Surface Behavior and Thickness Measurement of Free Standing Thin Film of Liquid Crystal Compound Biphenyl (E7)

M. Asif Siddiqui[1], Zaheer Uddin[2,*] and S. Naseem Shah[1]

[1]Department of Physics, Federal Urdu University of Science and Arts, Karachi, Pakistan

[2]Department of Physics, University of Karachi, Pakistan

Abstract: A simple experimental setup based on a polarizing optical technique is designed to find the thickness of free standing thin film of Biphenyl (E7). Monochromatic light is passed through a liquid crystal thin film in two different modes of placement. In each mode approximately 10 mg of Biphenyl is used. The films of varying area were used in this study. The thin films were highly stable and could survive more than one day. The intensity of transmitted monochromatic radiation is measured using this technique by placing thin film in horizontal and vertical modes. Using Beer-Lambert's Law the thickness of thin film is also measured using polarizing optical technique. In both the modes (horizontal and vertical) different behaviors of thickness of thin film are observed.

Keywords: Thin film, Biphenyl (E7), Polarizing Optical Technique, Beer-Lambert's Law.

INTRODUCTION

The thickness of a thin film is a very important parameter due to quantitative characterization of Thermodynamic behavior and Electro optical study of different liquid crystal compounds. In the case of free standing thin film, not only thickness plays a vital role but surface behavior as well. There is a sufficiently large number of experimental methods for finding the thickness of a thin film for instance by laser reflectivity, optical microscopy, interference of light, capacitance, resistance measurement and EHD instability. All these techniques are not very precise since only the average film thickness can be determined by these techniques.

The study was conducted by using biphenyl (E7), a room temperature nematic liquid, formed by combining four different "cyano biphenyl liquid crystals" i.e.

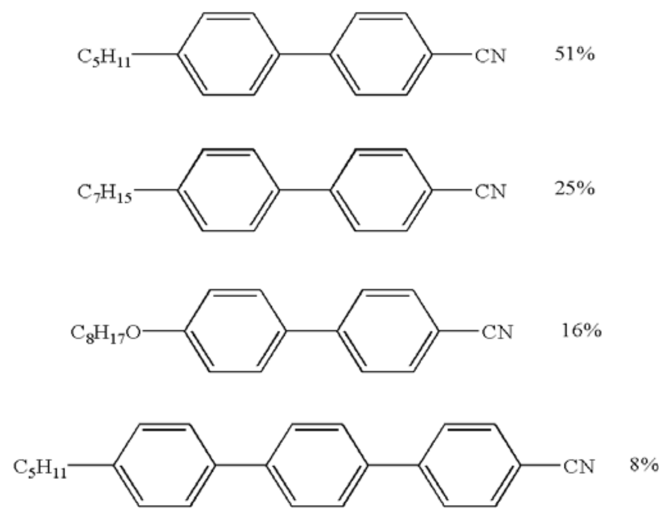
1. 5CB (4-cyano-4'-pentyl biphenyl (47 mol. %), (51% by weight)),

2. 7CB (4-cyano-4'-heptyl biphenyl (25 mol. %), (25% by weight)),

3. 8OCB (4-cyano-4'-octyle biphenyl (18 mol. %), (16% by weight)),

4. 5CT (4-cyano-4'-pentyl teraphenyl (10 mol. %), (8% by weight)).

*Address correspondence to this author at the Department of Physics, University of Karachi, Pakistan; E-mail: zaheer103@yahoo.com



Biphenyl is an aromatic hydro-carbon; at room temperature it is a colorless solid. The main sources of biphenyl are natural gas, coal tar and crude oil and their byproducts. According to Paschke *et al*. a concentration of 1.5 mg/kg of biphenyl is found in unused lubricating oil [1].

The traces of biphenyl can be found in exhaust gases of various sources, which include both industrial and residential heating and exhausts of vehicles [2]. Biphenyl is used as a preservative because it prevents fungus and molds; it is also used in organic synthesis.

A thin film means a very thin layer of materials having thickness within the range of nanometers to micrometers. Thin films are ubiquitous in nature. They have applications in Geology, Fluid Dynamics, Biophysics, Chemistry, Physics, and Electronics Display Devices, etc. [3, 4]. In last two decades these

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films have found considerable attraction in both theoretical and experimental investigations. The free standing liquid thin film has been extensively used for Electro-Optical Investigation, Fluid Dynamics and Phase Transitions Studies [5]. The free standing films in contrast to sandwiched liquid crystal films provide good interpretation for the electro-optic studies. The preparation of free standing films is relatively straightforward and relatively less distortion occurs during their preparation. A solid frame is used to support these freely suspended thin films. These films develop meniscus having structures of complex nature [6, 7]. The freely suspended thin film menisci were studied using optical interferometry and atomic force microscopy [7]. Furthermore, the growth of regions of several micrometers (known as holes) was studied by polarizing microscopy [8]. A negative pressure is created by the meniscus curvature in liquid crystal thin film, and using the radius of curvature of this meniscus, this pressure difference was measured [9]. A linear relationship between the curvature of the meniscus and the radius of holes formed in the free standing film were also found [10]. A constant speed of dislocation for thick film and its depends on meniscus pressure was studied through growth of dislocation in thin octylcyanobiphenyl layer. An inverse relation between layer thickness and the velocity of dislocation motion was found [11]. The corona pattern was studied through spraying micrometer sized droplets on thin film. They structure and physical origin of such patterns were also studied. [12]. It was found that fusion of menisci is responsible for the strong attraction of absorbed colloids [13]. The information about the internal structure of some stripe domain was gathered [14]. A model was proposed for the different interpretation in films, the correlation between shrinkage layer in the transition, contact with substrate and the shape of the stripe was suggested [4]. Nevertheless, the model fails to explain the origin of the stripes. The macroscopic theory of thinning of a liquid film with rigid boundaries was also presented [15]. Several studies have been carried out for the determination of refractive index and thickness of thin films [16, 17]. There were a number of experiments performed for finding the thickness of a thin film such as laser reflectivity, optical microscopy, and interference of light, capacitance and resistance measurement [18, 19].

EXPERIMENTAL DETAILS

The experimental work is based on polarizing optical technique. The experimental setup is shown in Figure **1**. The liquid crystals biphenyl (E7) is used to form a thin film. The sample (thin film) is placed between two polarizing plates; one of them acts as a polarizer and the other one as an analyzer. The sample placed between them is free standing film formed in rectangular or square Aluminum foil frames. The thin free standing films are formed by placing few drops of liquid crystal on aluminum foil and which is swept along the aperture. The thickness of the film depends upon the thickness and smoothness of the aperture, and also on the cohesive forces between the crystal molecules and adhesive forces between aluminum and liquid crystal.

The surface of thin film of liquid crystal compound (E7) is divided into the various cells; the number of cells depends upon the size or surface area of the thin

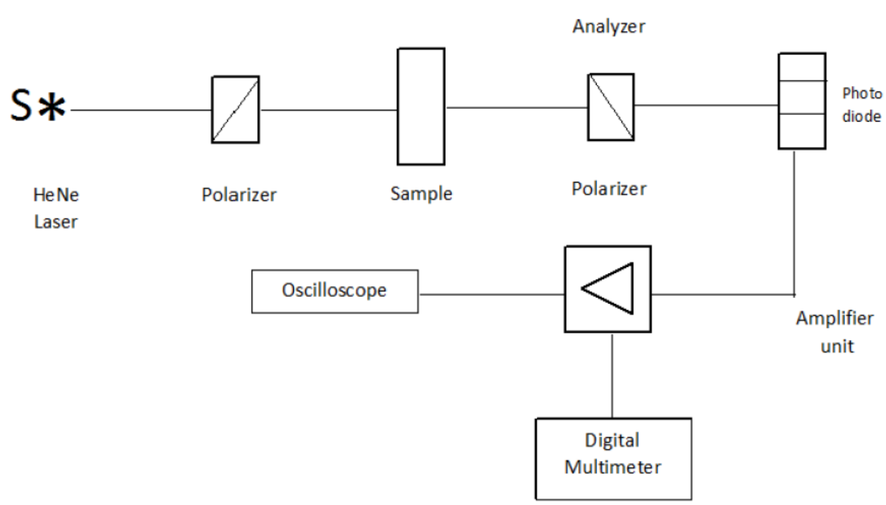


Figure 1: Experimental arrangement for monitoring the transmission intensities through the sample of free standing thin films of liquid crystal.

film. For example, a free standing thin film with an aperture dimensions of 5mm by 8mm (5000μm x 8000 μm) can be considered as arrangement of 160 cells in sixteen column (16C) and ten rows (10R); the size of each cell being 0.5mm by 0.5mm (500μm x 500μm). Each cell is recognized by its row and column numbers. The first cell is named as (1, 1) (first row and first column).

Each cell is illuminated with the Helium-Neon Laser after passing through polarizer. The intensity of transmitted light is measured by a photodiode; which is converted into equivalent current and voltage signals by photodiode. The cell by cell measurement is done with the help of travelling microscope attached to the Aluminum frame. The new cell is brought into the path of the laser by moving the frame 0.5 mm horizontally or vertically.

The transmitted intensity is monitored by oscilloscope and is recorded by a digital multimeter. The transmitted intensity is recorded into two modes; i.e. the surface of thin film in; (i) the surface of thin film in vertical position and (ii) the surface of thin film in horizontal positions. Beside different modes of measurements different configuration square and rectangular frames are used to form square as well as rectangular thin films.

RESULTS AND DISCUSSION

Forty two samples of liquid crystal thin film of biphenyl (E7) were experimentally investigated. These samples were divided into two equal categories and studied by placing them in, (i) vertical positions and (ii) horizontal positions. Each of them has different sizes and surfaces areas. The Beer-Lambert's law was used to find the thickness of the free standing film of liquid crystal by using measured values of incident and transmitted intensities, the Beer-Lambert's law is given by

$$I = I_0 \exp^{-\varepsilon bc} \quad (1)$$

where, ε is absorptivity, c is concentration of absorbing species, b is path length or the thickness of thin film; the rearrangement of eq. (1) gives the thickness 'b'

$$b = \frac{\ln I_0 - \ln I}{\varepsilon c} \quad (2)$$

I_o and I are the incident and transmitted intensities, respectively. Following are findings of this study.

In Figure **2a** the thickness of upper and central part of thin film in horizontal placement is shown. The thickness is plotted against the area of the thin film; the difference between the thickness of upper edge and central region is less for smaller area of the thin film, as the area increases the difference also increases. In Figure **2b** the thickness of upper and lower edges of thin film in vertical placement is plotted against its area. The thickness increases as one goes from upper to the lower edge. The difference in thicknesses of lower and upper edges is more for smaller thin film area. As the area of thin film increases the difference becomes less.

For Vertical Placement

In Figure **3a** the thickness of typical thin film is shown when it is placed in vertical position, in Figure

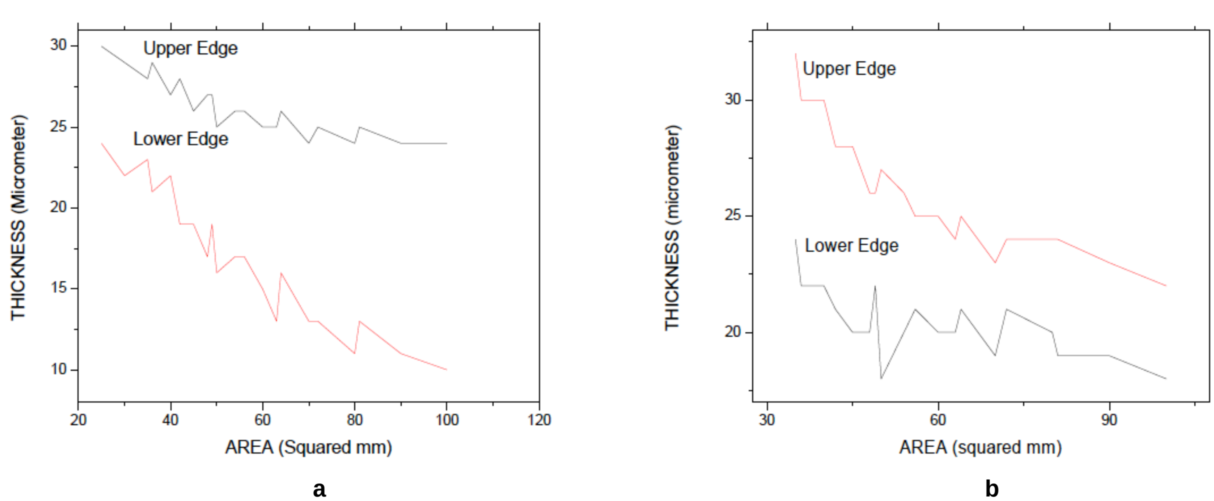
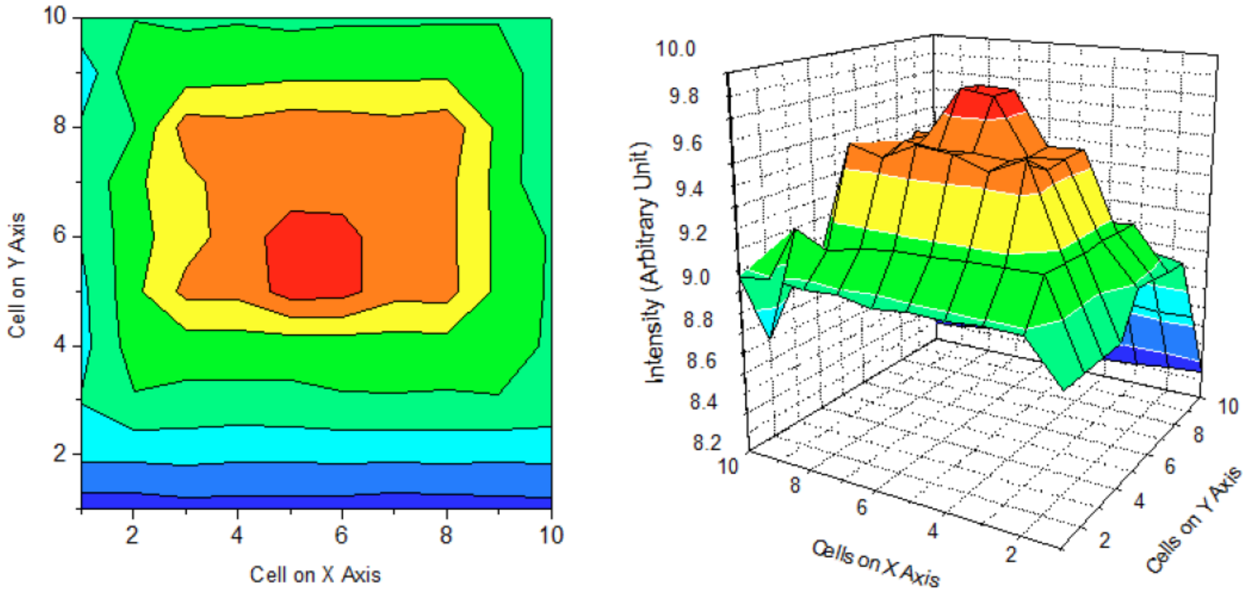


Figure 2a: Variation of thickness Vs Area of thin film, when thin film is placed in horizontal position.
b: Variation of thickness Vs Area of thin film; when thin film is placed in vertical position.



a b

Figure 3: Liquid crystal thin film in vertical placement with a dimension 5mm × 5mm (**a**) 2D colored contour for thickness of thin film (**b**) 3D colored pyramid for intensity distribution.

3b the transmission intensity of vertical thin film is plotted against the position of thin film. The thickness of the thin film is depicted by the various colors; there is an inverse relation between color wavelength and the thickness, the greater the wavelength the smaller the thickness. Following are the main features of investigations of transmission of intensity through thin film placed vertically.

1. In vertical placement the thickness of thin film at lower edge is higher as compared to upper edge.

2. The difference of thickness varies from 4μm to 9 μm, and it depends upon area of the thin film. For small area (5mm × 5mm) the thickness measured is about 9 μm to 6 μm but for large area (10mm × 10 mm) the difference of thickness measure is about 6 μm to 4 μm.

3. In all samples lateral edges have approximately the same difference in thickness of approximately 1 μm.

4. The thickness of thin film decreases from upper edge to middle of the film but then increases till the lower edge.

5. The thickness of small sample (5mm × 5mm) is 16 μm and for large sample (10mm × 10mm) 10 μm approximately. The average thickness in middle region is 13 μm.

6. The thickness of the central region depends on cell area; the smallest cell area has larger distribution of thickness of the film around the center.

For Horizontal Placement

The behavior of thin film of liquid crystal in horizontal placement is quite different as compared to vertical placement. Thickness of one of the samples in Figures **4a** and **4b** shows the intensity distribution of transmitted intensity against cell position.

1. The thickness of thin film around all edges is same for a cell but it decreases with increasing area.

Cell area	Thickness
5mm × 5mm	30 μm
7mm × 7mm	27 μm
9mm × 9mm	25 μm

2. The overall thickness at the edges varies from 30μm to 24μm.

3. The film thickness decreases gradually from edges to centre but at the centre the thickness again increases.

4. The central region of the film is relatively thicker in area than its surroundings. The thickness is approximately symmetric about the center. This

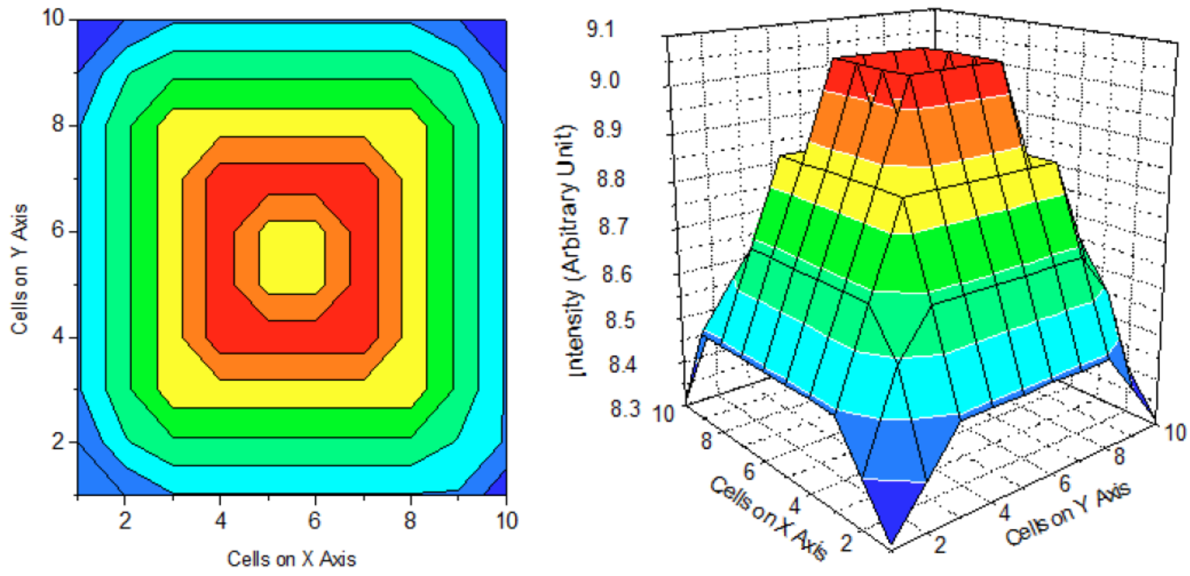


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Figure 4: Liquid crystal thin film in horizontal placement with a dimension 10mm × 10mm (**a**) 2D colored contour for thickness of thin film (**b**) 3D colored pyramid for intensity distribution.

can be seen from Figure **4a**. The intensity increases from as we move from edges to the center, but at center it again decreases.

CONCLUSION

In this study we investigated the surface behavior of biphenyl (E7) liquid crystal thin film. We also measured the thickness of thin film by polarizing optical technique. The thickness of thin films is measured in two different orientations: (i) horizontally placement and (ii) Vertical Placement. In both the orientations the thickness of free standing thin film of Liquid Crystal is non-uniform throughout the film. Symmetric distribution of thickness in horizontal placement and increasing thickness in downward direction in vertical placement show that gravitational effect plays its role in the distribution. In horizontal placement the central region of the film is thicker than its surroundings. This thick part is called “eye” or “lens”. Beside gravitational effect surface tension also plays a role in the difference in thickness.

The thickness of the thin film is approximately proportional to the amount of liquid crystal used to develop free standing film. The thickness also depends on the size of the cell. The same amount used in a cell with an area 10mm × 10mm has lower value of thickness as compared to the thickness measured for small area 5mm × 5mm. This means that the thickness varies with cell sizes. The life of thin film of large area is short.

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