflection peak obtained after immediate addition of 1,2-didodecanoyl-sn-glycero-3-phosphocholine solution, the wavelength obtained after 2 h duration shifted by approximately 70 nm. On the other hand, after standing for 3 h, the wavelength of the reflectance peak in the surface reflectance spectrum of the reflection peak obtained after 2 h, the wavelength of the reflection peak is noted to 959.96 nm. As compared with the wavelength of the reflection peak obtained after 2 h, the wavelength of the reflection peak is noted to drift by approximately 4.8 nm. Therefore, with the evolution of the time duration of interaction, the hydrophobic association between 1,2-didodecanoyl-sn-glycero-3-phosphocholine and nematic liquid crystal gradually stabilizes. Therefore, after 3 h, the shift in the wavelength of reflection peak of the mixed cholesteric liquid crystals almost stops.

2. The characteristics of the surface reflectance spectrum of mixed cholesteric liquid crystals with respect to the phosphatidylcholine concentration

The wavelengths of light reflected by the mixed cholesteric liquid crystal with respect to the 1,2-didodecanoyl-sn-glycero-3-phosphocholine solutions with concentrations of 0, 0.025, and 0.1 mM are shown in Figure 7. After the addition of the 1,2-didodecanoyl-snglycero-3-phosphocholine solution with a concentration of 0 mM and standing the mixture for 3 h, the reflection peak in the surface reflectance spectrum of the mixed cholesteric liquid crystals was observed to appear at the wavelength of 753.17 nm. On the other hand, as the concentration of 1,2-didodecanoyl-sn-glycero-3-phosphocholine was increased to 0.025 mM, the wavelength of the reflection peak in the surface reflectance spectrum of the mixed cholesteric liquid crystals red-shifted to 872.49 nm. Finally, for the 1,2-didodecanoylsn-glycero-3-phosphocholine concentration further increased to 0.1 mM, the wavelength of the reflection peak in the surface reflectance spectrum of the mixed cholesteric liquid crystals red-shifted to 959.96 nm. Thus, for the 1,2-didodecanoyl-sn-glycero-3-phosphocholine concentration increasing from 0 to 0.1 mM, the wavelength of the selective reflected light of the mixed cholesteric liquid crystals red-shifted by 206.49 nm. Based on Equation (1), the red shift indicates that an increase in the concentration of 1,2-didodecanoyl-sn-glycero-3-phosphocholine correspondingly enhances its hydrophobic association with the nematic liquid crystals. The enhanced degree of change in the orientation of the nematic liquid crystal molecules or an increase in the amount of the nematic liquid crystal molecules in hydrophobical association with 1,2-didodecanoyl-sn-glycero-3-phosphocholine correspondingly enhances the equivalent pitch of the mixed cholesteric liquid crystals. As a result, the wavelength of the selective reflected light of the mixed cholesteric liquid crystals red-shifts with the concentration of the 1,2-didodecanoyl-sn-glycero-3-phosphocholine solution.

3. Surface reflectance spectrum of 100% cholesteric liquid crystals with respect to the phosphatidylcholine concentration

Figure 8 presents the wavelengths of the selective reflected light of 100% cholesteryl ester liquid crystals with respect to the solutions with 1,2-didodecanoyl-sn-glycero-3-phosphocholine concentrations of 0, 0.025, and 0.1 mM after standing for 3 h. It can be observed from the experimental findings that the wavelength of the selective reflected light of the 100% cholesteryl ester liquid crystals hardly shifts with the concentration of the 1,2-didodecanoyl-sn-glycero-3-phosphocholine solution. It can be noted from Equation (1) that no hydrophobic association occurred between 1,2-didodecanoyl-sn-glycero-3-phosphocholine and cholesteryl ester liquid crystal molecules, with the pitch of the cholesteryl ester liquid crystals not sensitive to the changes in the concentration of the 1,2-didodecanoyl-sn-glycero-3-phosphocholine solution. Therefore, the 100% cholesteric liquid crystals sample was unable to reflect the changes in the concentration of the 1,2-

didodecanoyl-sn-glycero-3-phosphocholine solution. The mixed cholesteric liquid crystal could be used to sensitize the measurement of the concentration of the 1,2-didodecanoyl-sn-glycero-3-phosphocholine solution with respect to the changes in the orientation and structure of the liquid crystals. In other words, the optical response associated with the changes in the orientation and structure of the liquid crystals was magnified.



**Figure 7.** The wavelengths of the selective reflected light associated with the mixed cholesteric liquid crystals with respect to solutions with different 1,2-didodecanoyl-sn-glycero-3-phosphocholine concentration after standing for 3 h.



**Figure 8.** The wavelengths of the selective reflected light of 100% cholesteryl ester liquid crystals with respect to the solutions with different 1,2-didodecanoyl-sn-glycero-3-phosphocholine concentrations after standing for 3 h.

#### 5. Conclusions

In this study, the wavelengths of the light reflected by mixed cholesteric liquid crystals with respect to the concentration of 1,2-didodecanoyl-sn-glycero-3-phosphocholine solution were studied basing on the anchoring effect associated with the self-assembling behavior of the phospholipid molecules at the interface between the liquid crystal and the water phases on the orientation of the liquid crystals. Further, a method of mixing nematic liquid crystals with cholesteric liquid crystals so as to sensitize the optical measurement of the phosphatidylcholine concentration has been proposed and demonstrated.

The characteristics of the optical response associated with the changes in the orientation and structure of mixed cholesteric liquid crystals with respect to the change in the phosphatidylcholine concentration were experimentally studied. The feasibility of using the prepared mixed cholesteric liquid crystal to measure the concentration of phosphatidylcholine was further verified. Subsequently, a method employing the use of the mixed cholesteric liquid crystals to measure the concentration of phosphatidylcholine was successfully realized. The sensitization effect of mixed cholesteric liquid crystals on the measurement of the phosphatidylcholine concentration was effectively verified. The findings presented in this study lay the foundation for the development of side-polished fiber-optic bio-sensors based on liquid crystal media.

**Author Contributions:** Conceptualization, Y.H.; methodology, Y.H.; formal analysis, Y.H.; investigation, Y.H.; resources, W.G., L.Z., and J.W.; data curation, Y.H., Y.J., B.L., T.L., and H.W.; writing—original draft preparation, Y.H.; writing—review and editing, Y.H.; project administration, Y.H. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by Fundamental Research Funds for the Science and Technology Program of Guangzhou, China, grant number 201707010496, and Fundamental Research Funds for the Youth Innovation Personnel Training Project of Guangdong, China, grant number 2017GkQNCX042.

Acknowledgments: The authors would like to express their gratitude to EditSprings (https://www.editsprings.com/, accessed on 12 June 2021) for the expert linguistic services provided. And the authors would like to express their gratitude to Zhe Chen, Jinan University for the technical support.

**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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