Utilizing 1-D Photonic Cavity of a Cholesteric Liquid Cyrstal to Increase Efficiency of Solar Concentrators

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Introduction

Solar concentrators have been identified as attractive systems to retrofit windows in existing buildings for solar energy harvesting. In order to be viable these systems need to be thin films or cheap integrated replacement windows. This project aims at using the 1-D photonic nature of a cholesteric liquid crystal film to increase the absorptance of dye in a concentrator.

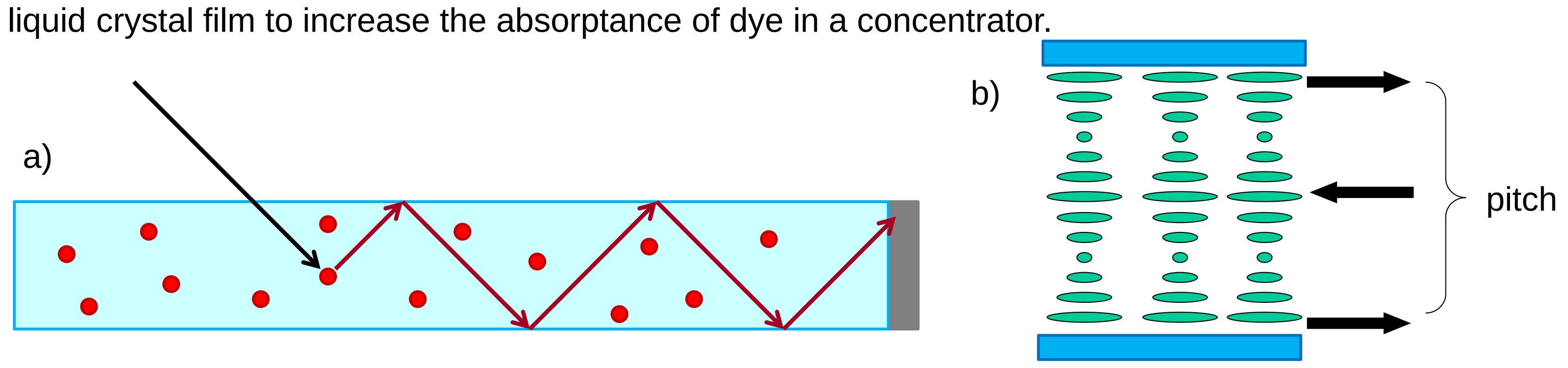

FIG. 1: Schematics of (a) light collection via luminescent solar concentrator (b) planar alignment of a cholesteric liquid crystal

- ❖ Solar concentrators function by using a luminescent species in a transparent medium to absorb solar radiation
- ❖ The dye then re-emits light which is trapped via total internal reflection and guided to the edge of the cell where it is collected by a thin strip of photovoltaic cell
- ❖ Cholesteric liquid crystal materials consist of chiral rod shaped molecules.
- ❖ When aligned in a planar configuration the director axis of the material (black arrows in Figure 2b) precesses 360°
  - ❖ This distance is defined as the pitch of the cholesteric (ref 1)

Cholesteric as a 1-D Photonic Crystal

- ❖ The periodically repeating change of index of refraction in the cholesteric liquid crystal creates a 1-D photonic band gap in the material (ref 2).
- ❖ Light incident of the cholesteric is reflected if the wavelength and circular polarization matches the pitch and handedness of the material (Figure 2)

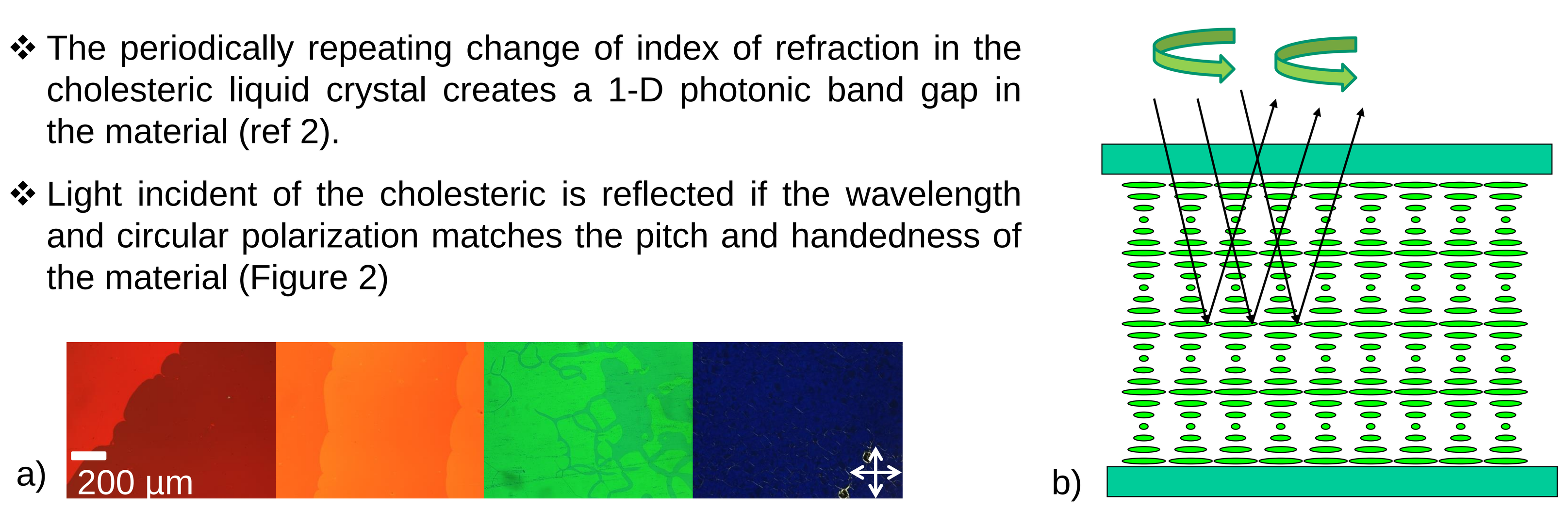

Figure 2 – polarized microscopy images of cholesteric mixtures of varying pitch, (b) schematic of planar aligned cholesteric liquid crystal cell reflecting light incident on the surface

- ❖ When placed under sunlight the wavelength and polarization of the incident light determines how the light interacts with the material (Figure 3)
  - ❖ Light of wavelengths outside the stop band pass through unobstructed
  - ❖ Light inside the stop band and circularly polarized **opposite** to the handedness of the cholesteric passes through unobstructed
  - ❖ Light inside the stop band and same polarization handedness as the cholesteric is reflected
- ❖ At the edge of the stop band the group velocity of the light drops to zero and the light acts as a standing wave (ref 3)
  - ❖ Dye molecules dispersed in the cholesteric liquid crystal have a higher probability of absorbing light at the edge of the stop band
    - ❖ Higher absorption should result in more trapped light in a cholesteric phase compared to a disordered isotropic phase

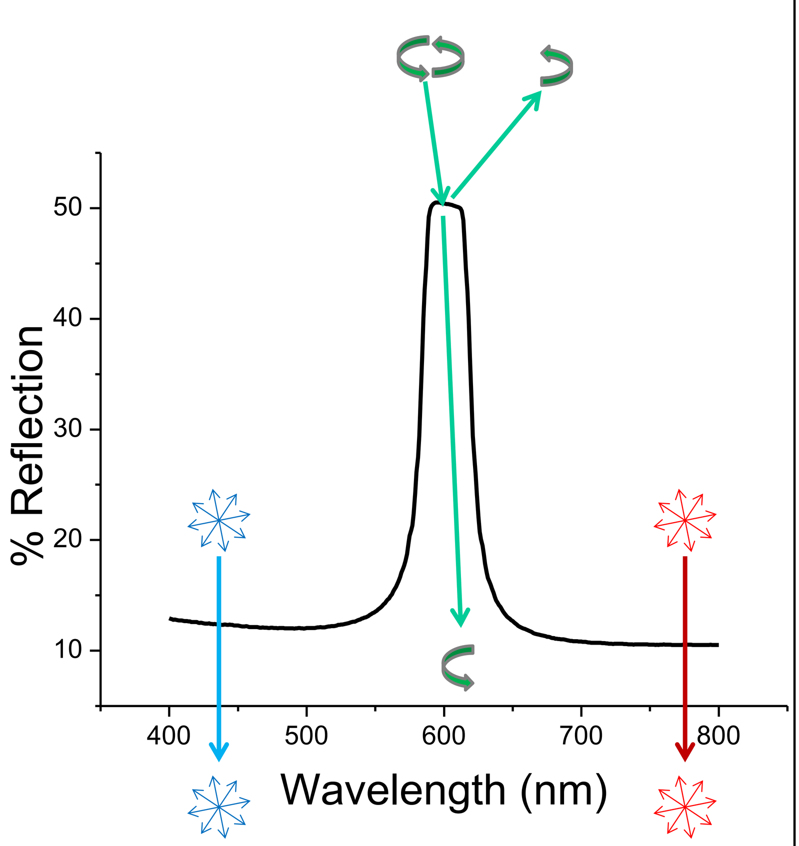

FIG. 3: Plot of the reflection band and how light throughout the visible spectrum interacts with the stop band.

Method

- ❖ Liquid crystal mixtures are prepared using the nematic 4-Cyano-4'-pentylbiphenyl (5CB) mixed with the chiral cholesteryl oleyl carbonate (COC)
- ❖ Cholesteric stop band is modulated by varying the concentration of nematic to cholesteric in the liquid crystal mixture
- ❖ Lumogen Red F 300 is added to the isotropic liquid crystal in concentrations of 4, 9 and 14 mM.
- ❖ 2 by 2 cm cells are filled with the isotropic liquid crystal dye mixture by capillary action and are cooled slowly (1°C/min) into the cholesteric phase

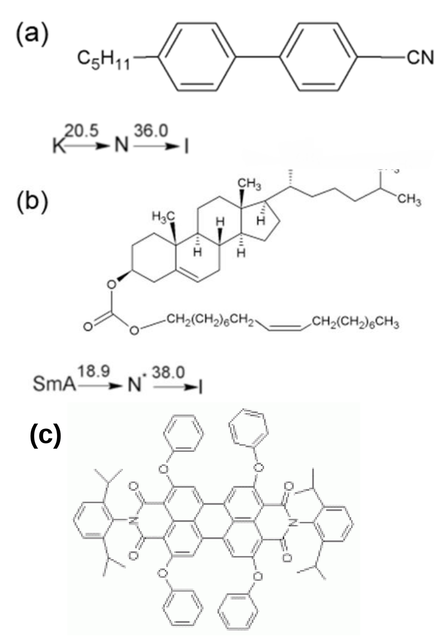

FIG. 4: The molecular structure of (a) liquid crystal 5CB (b) chiral COC and (c) dye Lumogen Red F

Absorptance

- ❖ Absorption of Red F in toluene is shown in red
- ❖ Stop band of a cholesteric mixture with no dye is shown in blue
- ❖ The presence of a stop band should allow the Red F to more readily absorb wavelengths at the edges of the stop band

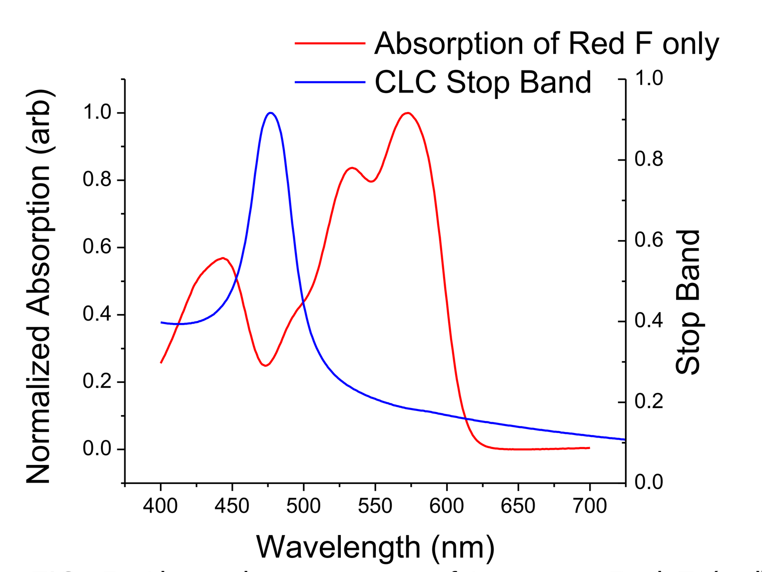

FIG. 5: Absorption spectrum of Lumogen Red F (red) and spectral stop band for cholesteric mixture (blue)

$$Absorptance = \frac{I_{incident} - I_{LSC}}{I_{incident}}$$

- ❖ Absorptance is measured for cells with stop bands throughout the visible spectrum
- ❖ When heated into the isotropic phase the absorptance of the dye matches that of dye in toluene
- ❖ In the cholesteric phase the **absorptance is increased around the stop band**

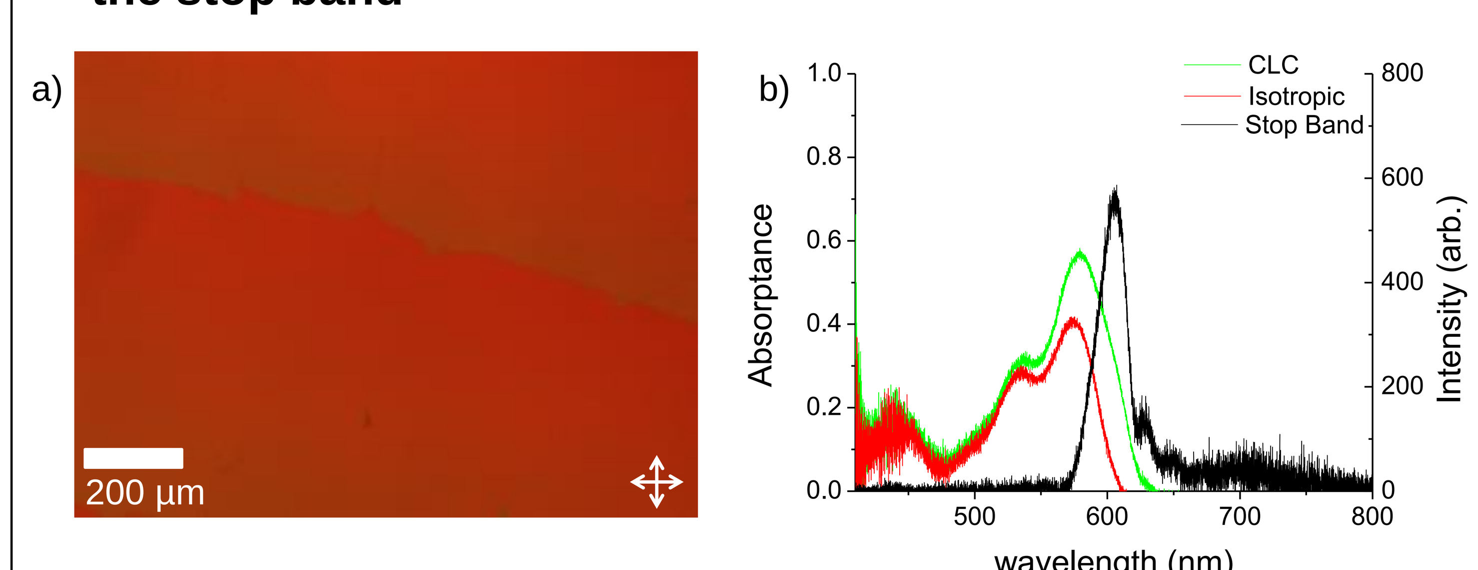

FIG. 6: (a) Crossed polarized image of liquid crystal cell, (b) absorptance for cholesteric (green) and isotropic (red) cell

Edge Emission Intensity

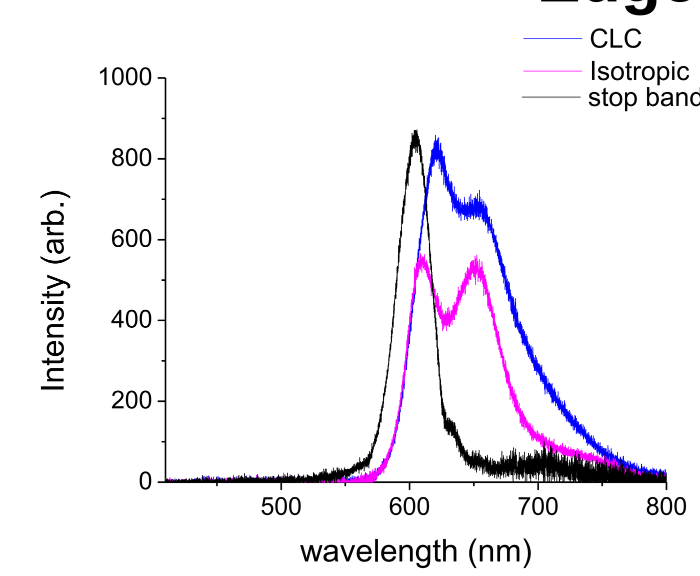

FIG. 7: Emission intensity collected from the edge of concentrator cell in cholesteric (blue) and isotropic (pink) phases

- ❖ Emission from the edge of the concentrator is collected in the cholesteric and isotropic phases
- ❖ Increased absorption in the cholesteric phase allows **more light** to reach the edge of the cell than in the isotropic phase

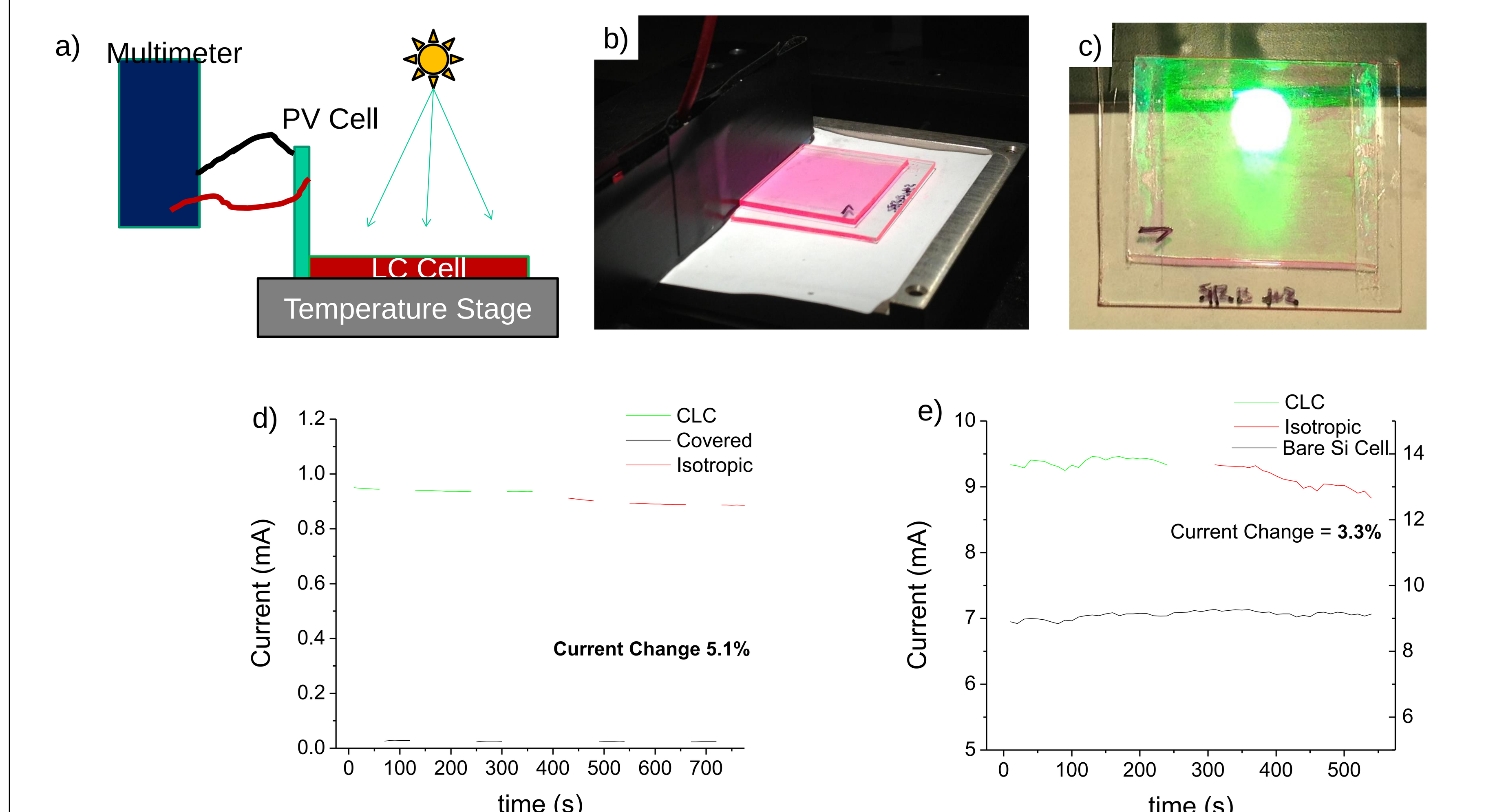

FIG. 8: (a) schematic for PV current measurements, (b) photo of concentrator cell under white light source, (c) photo of same cell showing the cholesteric reflection band, and PV current of cells under controlled white light (d) and outside in direct sun (e) for both cholesteric (green) and isotropic (red) phases.

- ❖ The cells are attached to a silicon photovoltaic (PV) cell with optical gel
- ❖ Photovoltaic current is measured over minutes in the liquid crystal phase
- ❖ The sample is heated past the isotropic transition temperature and the current is measured again
- ❖ Current in well aligned cells is up to **5% higher** in the cholesteric phase than in isotropic for controlled white light source and **3% higher** for actual sun measuements

Conclusions and Future Work

- ❖ The cholesteric stop band has been shown to allow for greater absorption for dye dispersed within
- ❖ Increased absorption leads to greater light emission at the edges of the concentrator cell
- ❖ Photovoltaic current measurements confirm a higher current delivered in the cholesteric phase than in an isotropic medium
- ❖ Future work includes stacking cells to determine whether the current increase is additive

Acknowledgements

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