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作品名稱

節能省碳—反射式紅外光液晶智能窗之研發

得獎獎項

工程學科大會獎第一名

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關 鍵 字： 隔熱、膽固醇型液晶、旋光物質

作者簡介

興趣和專長是語文，高中誤打誤撞進入科學高中，自此三年光陰貢獻於物理專題。吞嚥做研究的不能言之辛苦，反芻為另一種人生態度，過程中一切學習和成長縱然無法量化，卻是比起獎項或成績更為有價值的存在。

敏感善變，喜歡思考，然而行事少坨筋。相信心想事成，重視追求理想的過程遠勝於成果。自許為不繫之舟。

我是趙予靖，國中時期的我，對科學的領域並未擁有極高的興趣，但因我所就讀的高中對於科學方面的重視，便慢慢的踏出了在科學領域的第一大步，在老師的鼓勵與支持下，科學方面的興趣就慢慢被培養出來了，即便我在科學方面的知識，就像小孩子牙牙學語懵懵懂懂的階段，不過我不會放棄繼續鑽研於其中的。在參與這次科展的期間，學到了在平常學習中獲得不到的能力，讓我覺得有滿滿的收穫。

摘要

本研究以液晶製作節能窗戶，使用 S811 及 E7 合成之雙穩態膽固醇型液晶，並調整其比例，使其在常態僅反射紅外光，成透射態，如此一來，進入室內的熱量減少，便可以節省消耗在空調系統的能量，具隔熱、省能之功能，並保有高透明度；亦可藉由施加電壓使液晶分子排列改變，使其同時反射可見光，呈現散射態，達遮光之效果。

本研究調整旋光物質之比例並測量其光電性質，發現以 S811-30 %、E7-70 %合成及以 S811-20 %、E7-80 %合成之雙穩態膽固醇液晶為紅外光反射率最高以及最高透明度之比例。施加 6V 時，以 S811-30 %、E7-70 %合成之雙穩態膽固醇液晶可達反射率 70 %，反射範圍約 1200 nm 到 1500 nm；施加 6 V 時，以 S811-20 %、E7-80 %合成之雙穩態膽固醇液晶，可達反射率 60 %，反射範圍約 700 nm 到 900 nm，皆屬紅外光。兩者在施加電壓時可同時反射紅外光及可見光，反射率皆可達 75 %。故以 S811-30 %、E7-70 %合成及以 S811-20 %、E7-80 %合成之雙穩態膽固醇液晶可製成具隔熱、省能之功能，並保有高透明度。

Abstract

In this project, an innovative energy-saving equipment, so called smart window, utilizing Choleateric Liquid Crystal(CLC), is established.

In this project, the CLC window is made of a mixture with specific ratios of 2 kinds of liquid crystal: S811, the chiral material and E7, nematic liquid crystal, which enables it to reflect infrared. In this way, the thermal conduction entering the habitation, as well as the expense on energy of air conditioning, is reduced. Thus the window is heat-proof, energy-conserving, and its transparency remains strong because only infrared is reflected. Moreover, when applying voltage to differ the arrangement of CLC, the window will reflect the visible light simultaneously in reflective zone and thus serves as the function as a blinder.

After trying different ratios of chiral material and measuring their photoelectron, the study find that the mixture of 30 % of S811 and 70 % of E7, which reflects 50 % of infrared around 1200 nm to 1500 nm, and the mixture of 20 % of S811 and 80 % of E7, which reflects 50 % of infrared around 700 nm to 900 nm, come out to be the best two functioned CLC. Both of the two CLC are able to reflect 75% of visible light simultaneously when proper voltage is applied.

節能省碳－反射式紅外光液晶智能窗之研發

壹、前言研究動機與目的

一、研究動機

每到夏天艷陽高照，連教室也逃不過烈日的魔掌，溫度節節升高，很想開冷氣，但一想到開冷氣的花費和「節能省碳」的愛地球之道，每每作罷，故總是上課上得汗流浹背。

難道就不能減少進入教室的熱量嗎？我們知道，溫度上升主要來源是紅外光，那能不能把紅外光阻擋在窗戶外呢？我們有了這個想法之後，便上網搜尋市面上的隔熱材料，發現透明的材質大多只能阻隔 15 %-20 %的熱量，於是我們想到液晶能夠藉由控制螺距改變反射波長，便試著將其控制在紅外光波段，在液晶呈現透明的狀態下，盡可能提高反射紅外光量。

二、研究目的

（一） 製作不同比例旋光物質之雙穩態膽固醇型液晶

（二） 探討調整不同比例成分之液晶未施加電壓時之反射率關係

（三） 找出紅外光率最高之雙穩態膽固醇型液晶製作比例

（四） 測量外加電壓時，紅外光反射率最高之液晶外加電壓與反射率之關係

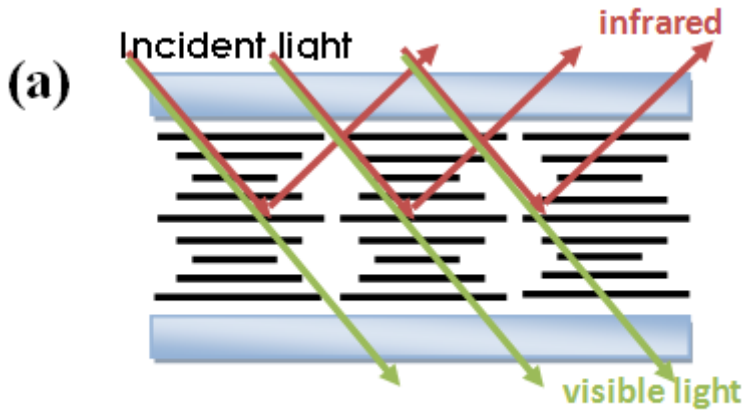
（五） 測量紅外光反射率最高比例之液晶電性

貳、研究設備及方法

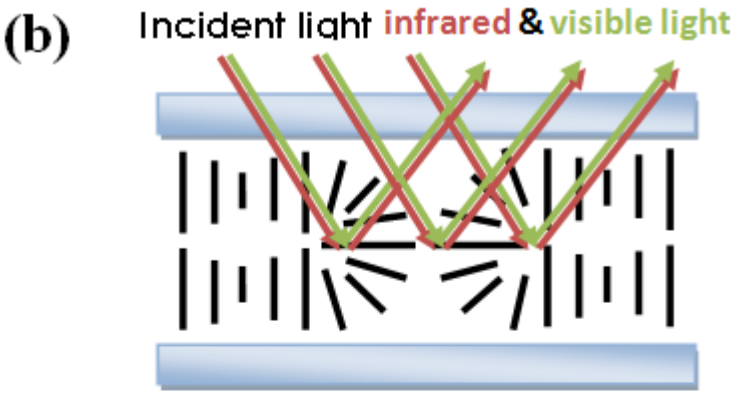
一、原理

膽固醇型為向列型液晶及旋光物質混合形成，因具有螺旋狀的構造，故有獨特的光學特性，其一特性為產生選擇性反射的現象。以入射光定義圓偏光的旋光方向時，若與膽固醇型液晶的螺旋方向保有同一方向圓偏光入射時，其將被選擇性反射，選擇性反射光的波長可藉由下式求得：$\lambda = n \cdot p$，其中 λ 為反射光的波長-單位(nm)、P 為螺距-單位(nm)、n 為螺旋垂直的平面內的平均折射率。

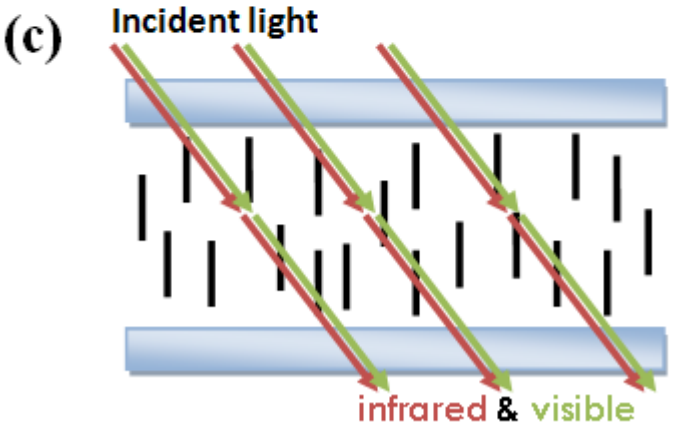
雙穩態膽固醇型液晶在未施加電壓的狀態下，液晶分子順配向膜平行排列，呈透射態；隨施加電壓增大，部分液晶分子感應電偶極受靜電力驅動，呈散射態，當靜電力足以使液晶分子直立排列，則呈透射態。雙穩態膽固醇型液晶所需靜電力之大小與其成分及比例有關。



（圖 a）透射態



（圖 b）散射態



（圖 c）透射態

圖 1 雙穩態膽固醇型液晶原理示意圖

二、研究設備及器材

（一） 耗材

1. E7（低分子向列型液晶）
2. S811（旋光物質）
3. 液晶 Cell（10 μm）

（二） 儀器

1. 分光光譜儀 V-670（370 nm 至 2000 nm）（如圖 2.c 所示）（測量穿透率）

2. 電源供應器（產生直流電 0 V 至 30 V）（如圖 2.b 和圖 3.d 所示）

3. 熱源供應器（加熱液晶至 97 度）

4. 光偵測器（量測反應速率）

5. 數據收集器－GLX（如圖 3.e 所示）

6. 微安培計（測量電流）

7. 電腦（如圖 2.a 所示）

8. 溫度感應器（如圖 3.f 所示）

9. 鹵素燈（如圖 3.g 所示）

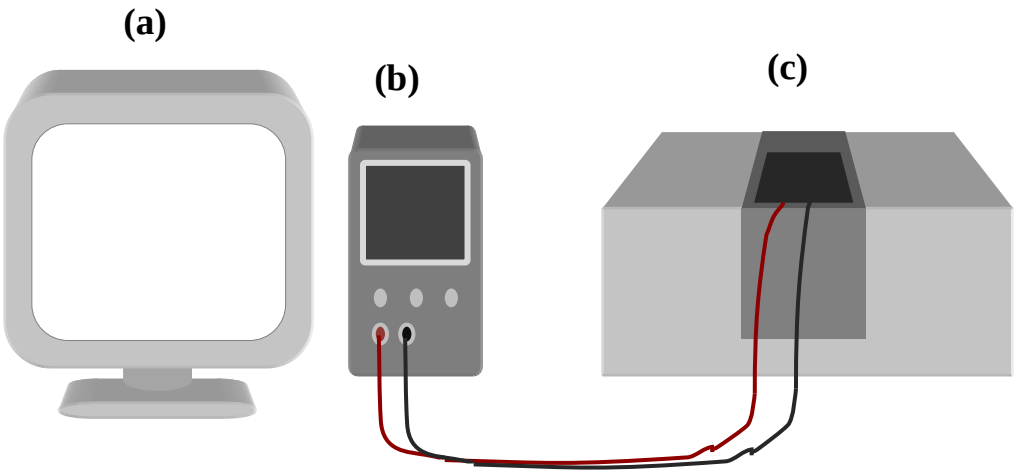


圖 2　穿透率測量系統

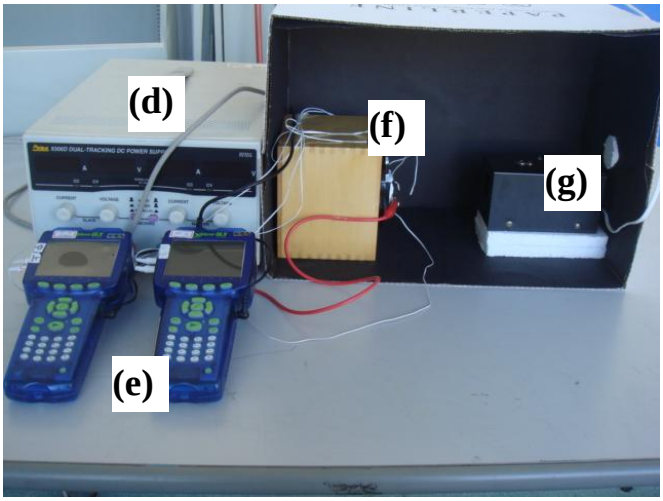


圖 3　隔熱效果測量系統

三、研究方法

利用平行電場改變外加電壓大小，可使液晶分子做不同程度的旋轉。量測液晶穿透光譜，探討不同電壓下液晶分子旋轉程度及反射光波長的變化。

（一） 製作液晶樣本

1. 配製液晶：以 E7（低分子向列型液晶）和 S811（旋光物質）組成膽固醇型液晶結構。

	E7	S811
一號材料	90 %	10 %
二號材料	80 %	20 %
三號材料	70 %	30 %
四號材料	65 %	35 %
五號材料	60 %	40 %

2. 加熱液晶至攝氏 55 度使呈現液態，灌入液晶 Cell 中。

（二） 液晶性質量測

1. 測量液晶未施加電壓之反射率

(1) 將空 cell 置於量測系統中，測量其穿透光譜作為背景。

(2) 將已灌入液晶的 cell 置於量測系統中，測量其穿透光譜。

(3) 將穿透光譜整理為反射光譜。

(4) 比較不同比例旋光物質與反射率之關係，找出雙穩態膽固醇型液晶(CLC)紅外光反射率最高之比例。

2. 測量紅外光反射率最高比例之 CLC 之電壓與反射率關係

(1) 將空 cell 置於量測系統中，測量其穿透光譜作為背景。

(2) 將已灌入液晶的 cell 置於量測系統中，測量其穿透光譜。

(3) 為便於探討，將實驗之穿透光譜整理為反射光譜。
（反射率=1-折射率-吸收率，由文獻得知液晶之吸收率極小，故在此忽略。）

(4) 探討外加電場時不同旋光物質比例與液晶反射率之關係。

3. 測量紅外光反射率最高比例之 CLC 之隔熱效果

(1) 以鹵素燈為熱源。

(2) 將液晶片黏貼於隔熱箱之開口。

(3) 在隔熱箱外部與內部接上溫度感應器。

(4) 測量隔熱箱外部與內部之溫差。

4. 測量紅外光反射率最高比例之 CLC 之電性－外加電壓時液晶相態轉換反應時間

(1) 以光偵測器測量空 cell 之穿透光強，作為背景。

(2) 將已灌入液晶的 cell 置於測量系統中，量測液晶偏轉影響穿透光之變化時間。

(3) 探討外加電壓時不同比例旋光物質與液晶相態轉換時間之關係。

5. 測量紅外光反射率最高比例之 CLC 電性－外加電壓時液晶相態轉換之電功率

(1) 以檢流計測量液晶電壓與電流之關係。

(2) 計算液晶電壓與電功率之關係。

參、研究結果

一、製作之液晶成品

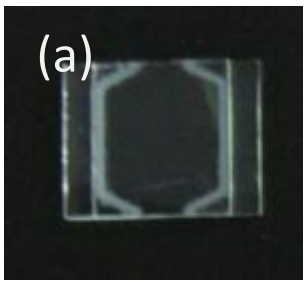
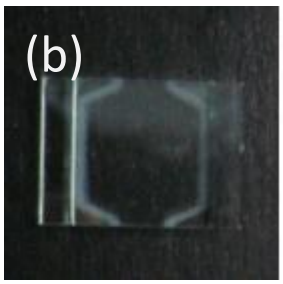
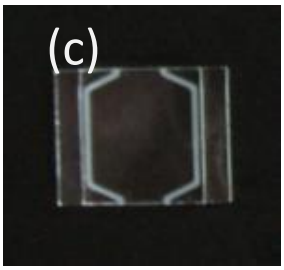
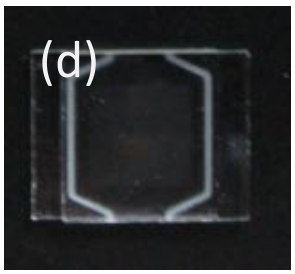
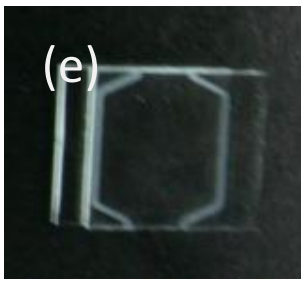
		
（圖 4.a）E7-**90 %、S811-10 %**	（圖 4.b）E7-80 %、S811-20 %	（圖 4.c）E7-70 **%、S811-30 %**
		
（圖 4.d）E7-65 %、S811-35 %	（圖 4.e）E7-60 %、S811-40 %	

圖 4　配製之不同比例膽固醇型液晶成品

二、探討不同比例旋光物質與反射率之關係

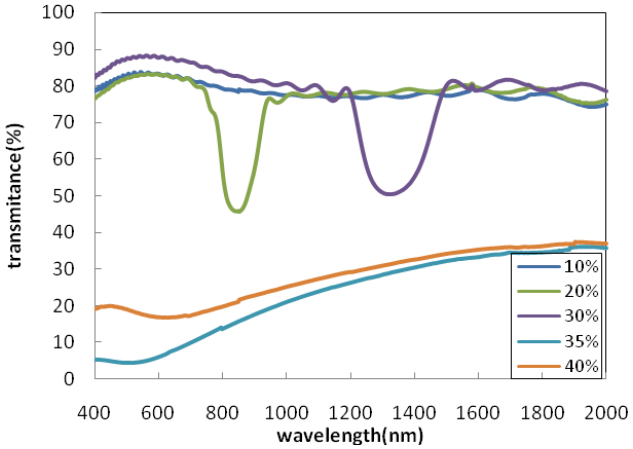


圖 5　各不同比例旋光物質之穿透率關係圖

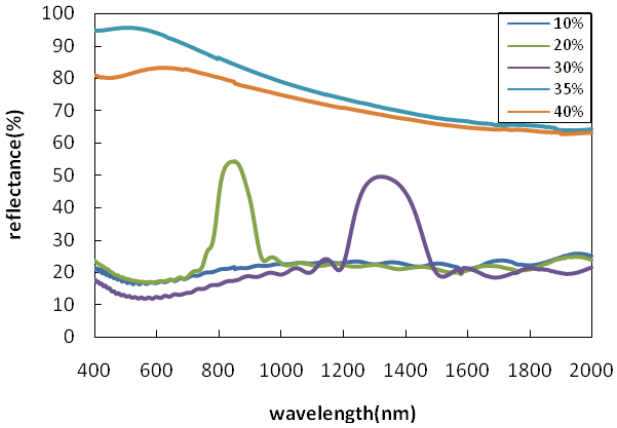


圖 6　各不同比例旋光物質之反射率關係圖

(一) 由穿透率關係圖(如圖 5 所示)整理得反射率關係圖(如圖 6 所示)，討論不同比例旋光物質與反射率之關係。

(二) 400 到 2000 nm 之間，S811-10 %的反射率沒有特別高的波段，約維持在 20%。

(三) 400 到 2000 nm 之間，S811-20 %、30 %的紅外光反射率高於其他波段。

(四) 400 到 2000 nm 之間，S811-35 %、40 %的可見光反射率高於其他波段，且整體反射率高於 S811-10 %、20 %、30 %。

(五) 整體反射率隨旋光物質比例上升而增加。

(六) S811-20 %、S811-30 %為紅外光反射率最高之比例，且具高透明度。故接續實驗以此二者為主要研究之比例。

三、紅外光反射率最高之 CLC 比例外加電壓與反射率關係

(一) 旋光物質比例 20 %之外加電壓與反射率關係

(如圖 7、圖 8 和圖 9 所示)

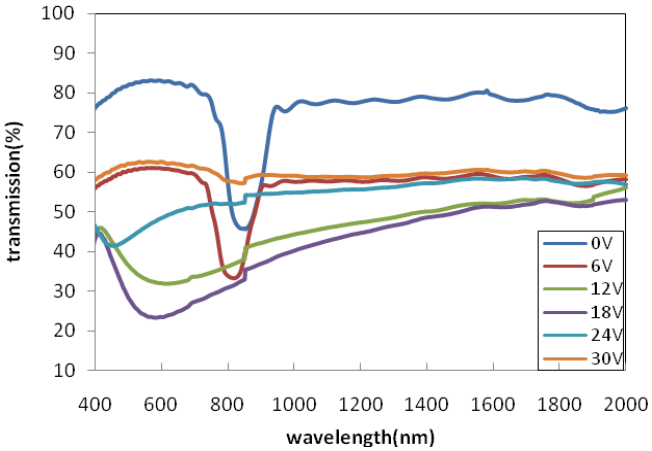


圖 7　旋光物質比例 20 %之外加電壓與穿透率關係圖

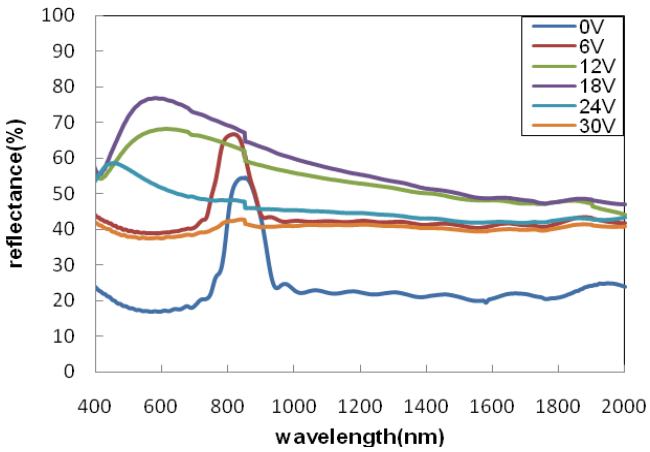


圖 8　旋光物質比例 20 %之外加電壓與反射率關係圖

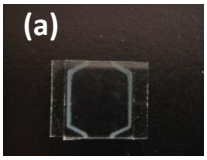
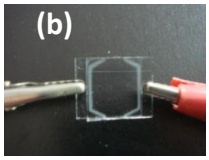
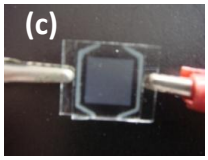
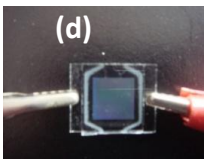
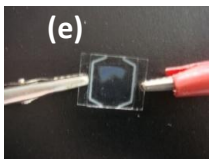
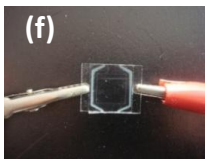
		
(圖 a) 0 V	(圖 b) 6 V	(圖 c) 12 V
		
(圖 d) 18 V	(圖 e) 24 V	(圖 f) 30 V

圖 9　配製之不同比例膽固醇型液晶成品

1. 由穿透率關係圖整理得反射率關係圖，討論不同比例旋光物質之外加電壓與反射率關係。

2. 隨外加電壓升高，S811-20 %反射率最高處之波長逐漸變小。0 V 至 6 V 之間，反射率最高處之波長約為 700 nm 到 900 nm，為紅外光；12 V 到 18 V 之間，反射率最高處之波長降至可見光範圍；24 V 至 30 V 之間反射率於各波長皆維持在 40%左右，無明顯波動。

3. 整體反射率亦隨電壓升高而有所改變。0 V 至 12 V 之間，整體反射率隨電壓值升高而上升，至 12 V 達最大值。15 V 至 30 V 之間，整體反射率約維持在 40 %。

(二)探討旋光物質比例 30 %之電壓與反射率關係

(如圖 10、圖 11 和圖 12 所示)

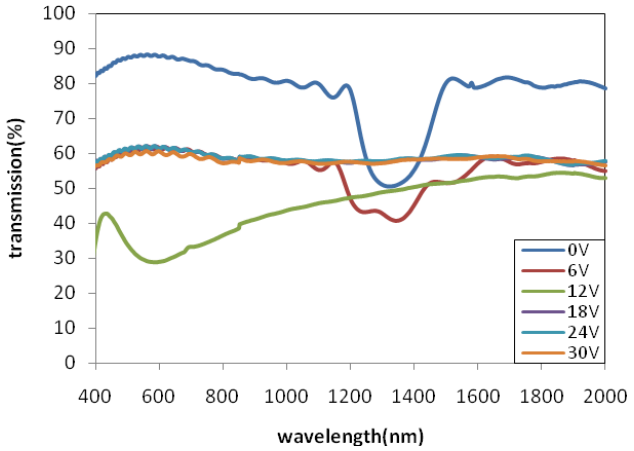


圖 10　旋光物質比例 30 %之電壓與穿透率關係圖

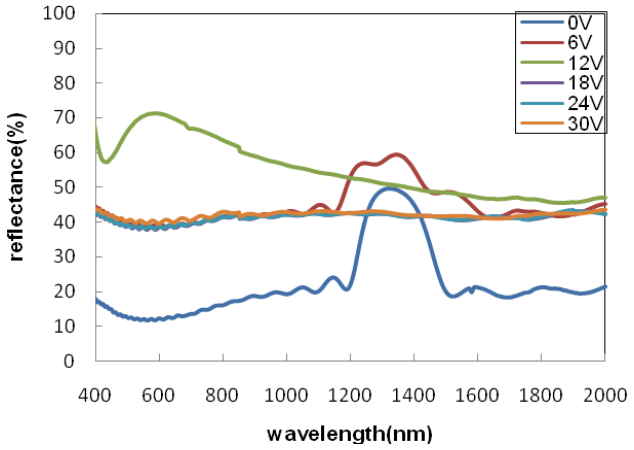


圖 11　旋光物質比例 30 %之電壓與反射率關係圖

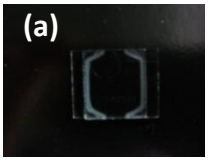
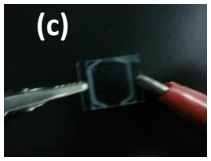
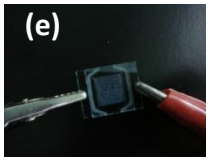
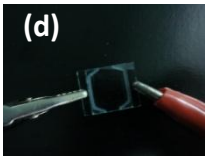
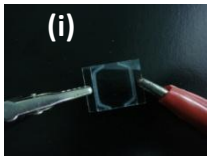
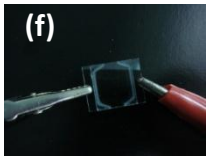
		
(圖 12.a) 0 V	(圖 12.b) 6 V	(圖 12.c) 12 V
		
(圖 12.d) 18 V	(圖 12.e) 24 V	(圖 12.f) 30 V

圖 12　配製之不同比例膽固醇型液晶成品

1. 由穿透率圖整理得反射率關係圖，討論不同比例旋光物質之外加電壓與反射率關係。

2. 隨外加電壓升高，S811-30 %之反射率最高處往短波長移動。0 V 至 6 V 之間，反射率最高約波段在 1200 nm 到 1500 nm，為紅外光；12 V 時，反射率最高處屬於可見光範圍;18 V 至 30 V 反射率於各波長皆維持在 40 %左右，無明顯波動。

3. 隨外加電壓升高，整體反射率亦有所改變。0 V 至 12 V 之間，整體反射率隨外加電壓升高而上升，至 12 V 達最大值。18 V 至 30 V 之間，整體反射率約維持在 40 %。

四、紅外光反射率最高之 CLC 比例之隔熱效果

(如圖 13、圖 14 和圖 15 所示)

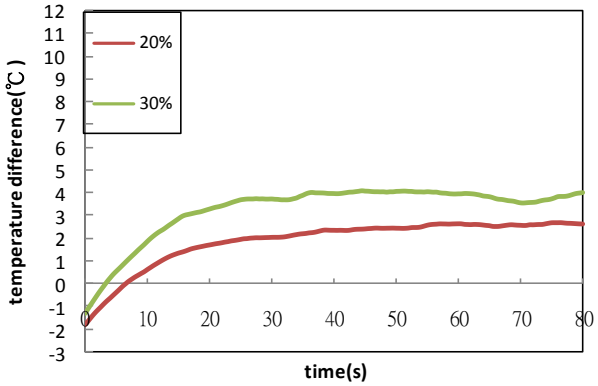


圖 13　各不同比例旋光物質之時間與溫差關係圖

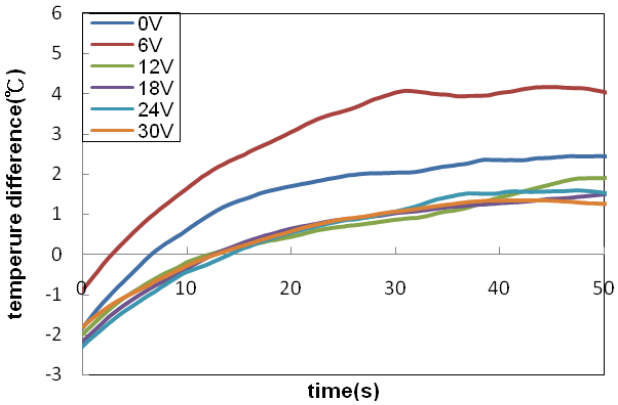


圖 14　旋光物質比例 20 %之與穿透率關係圖

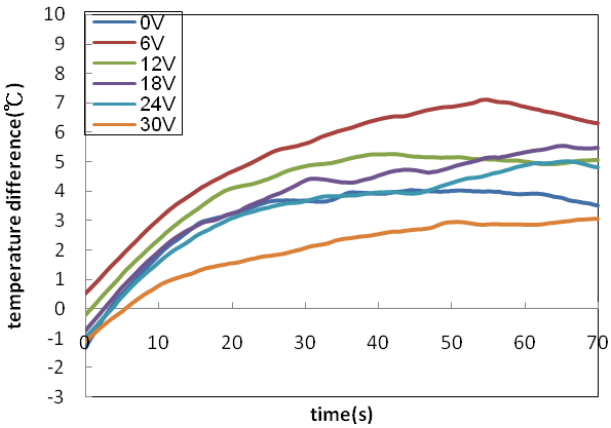


圖 15　旋光物質比例 30 %之與穿透率關係圖

1. 絕熱箱內外的溫差隨時間增加而增加。

2. 於 6 V 時，絕熱箱內外溫差最大，與旋光物質比例 20 %電壓與穿透率關係圖中，於 6 V 時紅外光反射率最高之結果相符。

五、探討外加電壓時旋光物質比例 20 %、30 %液晶相態轉換反應時間及消耗電功率

(一)探討外加電壓時液晶相態轉換之反應時間

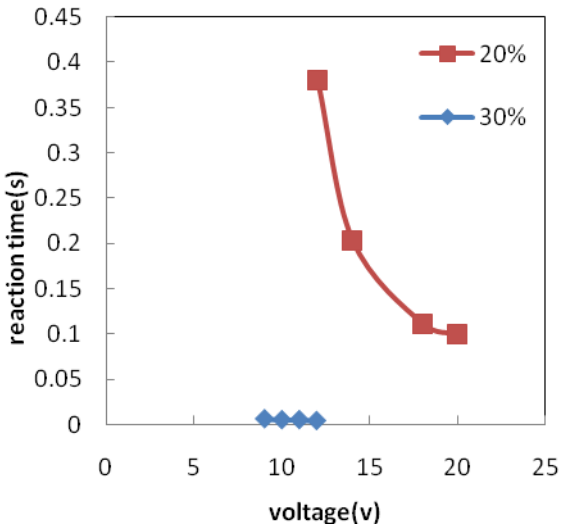


圖 16　外加電壓與液晶相態轉換之反應時間關係圖

S811-20 %		S811-30 %	
電壓(V)	反應時間(s)	電壓(V)	反應時間(s)
12	0.381	9	0.006
14	0.204	10	0.005
18	0.112	11	0.005
20	0.1	12	0.004

1. 隨外加電壓升高，液晶相態反應時間下降。
2. 旋光物質比例 20 %相態反應時間最快可達 0.1 秒。
3. 旋光物質比例 30 %相態反應時間最快可達 0.04 秒。

(二)探討外加電壓時液晶相態轉換之耗能

各比例旋光物質之液晶自外加電壓 0 V 至 30 V，電流皆小於微安培計之最小感測量，表示其消耗電功率小於 0.3 毫瓦，相當省能。

肆、討論

一、由不同比例旋光物質反射率關係圖中可以看出

(一) 旋光物質比例 20 %、30 %之反射率皆在某一波長範圍升高，顯示液晶中形成螺距結構，造成光干涉，反射光增強。

(二) 旋光物質比例 10 %無特定反射波段，推測因旋光物質比例過低，導致向列型液晶與旋光物質無法建構螺距結構。

(三) 旋光物質比例 35 %、40 %未施加電壓時，可見光反射率高於紅外光。推測由於旋光物質比例過高，形成之液晶為層列型液晶，不具螺距結構。

(四) 旋光物質比例 10 %紅外光及可見光反射率皆過低，而 35 %、40 %紅外光及可見光反射率皆高，僅 20 %、30 %紅外光反射率高於可見光，且整體反射率低於 30%， 具高透明度。

二、由旋光物質比例 20 %、30 %之外加電壓與反射率關係圖可以看出

(一) 隨電壓增加，旋光物質比例 20 %、30 %之反射率最高處往短波長移動。於外加電壓 6 V 時在一紅外光範圍上升，至 12 V 已包含可見光。推測液晶隨驅動電壓增加，每層液晶分子間的偏轉角度亦增加，使螺距變小，導致反射光波長變小。

(二) 整體反射率亦隨電壓增加而上升。推測因液晶受電壓影響而偏轉，當施加電壓至一定值時，部分液晶偏轉平行於電場，而上有部分液晶依然順

著配向膜排列。此現象於小範圍是規則的，但就大範圍而言，液晶排列呈現散亂的狀態，此時各液晶分子依然會反射特定光波長，但各液晶分子反射光波長皆不同，經干涉後各波長之色光經混合後呈現所看到之霧狀白色。

(三) 由旋光物質比例 20 %、30 %之液晶穿透光譜，可發現當電壓施加至一定值時液晶均不反射特定光波長，且整體反射率下降，推測此時液晶分子全數平行電場方向，由於排列整齊使光可通過呈現透射態。

三、外加電壓時旋光物質比例 20 %、30 %之液晶相態轉換反應時間及消耗電功率

(一) 液晶相態反應時間隨外加電壓升高而下降，旋光物質比例 20 %相態反應時間最快可達 0.1 秒，旋光物質比例 30 %相態反應時間最快可達 0.04 秒。

(二) 外加電壓之消耗電功率方面，各比例旋光物質之液晶自外加電壓 0 V 至 30 V，電流皆小於微安培計之最小感測量，表示其消耗電功率小於 0.3 毫瓦，相當省能。

伍、結論與應用

一、研究結果發現，在調整旋光物質比例時，以 S811-30 %、E7-70 %合成及以 S811-20 %、E7-70 %合成之雙穩態膽固醇液晶具有最高之紅外線反射率及最高透明度。

二、以 S811-30 %、E7-70 %合成之雙穩態膽固醇液晶可達反射率 50 %，反射範圍約 1200 nm 到 1500 nm；以 S811-20 %、E7-80 %合成之雙穩態膽固醇液晶，可達反射率 50 %，反射範圍約 700 nm 到 900 nm 皆屬紅外光。

三、以 S811-30 %、E7-70 %合成及以 S811-20 %、E7-70 %合成之雙穩態膽固醇液晶，在施加電壓時可同時反射可見光及紅外光，具遮光之功能。

四、以 S811-30 %、E7-70 %合成及以 S811-20 %、E7-70 %合成之雙穩態膽固醇液晶，未加電壓時反射紅外光波長，可阻絕紅外光形成之熱量，達隔熱之功能，並具有高透明度；施加電壓時，可轉換液晶至散射態，同時反射、阻擋可見光及紅外光，達遮光之功能。

五、可以疊加兩片 cell，其濃度不相同，製作成隔熱複合型液晶窗，施加電壓後可控制成反射紅外光與可見光達到完全遮光。

六、未來可應用於汽車之擋風玻璃。

七、液晶隔熱窗反射波段不會影響到手機通訊，廣播與車上電視訊號。

陸、參考資料

[1] 奇妙的液晶, 升學資訊輔導雜誌 9103 期

[2] 章舜雯,毛舜虞,液晶旋光性質與光電性質之探討

[3] 廖敏翔,黃振球, 向列型液晶旋光性物質的圓偏光二色性與光電特性, 私立元智大學化工系

[4] 陳郁壬, The study of the interaction of spatial solitons in nematic liquid crystal, 國立中山大學物理學研究所碩士論文

柒、附錄

一、E7-90 %、S811-10 %之外加電壓與反射率關係

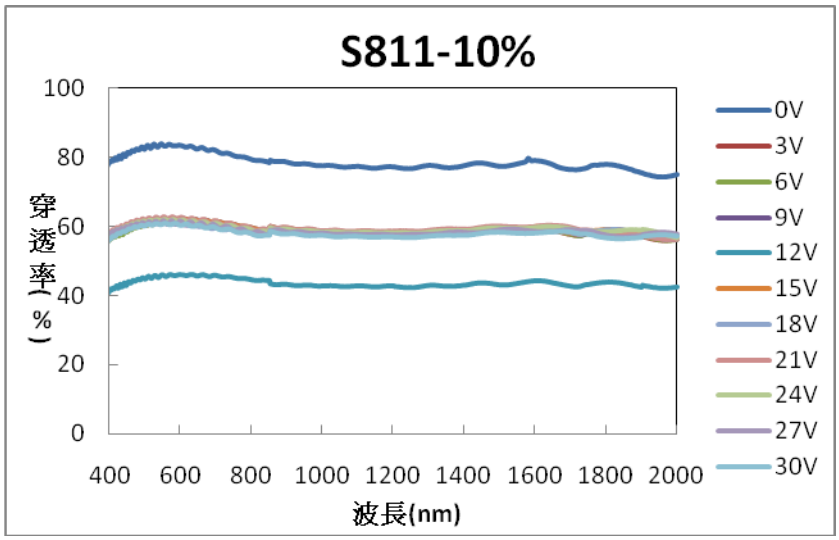


圖 17　旋光物質比例 10 %之外加電壓與穿透率關係圖

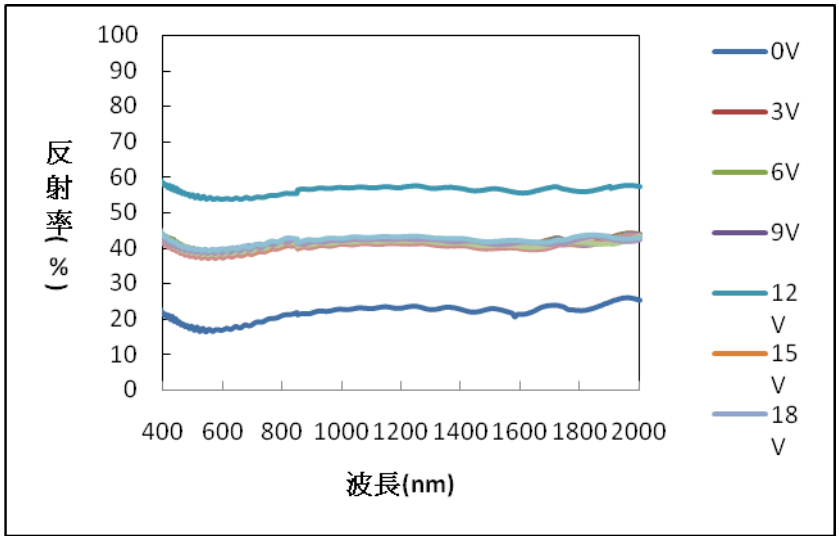


圖 18　旋光物質比例 10 %之外加電壓與反射率關係圖

二、E7-85 %、S811-15 %之外加電壓與反射率關係

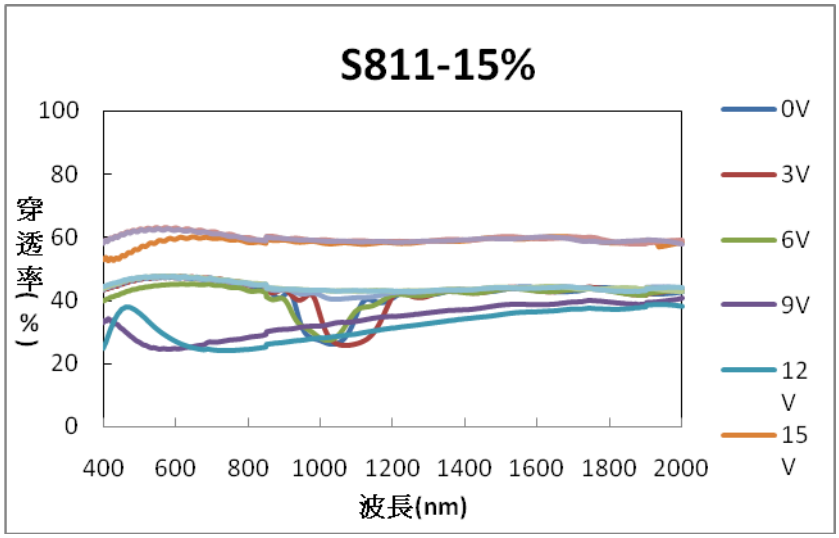


圖 19　旋光物質比例 15 %之外加電壓與穿透率關係圖

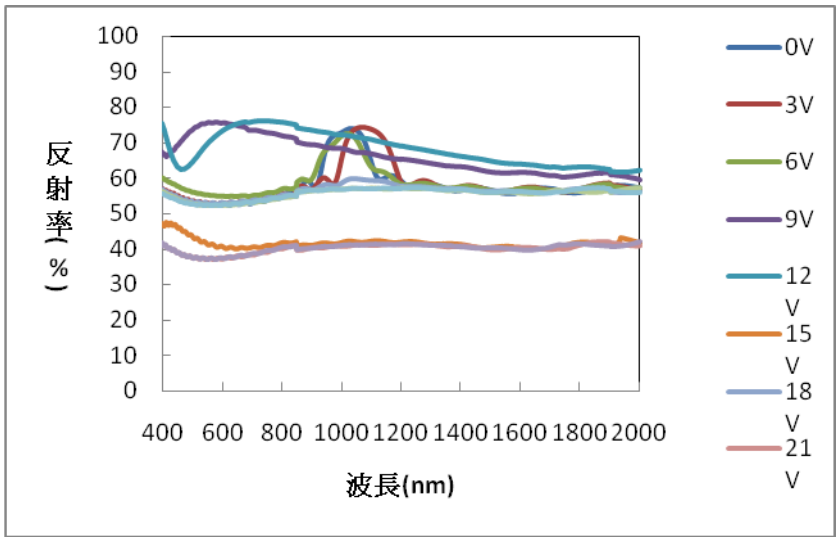


圖 20　旋光物質比例 15 %之外加電壓與反射率關係圖

三、E7-65 %、S811-35 %之外加電壓與反射率關係

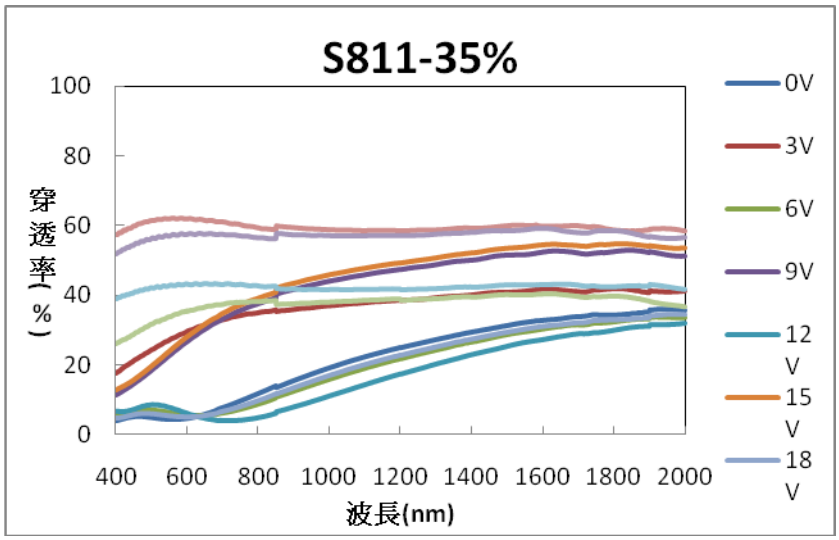


圖 21　旋光物質比例 35 %之外加電壓與穿透率關係圖

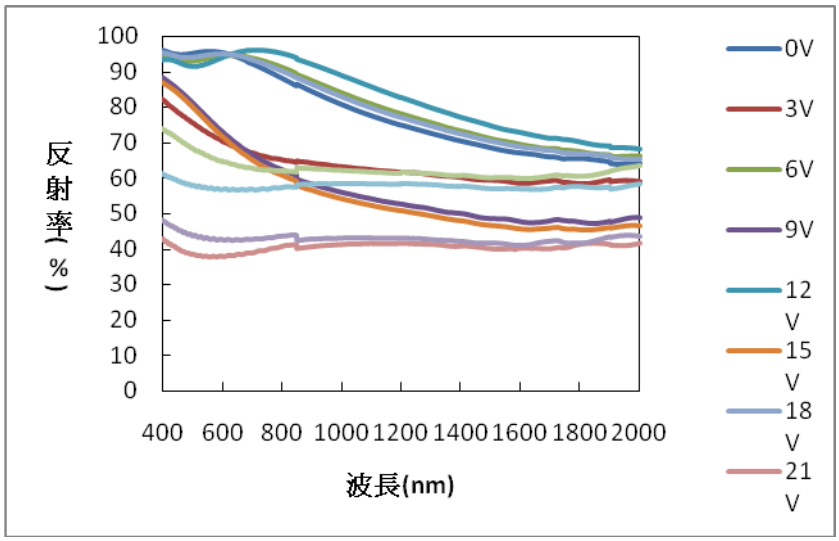


圖 22　旋光物質比例 35 %之外加電壓與反射率關係圖

四、E7-60 %、S811-40 %之外加電壓與反射率關係

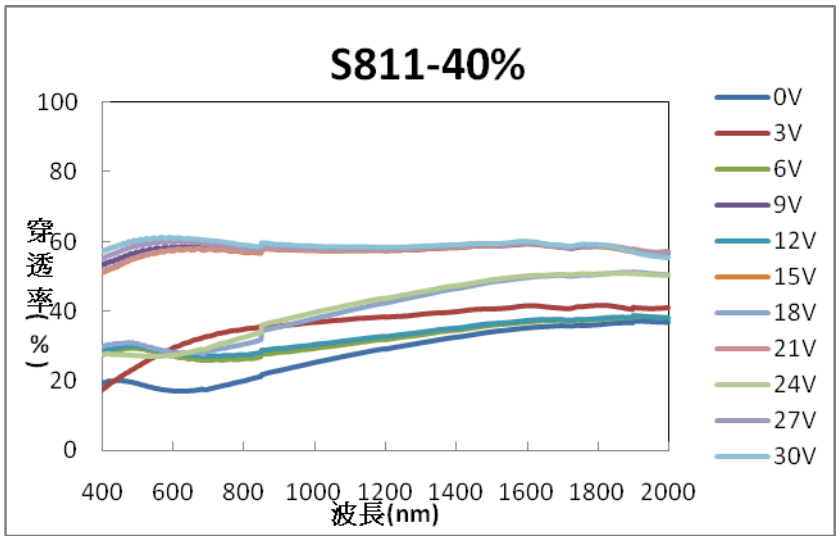


圖 23　旋光物質比例 40 %之外加電壓與穿透率關係圖

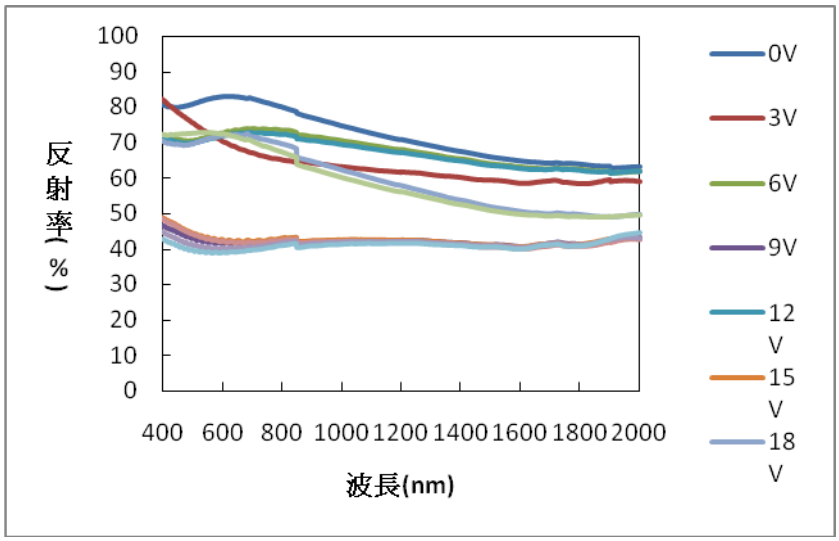


圖 24　旋光物質比例 40 %之外加電壓與反射率關係圖

評語

本作品技巧地利用雙穩態膽固型醇液晶的旋光性，製作可以電壓調控的反射/穿透架構。藉由電壓的改變，可達成改變散射、透光性，且此控制功能隨波長而變。整體而言，本作品頗具創意，且作者對相關技術與原理有極佳之瞭解。

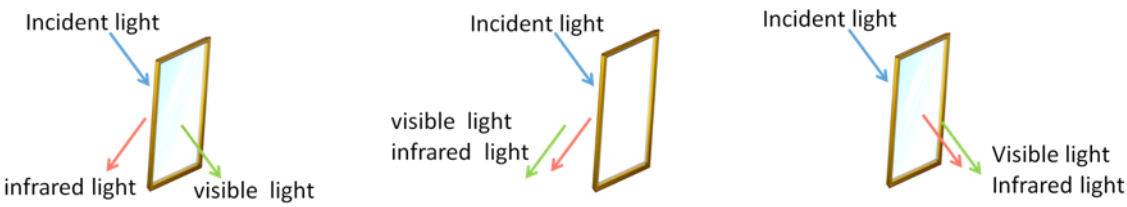
本作品若再加強偏振校應急旋光性的瞭解與應用月其可有更進一步的發展。

Abstract

In this project, a switchable Cholesteric liquid crystal (CLC) based window is fabricated to enable selective transmission of sunlight. It is aimed to improve the quality of life and to comply with the global trend of energy conservation.

CLC is a mixture of nematic liquid crystal and chiral material, which possesses the characteristics of selective reflection at a specific spectral range due to the multilayered structure formed. By adjusting the concentration of chiral material in CLC, the spectral range of reflection can be shifted to the infrared while maintaining high transparency in the visible. The CLC exhibits the first transparent state (selectively reflecting a spectral range), the scattering state (rejecting all spectral range), and the second transparent state (transmitting all spectral range) sequentially upon appropriate bias.

We found the following two CLC mixtures work best for our purposes with high transparency in the visible. The mixture of 20% S811 and 80% E7 reflects infrared from 700 nm to 900 nm while the mixture of 30% S811 and 70% E7 reflects infrared from 1200 nm to 1500 nm. Under appropriate bias, the CLCs can (1) reflect up to 70% of infrared with a maximum of 80% transparency, enabling the reduction of the air conditioning need in summer, (2) reject 70% to 75% of infrared and visible light simultaneously, serving as a blinder to improve the functional performance of the room, (3) reflect only 40% of infrared and visible light, reducing the heating requirement in winter, (4) control the transmission efficiency of sunlight so as to modulate the daylight illumination in a room.



Switchable Infrared-Reflecting Green Window

1. Introduction

1.1Motivation

The growing scarcity of global energy resources together with the strong demand from the nations with fast developing economy has made energy conservation a global issue. The attempts to balance the quality of life and energy conservation have become the theme behind this new wave of green movements. With this understanding, we are trying to develop a technology that may lead to Smart Windows for today's Smart Buildings.

Cholesteric Liquid Crystal (CLC) is known to form a structure that can selectively reflect a certain spectral range by forming multilayered structure. It was found that by adjusting the concentration of the CLC, the spectral range of selective reflection can shift to the infrared zone, while maintaining high transmission at visible range.

The CLC also forms bistable states upon bias. With the increase of applied voltage, the CLC forms the first transparent state, scattering state, and the second transparent state sequentially. The scattering state reflects both infrared and visible light, thus can serve as a blinder. The second transparent state allows both infrared and visible light to pass through, forming a proper condition for winter use.

1.2Project Goals

This project is aimed to fabricate a liquid crystal based device that:

A. Block the strong infrared spectrum of summer sunlight so as to reduce the need for air conditioning.

B. Serve as a blinder in the visible range for functional improvement of the room and control transmission efficiency of sunlight so as to effect the daylight illumination in a room.

C. Permit infrared spectrum of winter sunlight to enter the room so as to reduce the heating requirement.

2. Equipments & Methods

2.1Theoretical Model

A.Selective Reflection of CLC

The Cholesteric liquid crystal consists of multiple layers of nematic liquid crystal with incremental rotation on each layer. The overlapping layers of nematic liquid crystal possess an angular difference of orientation along the long molecular axis between each layer of the CLC. When the accumulated angle of rotation reaches 360°, the distance is defined as one pitch.

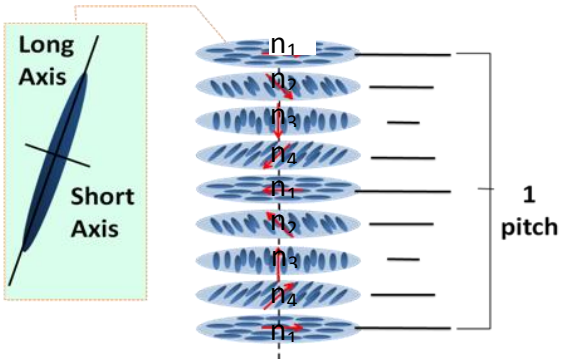


Figure 1. Schematic of pitch structure.

The periodical change of orientation of the long molecular axis leads to the periodical change in the refractive index. The periodical change in the refractive index also resembles the multilayer or photonic structure in optics, and leads to the characteristics of selective reflection at a certain spectral range. By simplifying Bragg's Refraction law, the peak wavelength of selective reflection can be expressed as:

$$\lambda = n \cdot p$$

λ=wavelength of selective reflection (nm)

n=averaged index of refraction of the CLC

p=pitch (nm)

B. Adjustable multilayer

Similar to the multilayer structure, the refractivity of each CLC layer varies periodically owing to the long axis direction. Additionally, the optical periodical structure of CLC can be modified depending on the bias voltage. A multilayer periodical system is explored in this project.

Multi-layer Periodic System

```
n0 = 1; ns = 1.5; n1 = 1.7; n2 = 1.6; n3 = 1.5; n4 = 1.4; λ0 = 800; e = (4*π*9*10^9)^-1; μ = 4*π*10^-7;
kh = 0.5*π*(λ/λ0)/3;
```

$$Y1 = \sqrt[2]{\frac{e}{\mu}} * n1;\ Y2 = \sqrt[2]{\frac{e}{\mu}} * n2;\ Y3 = \sqrt[2]{\frac{e}{\mu}} * n3;\ Y4 = \sqrt[2]{\frac{e}{\mu}} * n4;\ M1 = \begin{pmatrix} \mathrm{Cos}[kh] & (i \times \mathrm{Sin}[kh]) / Y1 \\ (i \times \mathrm{Sin}[kh]) \times Y1 & \mathrm{Cos}[kh] \end{pmatrix};$$

$$M2 = \begin{pmatrix} \mathrm{Cos}[kh] & (i \times \mathrm{Sin}[kh]) / Y2 \\ (i \times \mathrm{Sin}[kh]) \times Y2 & \mathrm{Cos}[kh] \end{pmatrix};\ M3 = \begin{pmatrix} \mathrm{Cos}[kh] & (i \times \mathrm{Sin}[kh]) / Y3 \\ (i \times \mathrm{Sin}[kh]) \times Y3 & \mathrm{Cos}[kh] \end{pmatrix};$$

$$M4 = \begin{pmatrix} \mathrm{Cos}[kh] & (i \times \mathrm{Sin}[kh]) / Y4 \\ (i \times \mathrm{Sin}[kh]) \times Y4 & \mathrm{Cos}[kh] \end{pmatrix};\ M = M1.M2.M3.M4.M3.M2.M1.M2.M3.M4.M3.M2;$$

```
M= M.M.M1
```

$$Y0 = \sqrt[2]{\frac{e}{\mu}} * n0;\ YS = \sqrt[2]{\frac{e}{\mu}} * ns;$$

```
r = (Y0*M[[1, 1]] + Y0*YS*M[[1, 2]] - M[[2, 1]] - YS*M[[2, 2]]) /
  (Y0*M[[1, 1]] + Y0*YS*M[[1, 2]] + M[[2, 1]] + YS*M[[2, 2]]); R = Abs[r]^2;
Plot[R, {λ, 300, 1400}, PlotRange -> {-0.1, 1.1}]
```

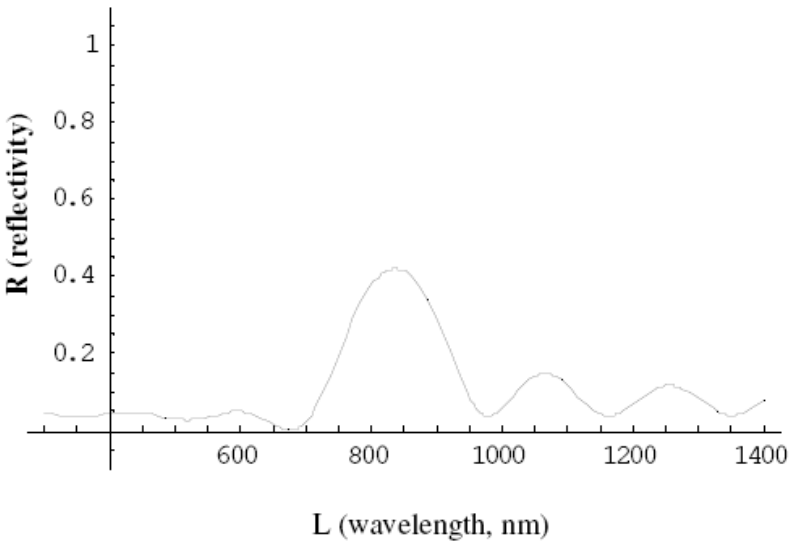


Figure 2. Reflection Spectrum of the multilayer periodical system.

C. Bistable State of the CLC

The bistable state refers to the two stable states [Figure 3.(A) & Figure 3.(C)], at which the CLC exhibits a transparent state. The first stable state is when all the liquid crystal molecules are arranged along the alignment film. It is the natural state when 0V is applied. The second stable state is when the electrical field is arranged perpendicular to the cell and forces all the molecules into a parallel alignment to the electrical field. The unstable intermediate state between the two transparent states is when some molecules are arranged along the alignment film while others are arranged along the electrical field. The scattering state [Figure 3.(B)] reflects all range of wavelengths owing to the irregular arrangement of molecules.

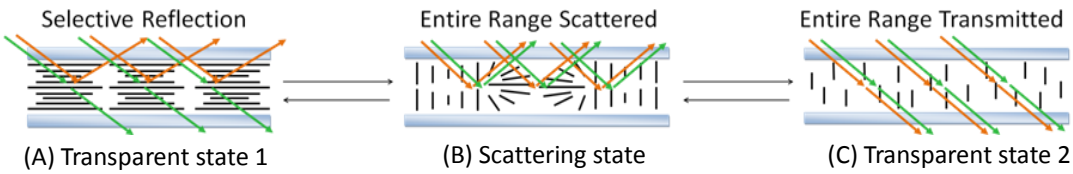


Figure 3. Schematics of the bistable state and the scattering state of the CLC.

2.2Experimental

A. Equipments

(a) Microbalance

(b) Ultrasonic oscillator

(c) Hot plate

(d) Spectrometer V-670 (370 nm to 2000 nm)

(e) Power supplier (0 V to 30 V)

(f) Light sensor

(g) Data collector GLX

(h) Rubbing Machine

(i) Coating Machine

(j) Glass Cutter

(k) Template

(l) Screw Press

(m)Oven

(n) Computer

B. Consumables

(a) Nematic liquid crystal E7

(b) Chiral material S811

(c) ITO glass

(d) TN type alignment film (AL-58, Daily Polymer Corp)

(e) Spacer (ten-micron)

2.3Methods

A. Fabrication of CLC samples (Figure 4.)

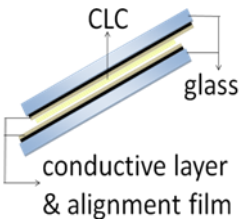
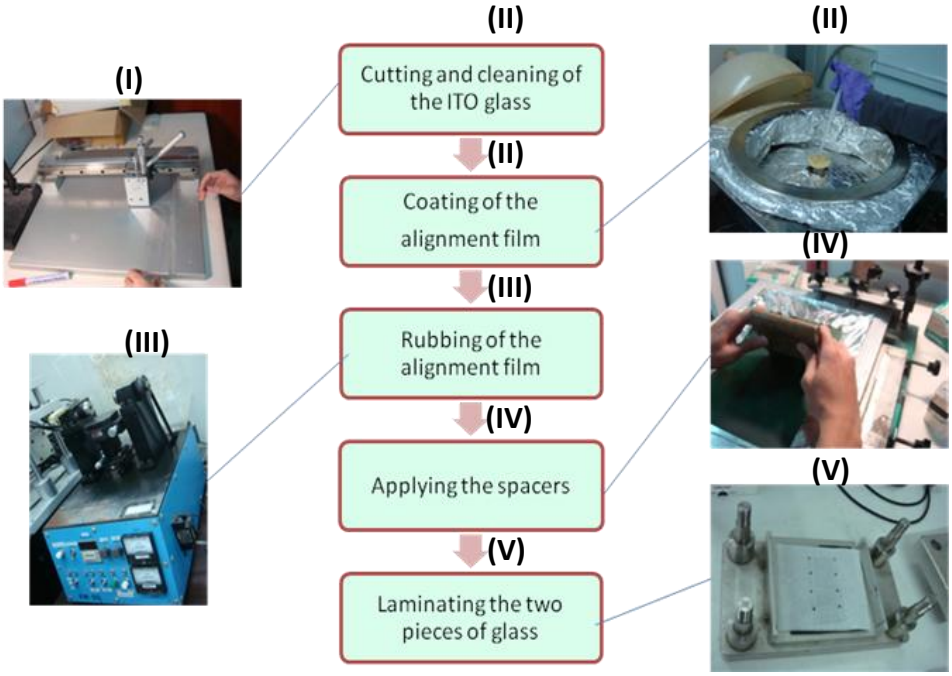


Figure 4. Schematic of a CLC sample.

(a) Fabrication of the Cells



(b) Fabrication of the CLC

1. Weigh and mix the desired amount of nematic liquid crystal E7 and chiral material S811 at ratios below:

	S811 wt(%)	E7 wt(%)
Sample 1	10	90
Sample 2	20	80
Sample 3	30	70
Sample 4	35	65
Sample 5	40	60

2. Put the tube into an ultrasonic mixer to ensure the two materials are well mixed so as to form Cholesteric Liquid Crystal.

3. Heat the CLCs to 55 degree Celsius, so it presents a liquid state.

4. Insert the CLCs into the cells, using a vacuum drying oven.

B. Measurement of Transmission Spectra

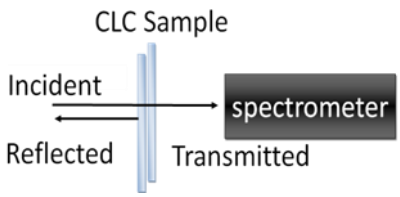


Figure 5. Schematic of the measurement.

(a) Transmission Spectra of Different Concentrations of the CLCs

1. Put the empty cell into the spectrometer and measure its transmission spectrum as the reference point.

2. Measure the spectra of CLC-loaded cells.

3. Observe the effect of different concentrations on the transmission spectra, and find out in which concentration the CLC exhibits the lowest infrared transmittance.

(b) Transmission Spectrum of the Scattering State

1. Put the empty cell into the spectrometer and measure its transmission spectrum as the reference point.

2. Measure the spectra of CLC-loaded cells when voltage is applied.

3. Transfer the transmission spectra into reflection spectra. (Transmittance + reflectance + absorbance = 1, the absorbance of the CLC is very low that can be ignored.)

4. Observe the effect of bias voltages on reflection spectra, and find out at which voltage the CLC exhibits the highest reflectance of visible light.

C. Response Time

(a) The Response time is defined as the time a CLC sample needs to change from 10% to 90% of the maximum dynamics range.

(b) Measure the intensity of transmitted visible light when the CLC goes through transition in between the first transparent state, the scatting state, and the second transparent state.

3. Results & Discussion

3.1Reflection Spectra

A. Different Concentration of the CLCs

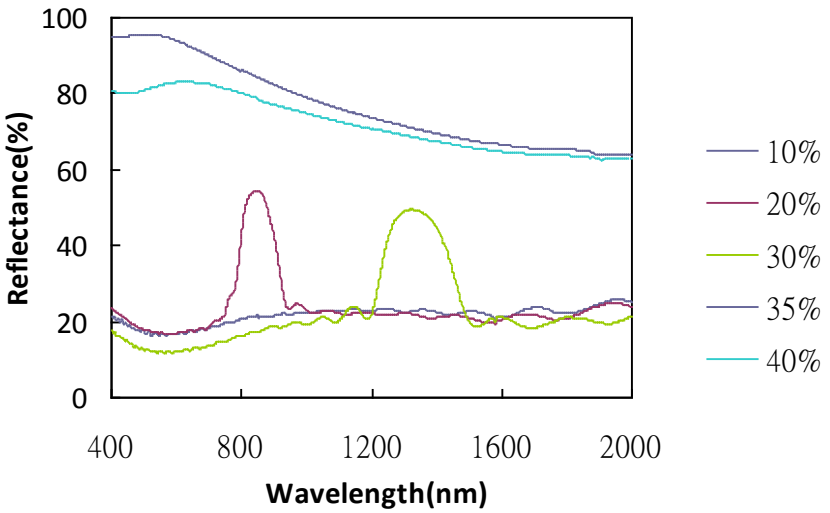


Figure 6. Reflection Spectra of Different Concentrations of CLCs.

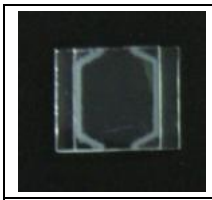
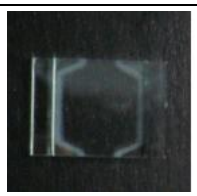
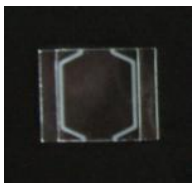
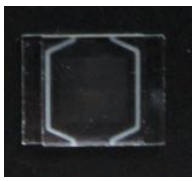
				
(a) E7-90wt% S811-10wt%	(b) E7-80wt%, S811-20wt%	(c) E7-70wt% S811-30wt%	(d) E7-60wt% S811-35wt%	(e) E7-90wt% S811-40wt%

Figure 7. Photos of Different Concentration of CLCs.

(a) The reflectance of S811 10wt% does not increase over a specific spectral range. It remains at 20% from 400nm to 2000nm. It is conjectured that the percentage of the chiral material was too low to form the pitched structure, and thus is without selective reflection.

(b) The reflectance of S811 20wt% is in a lower range starting at 700 nm and ending at 900 nm, with the highest reflectance around 55%, while remaining at around 80% transparency.

(c) The reflectance of S811 30wt% is in a higher range starting at 1,200 nm and ending at 1,500 nm, with the highest reflectance around 50%, while remaining at around 80% transparency.

(d) The reflectance of S811 35wt% and S811 40wt% increases as the wavelength increases, without an obvious selective reflection at visible light. It is conjectured that the percentage of chiral material was too high and thus the arrangement of the molecules was close to another liquid crystal, smectic liquid crystal, which does not possess selective reflection because it is without pitch.

(e) S811 20wt% and S811 30wt% are both able to reject infrared while low visible light reflectance remains, which means they possess high transparency.

(f) Due to the results of reflection spectra analyses of different concentrations of the CLCs, the project continued with S811 20wt% and S811 30wt%.

B. S811 20wt% under bias

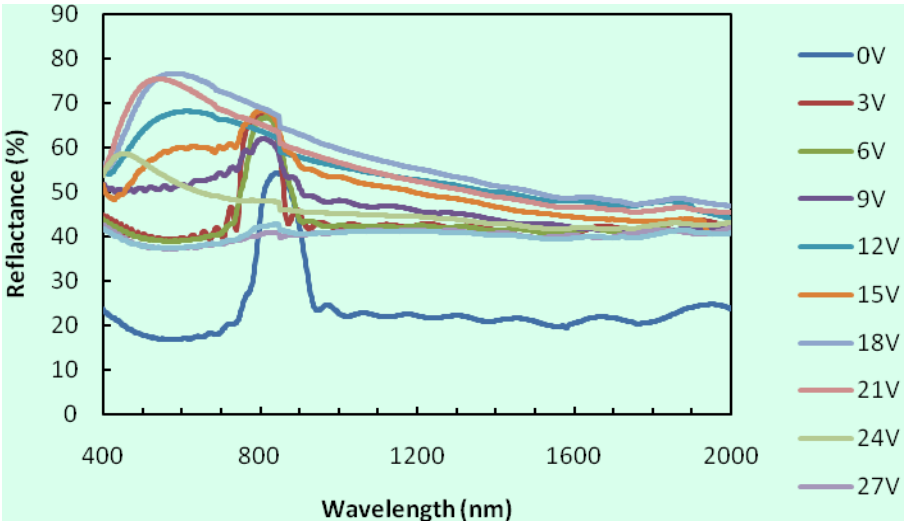


Figure 8. Reflection spectra of the S811 20wt% under bias voltage.

The range of selective reflection of S811 20wt% shifts to shorter wavelengths as the applied voltage increases from approximately 0V to 24V. While at approximately 27V to 30V, the whole reflectance remains approximately 40 %. It is conjectured that the electrical force enlarges the angle between each layer therefore the pitch, as well as, the wavelength of selective reflection decrease.

(a) When approximately 6V is applied the reflectance of the infrared light reaches 70% of its highest value from 700nm to 900nm, while remaining 40% at other wavelengths. It now exhibits the first transparent state.

(b) When approximately 18V is applied the reflectance of the visible light is approximately 80% of its highest value. It now exhibits the scattering state.

(c) When approximately 30V is applied the reflectance remains approximately 40%. It now exhibits the second transparent state.

C. S811 30wt% under bias

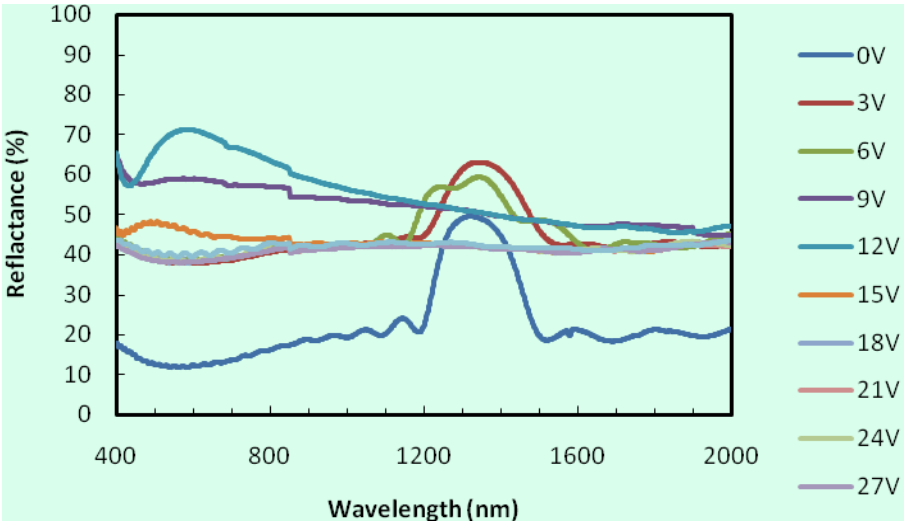


Figure 9. Reflection spectra of the S811 30 wt% under bias voltage.

(a) The selective reflection of S811 30wt% shifts to shorter wavelengths as the applied voltage increases from approximately 0V to 12V. While at approximately 15V to 30V, the whole reflectance remains at approximately 40%. It is conjectured that the electrical force enlarges the angle between each layer therefore the pitch, as well as, the wavelength of selective reflection decreases.

(b) When approximately 3V to 6V is applied the reflectance of the infrared light reaches 60% of its highest value from 1200nm to 1500nm, while remaining 40% at other wavelengths. It now exhibits the first transparent state.

(c) When approximately 12V is applied the reflectance of the visible light reaches around 70% of its highest value. It now exhibits scattering state.

(d) When approximately 30V is applied, the reflectance remains approximately 40%. It now exhibits the second transparent state.

3.2Response Time

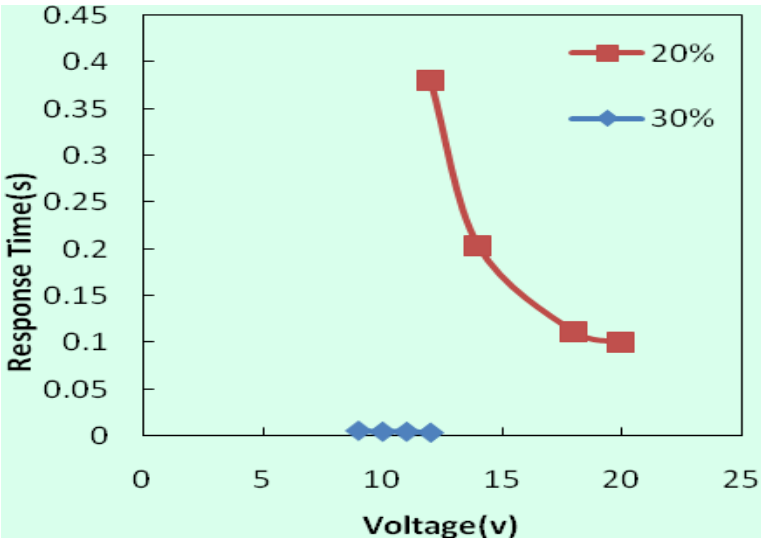


Figure 10. State changing response time of S811 20wt% and S811 30wt%.

The response time of the CLC devices is summarized in the following table. Note that S811 30wt% exhibits a much faster response time. All the devices are, nonetheless, sufficiently fast for our purposes.

S811 20wt%		S811 30wt%	
Applying Voltage (V)	Response Time (S)	Applying Voltage (V)	Response Time (S)
12	0.381	9	0.006
14	0.204	10	0.005
18	0.112	11	0.005
20	0.1	12	0.004

3.3Power Consumption

The Ohm resistance of LC (liquid crystal) material is very large. The device thus formed can be regarded as an electric capacitor when LC is placed in between two pieces of ITO (Indium Tin Oxide) glass and a direct current is applied. he electric current it consumes is extremely small.

4. Conclusion

4.1 After characterization, the custom mixtures of CLC are found to:

A. reject the infrared light under a natural state, which is ideal for use in summer.

B. reject both the infrared light and the visible light when proper voltage is applied, thus serving as a blinder to improve the functional condition of a room.

C. allow the infrared light and visible light to transmit when proper voltage is applied, so as to reduce the heating requirement in winter.

4.2 S811 20wt%.

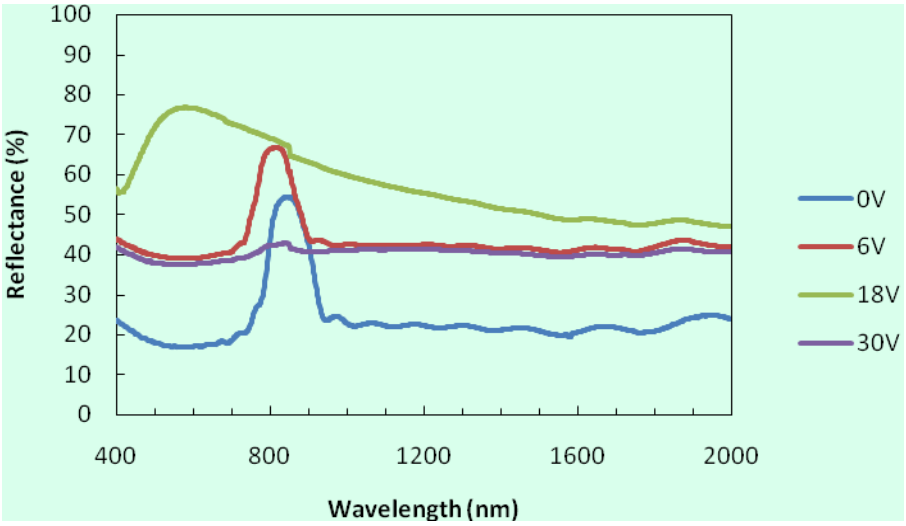


Figure 11. Reflection spectra of S811 20wt% when specific voltage is applied.

	Voltage (V)	Transmittance of infrared (%)	Transmittance of visible light (%)	Practical applications of a CLC window
Transparent state1	0	45	80	Reject infrared while maintaining high transparency in the visible
	3	30	60	
Scattering state	18	30	25	Serve as a blinder.
Transparent state2	30	60	60	Allows both infrared and visible light to transmit, which is ideal for use in winter.

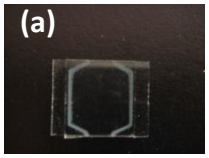
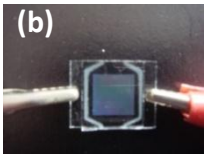
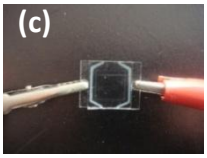
		
0 V	18 V	30 V

Figure 12. Photos of exhibiting states when proper voltage is applied.

4.3 S811 30wt%

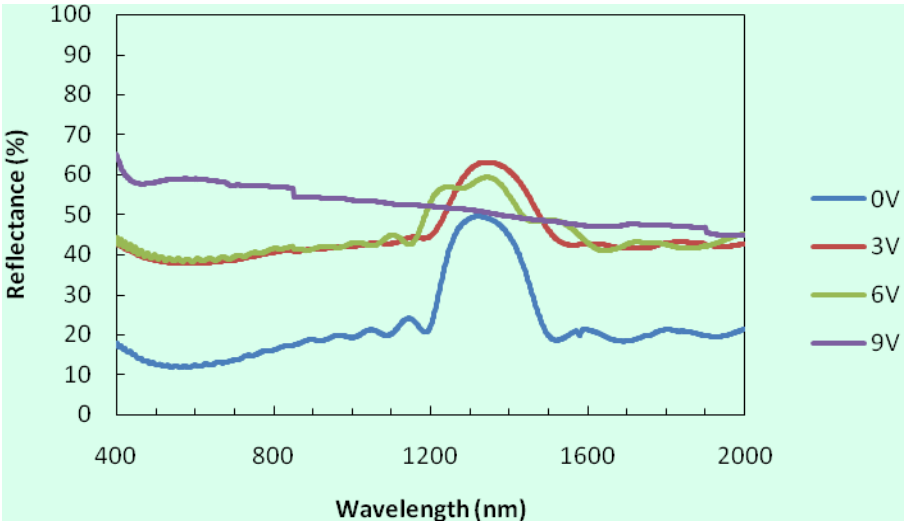


Figure 13. Reflection spectra of S811 30wt% when specific voltage is applied.

	Voltage (V)	Transmittance of Infrared (%)	Transmittance of visible light (%)	Practical applications of a CLC window
Transparent state1	0	50	80	Reject infrared while maintaining high transparency in the visible
	3	40	60	
Scattering state	12	40	30	Serve as a blinder.
Transparent state2	30	60	60	Allows both infrared and visible light to transmit, which is ideal for use in winter.

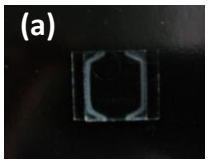
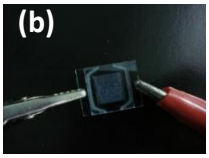
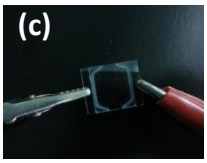
		
0 V	12 V	30 V

Figure 14. Photos of exhibiting states when proper voltage is applied.

5. References

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[2]. Peter J. Collings, Michael Hird, Introduction to Liquid Crystals: Chemistry and Physics (Liquid Crystals Book Series) (Paperback).

[3]. R. Padiyath (Woodbury, MN, US), Radcliffe, Marc D. (Newport, MN, US), Thomas, Cristina U. (Stillwater, MN, US),Marttila, Charles A. (Shoreview, MN, US),Jain, Manish (Minneapolis, MN, US),Weber, Michael F. (Shoreview, MN, US),Bai, Feng (Woodbury, MN, US). 2007. Infrared light reflecting film. U.S. Patent No. 20070109673.

[4]. Y. W. Chang “Measurements and computer simulation of reflection properties of bistable reflective polymer-stabilized cholestereric texture films” Department of Physics, National Cheng Kung University. (M. S. Dissertation)

[5]. Edward J. Bawolek, Chandler; Greogory W. Starr, Tempe; Zong-Fu Li,Gilbert. 2000, Liquid crystal color filter with integrated infrared blocking. U.S. Patent No. 6424392 B1.

[6]. K.N. Chang “The Study of Electro-Optic Effect of Hybrid Twisted Nematic Liquid Crystal” Department of Polymer Engineering, National Taiwan University of Science and Technology. (M. S. Dissertation)

6. Supplements

6.1 Heat blocking effects

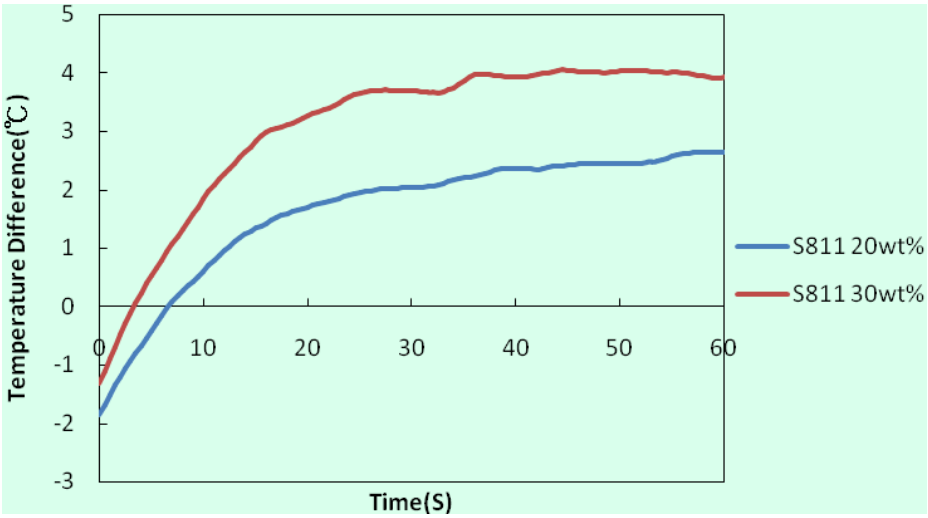


Figure 15. Heat blocking effects of S811 20wt% and S811 30wt%.

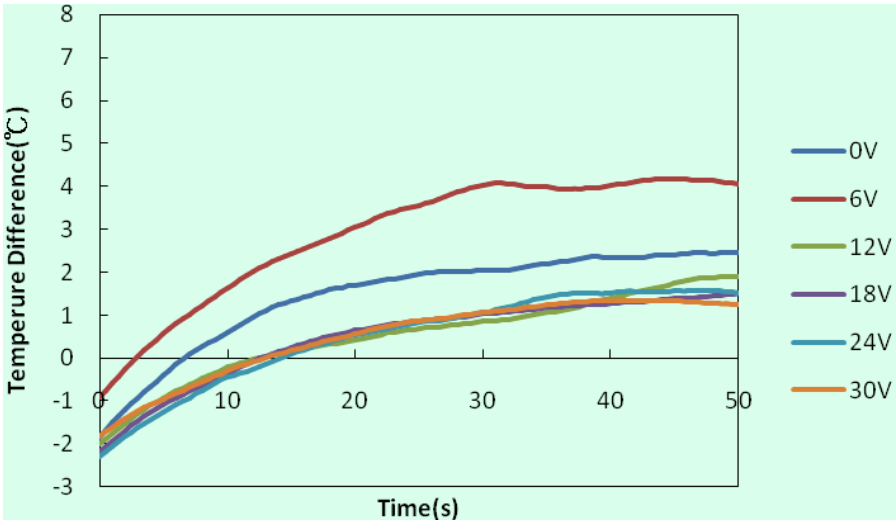


Figure 16. Heat blocking effects of S811 20wt% under bias.

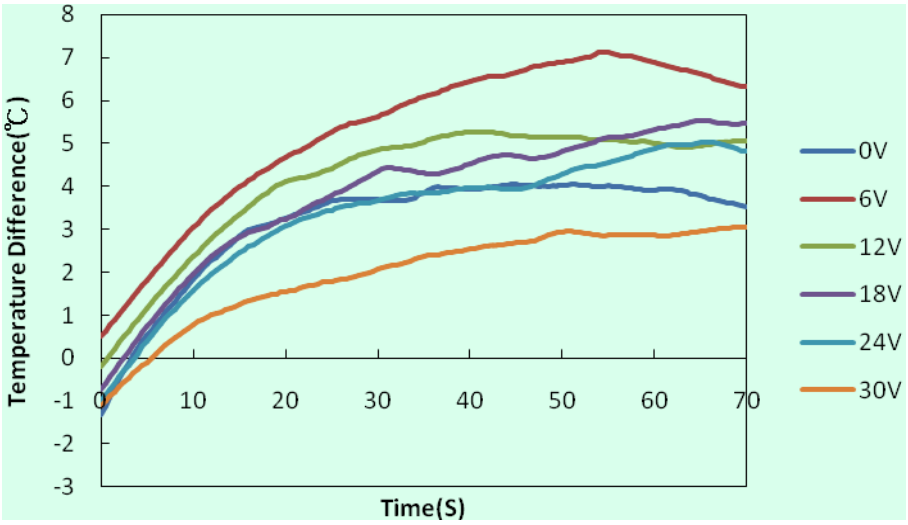


Figure 17. Heat blocking effects of S811 30wt% under bias.

6.2 Reflection spectra ofS811 10wt%, S811 35wt% S811 40wt%

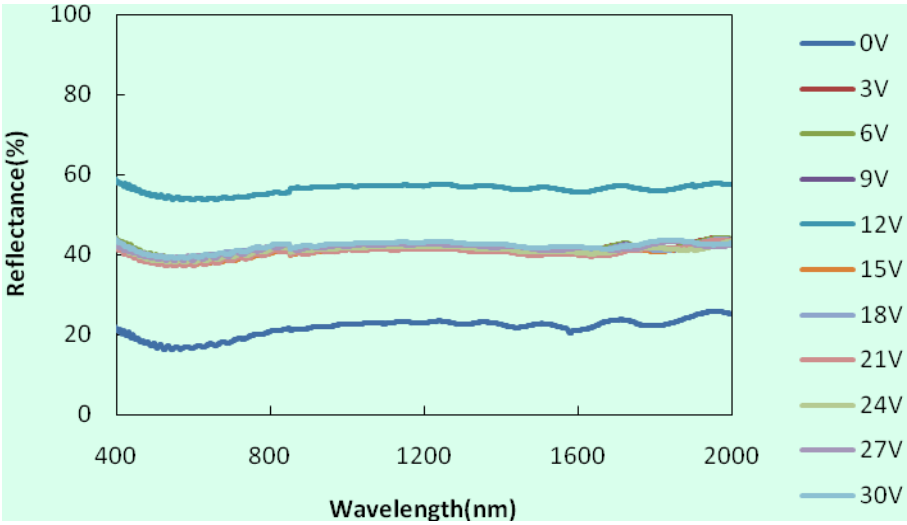


Figure 15. Effects of bias on S811 10wt%.

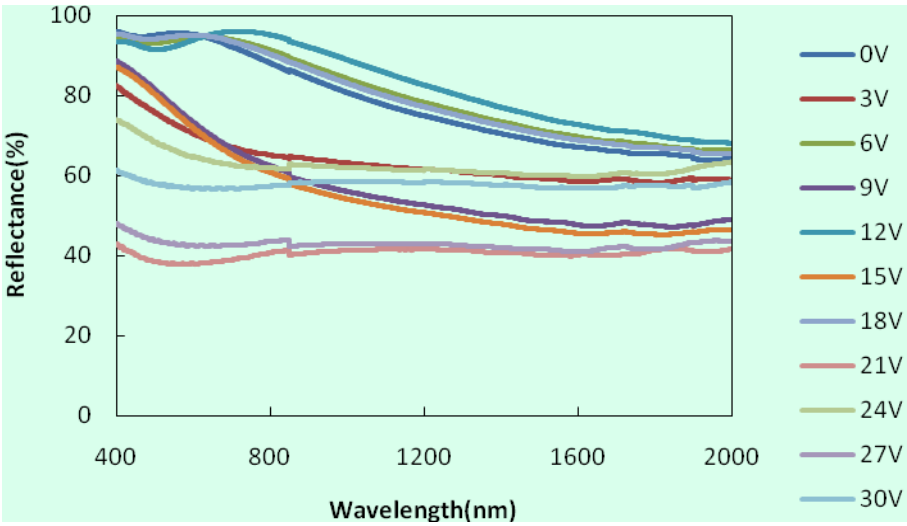


Figure 16. Effects of bias on S811 35wt%.

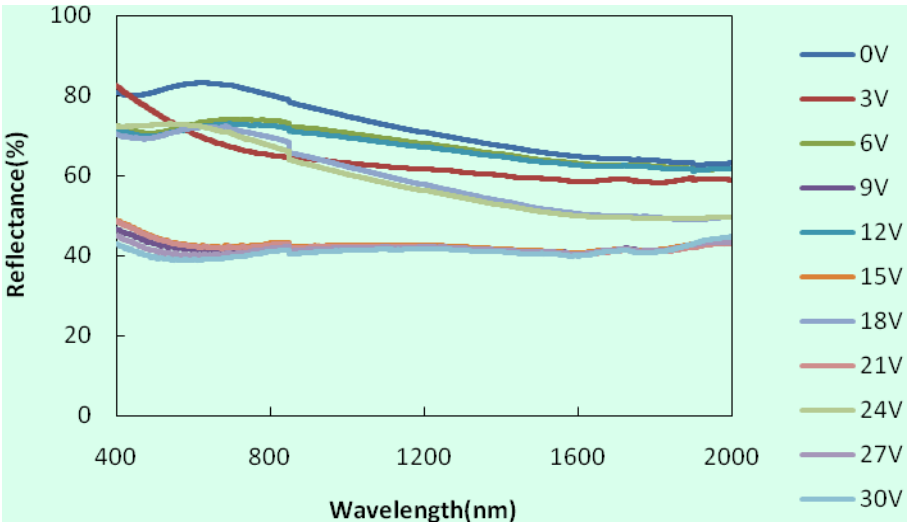
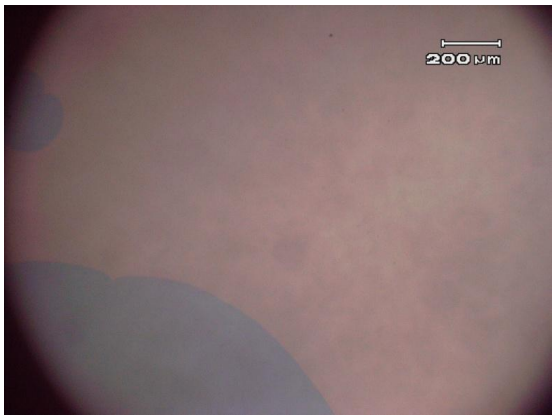


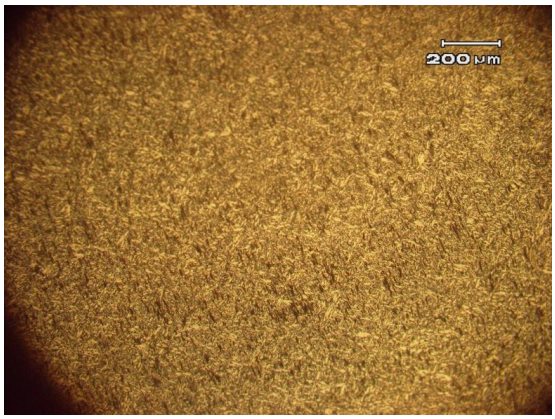
Figure 17. Effects of bias on S811 40wt%.

6.3 Optical texture of the S811 20wt% under bias



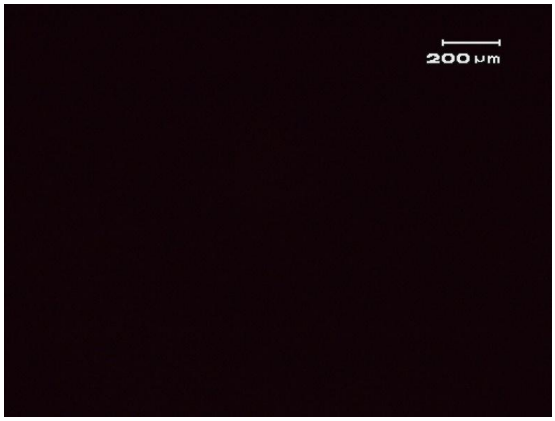
(A) 0V

(B) 6V



(C) 18V

(D) 20V



(E) 30V

Figure 18. photos of S811 20wt% under polarizing microscope.