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Development of a Novel Liquid Crystal Sensor for Pollen Detection

Polen Tespiti için Sıvı Kristal Esaslı Yenilikçi Sensör Geliştirilmesi

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Abstract

In this study, we have reported liquid crystal based-sensor for the detection of pollen concentration which triggers an allergy. Cholesteric liquid crystal which is mesophase of thermotropic liquid crystals was used a sensing element in the pollen sensor. The cholesteric liquid crystal samples operating at room temperature were formulated using nematic liquid crystal and chiral dopants in different compositions. The pollen concentration which is embedded in the cholesteric liquid crystal was determined as a function of change in color of cholesteric liquid crystal in the prototype. We demonstrated that the variation of color from green to blue with the increasing pollen concentration using Ocean Optics spectrophotometer. Therefore, the rapid and easy determination of pollen concentration have been became possible by using this prototype. Our sensor will provide simplicity and self-test as a screen of pollen concentration by using the optical advantage of cholesteric liquid crystal as a sensing element.

Keywords: *Allergy, Chiral dopant, Cholesteric liquid crystal, Pollen, Wavelength.*

Öz

Bu çalışmada, alerjiye neden olan polen konsantrasyonunun tespitine yönelik sıvı kristal esaslı bir polen sensörü geliştirilmiştir. Geliştirilen sensörde, algılayıcı madde olarak kolesterik sıvı kristal kullanılmıştır. Kolesterik sıvı kristal örnekleri; nematik sıvı kristal ve kiral maddelerin farklı bileşimleri kullanılarak hazırlanmıştır. Hazırlanan kolesterik sıvı kristal numunelerinin oda sıcaklığında da sıvı kristalin bir alt fazı olarak gözlemlenebilmesi istendiği için çeşitli kiral maddeler kullanılarak farklı numuneler formüle edilmiştir. Hazırlanan numunelere ağırlıkça farklı oranlarda polen eklenmiş ve renklerinde meydana gelen değişiklikler spektrofotometre yardımıyla saptanmıştır. Kolesterik sıvı kristalin optik özelliklerinin sağladığı renk değiştirme özelliğinden yararlanılarak, artan polen konsantrasyonuyla yeşilden maviye bir renk değişimi elde edilmiş, böylelikle değişen polen konsantrasyonunu renk değişiminin bir fonksiyonu olarak saptayan bir prototip geliştirilmiştir. Geliştirilen bu prototip kolay ve bireysel kullanım sağlaması bakımından yenilikçi bir ürün özelliği taşımaktadır.

Anahtar Kelimeler: *Alerji, Kiral Madde, Kolesterik Sıvı Kristal, Polen, Dalga boyu.*

1. Introduction

Currently, pollen allergy is a most common form of allergical disease and 22.3% of the world population suffers from pollen allergy according to World Allergy Organization (WAO) announcement [1,2]. The pollens of trees, grasses, and weeds cause pollen allergy which is a life-threatening reaction because of the allergic symptoms, such as nasal discharge, nasal congestion, and itchy and watery eyes, itchy nose. Allergical diseases generally starts in childhood the followed by the development of hay fever, rhinitis, conjunctivitis and bronchial asthma [3-5]. However, pollen grains contain many allergenic proteins which cause allergies in susceptible individuals. Although pollen is a male reproductive cell with a diameter of 5-200 µm, allergy-causing pollen is small enough to be carried by wind with an average size of 20-60 µm [4]. Pollen releases biomolecules, such as proteins, lipids, enzymes when contacted with an aqueous system. These biomolecules cause a misguided immune reaction in humans by acting as antigens [6]. Therefore, monitoring of different kinds of pollen and their concentration in ambient air with the help of fast alerting system is very important. The rapid and easy determination of pollen concentration is not possible by using the current methods, since these methods require large numbers of pollens as well as the technician who is capable of using them [7-14]. Moreover, many different materials were used to develop sensor technology [15]. Our method will provide simplicity and low cost for self-test as a screen of pollen concentration by using liquid crystal (LC) as a sensing element.

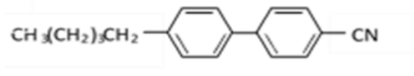
Liquid crystals are an attractive class of soft condensed matter with anisotropic properties based on their rod-like shape and long range orientational order. The molecular orientational order of LCs on the surface which is connected with the LCs can be differentiated depending on the surface characteristics. Liquid crystals have been used widely in the electronics industry as display devices due to their optical properties, and faster response time [16]. The advances in liquid crystals studies showed that these materials have potential for fundamental science as well as innovative applications, especially for the biosensors. LCs can be used as a unique optical probe for biosensors due to their optical amplification. Recently, the using of LC in biosensors as a sensing element leads the detection of bacterial, virus [1,17], enzymatic reactions [18,19], DNA hybridization [20,21], as well as the peptide–lipid membrane interactions [22,23], and bile acids [24].

Our goal is to predicatively understand how liquid crystals can be used to develop pollen sensor. To address this issue, we used cholesteric liquid crystals which are chiral nematic liquid crystals, where the handedness of the constituent molecules induces a change in the orientation of the local direction of nematic liquid crystal in space. The director aligned perpendicularly along the helix axis in the helical structure and the orientation of the director varies linearly with position through the helix axis. The spatial periodicity of cholesterics which is called pitch depends on the concentration and the helical twisting power of the chiral dopants. On the other hand, the pitch determines the wavelength of cholesteric liquid crystals. However, the wavelength which is reflected from cholesteric liquid crystals can be changed depending on the variation in the pitch in the presence of any dopant, such as pollen particles. This paper presents an investigation of a liquid crystal-based pollen sensor depending on the wavelength change of liquid crystal as a function variation in their pitch.

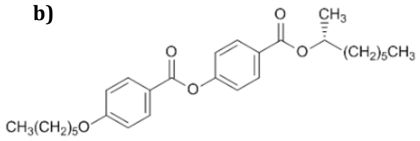
2. Material and Method

A representative cholesteric liquid crystal (ChLC) mixture was formulated with 55 wt% of a commercially available a nematic mixture 4′-Pentyl-4-biphenylcarbonitrile (5CB) (Merck, Germany) as well as chiral dopants of 20 wt%R811 (R-octan-2-yl 4-((hexyloxy)benzol)oxy)benzoate) (Sigma Aldrich), 20 wt% CB15 ((S)-4-Cyano-4′-(2-methylbutyl)biphenyl) (Sigma Aldrich), and 5 wt% R1011 ((1,2-bis[4-(4-pentyl cyclohexyl)benzoate]-1-(R)-phenyl ethane)). All the chiral dopants were commercially supplied from Sigma Aldrich Company. The molecular structures of liquid crystal 5CB and chiral dopants are shown in Fig. 1.

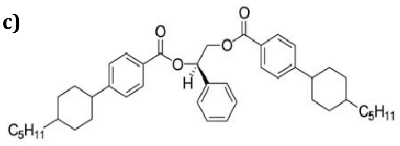
a)



b)



c)



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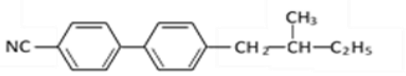

Figure 1. Chemical Structures of a) 4-cyano-4'-pentylbiphenyl (5CB); b) R811 (R-octan-2-yl 4-((hexyloxy)benzol)oxy)benzoate); c) R1011 ((1,2-bis[4-(4-pentyl cyclohexyl)benzoate]-1-(R)-phenyl ethane)); d) CB15 ((S)-4-Cyano-4´-(2methylbutyl)biphenyl).

The cholesteric liquid crystal mixtures were formed by stirring the nematic liquid crystal and chiral dopants in an ultrasonic bath at room temperature for half an hour. Cholesteric liquid crystal mixtures were doped with pollen at different concentrations as listed in Table I, and the mixtures were again stirred with a vortex shaker at 1000 rpm for 1 hour at room temperature.

Table I. Transition temperatures of samples.

Sample	*Pollen concentration (wt %)*	*Temperature Range ($\Delta T_{Iso\text{-}NI}$, °C)*
TE	0	22.5-6
TE1	0.06	25-18.6
TE2	0.1	22.2-15.5
TE3	1.0	22.6-8

Subsequently, one drop of the mixture is placed inside indium tin oxide (ITO)-coated glass cells separated by glass ball spacers to give a cell gap of 25 µm in order to determine the transition temperatures of all cholesteric liquid mixtures. Then all samples were heated to the isotropic phase and cooled to room temperature at a rate of 0.5 °C/min. A polarizing optical microscope (POM) with a pair of the polarizers crossed at 90° was used to observe the optical textures of the samples after these samples were positioned on a hot stage equipped which has a programmable temperature controller.

3. Results

In order to investigate the effects of the pollen on the ChLC phase behavior, samples with different pollen concentrations are formulated and the compositions of these samples are listed in Table I. Cholesteric textures of all pollen doped ChLC samples are observed via POM. Before doping of pollen, the cholesteric phase displayed isotropic-to-cholesteric-phase transition at 22.5 °C and cholesteric-nematic phase transition at 6 °C, as seen in Fig.2.

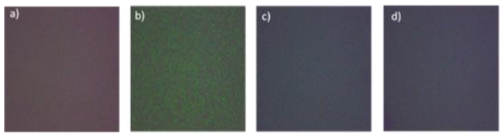

Figure 2. POM images of cholesteric textures of sample TE at a) 22 °C, b) 20.8 °C, c) 20 °C, d) 19.8 °C.

The POM observation proved that the ChLC phase temperature ranges are wider than the temperature ranges of the mixtures before doping of pollen. Samples of TE1, TE2 and TE3 show the isotropic-to-cholesteric-phase transition at 25 °C, 22 °C, and 21 °C respectively. However, all the samples are in the cholesteric phase even below 0 °C. Additionaly, it is observed that the pollen doping has an effect on the color of these samples at the certain temperature. Different pollen concentrations cause different color appearances in the samples at room temperature, as shown in Fig. 3. The textures of the ChLC mixtures are initially observed to have small, green colored domains and the domain size found to increase in the pollen-doped ChLC mixture with an increase in a pollen concentration up to 0.1wt%.

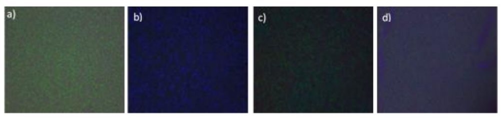

Figure 3. POM images of cholesteric textures of samples of a) TE, b) TE1, c) TE2, d) TE3 at 20°C.

Further, the reflected wavelengths as a function of the pollen concentrations are determined with an Ocean Optics spectrophotometer at 21oC. Fig. 4. shows that the Bragg reflection wavelengths of all the samples are temperature independent. However, the reflected wavelength of the sample is green-shifted as the pollen concentration was increased from 0 wt% to 0.06 wt%. The pollen concentration was increased from 0.06 wt% to 0.1 wt%, the reflected wavelength shifted from dark green to blue indicating a deformation or tilting in the ChLC phase. Moreover, the small colored pictures shown in Fig.4 are the photographs of the ITO-coated glass cells including the samples.

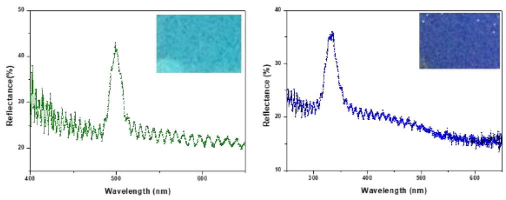

Figure 4. Plot of wavelength versus temperature for samples a) 0.06 wt% b) 0.1 wt% pollen doped ChLC.

The helical pitch of ChLC is very sensitive to the materials which are externally doped; therefore, Bragg reflection peaks can be easily changes in response to deformation or reorientation of the ChLC textures as seen in Fig. 5.

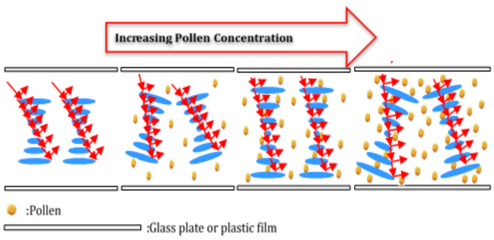

Figure 5. Schematic representation of the change in helical pitch of ChLC doped with pollen.

4. Conclusions

We have demonstrated the specific detection of a pollen concentration using the interactions between ChLC phase and pollen particles to modify the deformation or tilt of the ChLC textures. Our experimental results exhibit that the concentration of pollen plays an important role in the optical response of cholesteric liquid crystals which can be useful for a new application field as sensors. The changes of domain size as well as the reflected wavelength can be rapidly optically determined and lead a design for the new sensor.

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