An Artificial Light Driven Goldfish

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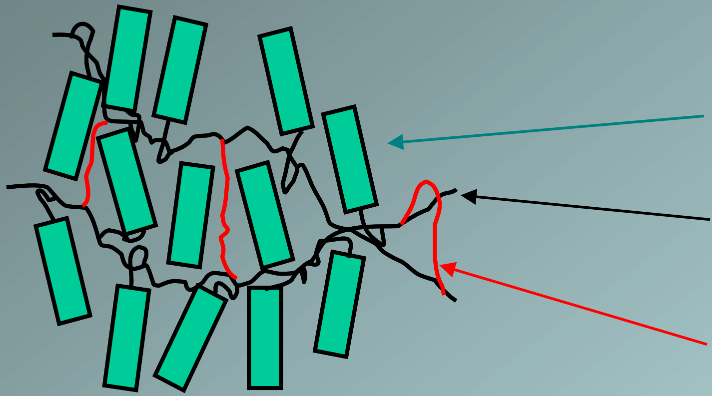
Project Aims:

- to understand how soft active materials interact with a fluid environment as in:
    - folding & motion of leaves in wind
    - fish swimming in water
    - peristaltic pumps
- to better understand of the interaction between light and liquid crystal elastomer (LCE) materials

Liquid Crystal Elastomers

- LCE: liquid crystal rubber



- strong coupling between nematic order and mechanical strain
- order parameter changes induce shape changes
- light can change the order parameter, resulting in shape changes

Elastomer Free Energy

Liquid Crystals: Order Parameter Tensor $Q_{\alpha\beta}$

Elastomers: Strain Tensor $\varepsilon_{\alpha\beta}$

$$F = \frac{1}{2}\left(\frac{T}{T_c}-1\right)Q_{\alpha\beta}^{\;2} + \ldots. + \frac{1}{2}\varepsilon_{\alpha\gamma}E_{\gamma}E_{\beta}Q_{\alpha\beta} + \frac{1}{2}\eta\varepsilon_{\alpha\beta}^{2} + \sigma_{\alpha\beta}\varepsilon_{\alpha\beta} + C\varepsilon_{\alpha\beta}Q_{\alpha\beta}$$

Nematic Free Energy

E-field Term

Elastomer Free Energy

Coupling Term

C – constant

η – Young's modulus

$\sigma_{\alpha\beta}$ – external stress tensor

Light Induced Order Parameter Changes

Light can change the order parameter via:

• direct heating of the sample

• disruption of nematic order due to photoisomerization

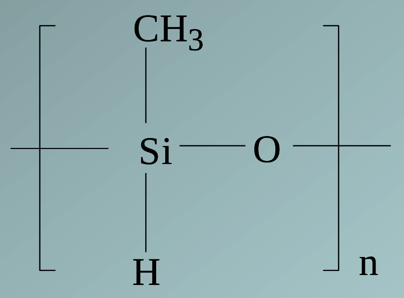
• direct optical torque due to direct angular momentum transfer from the light

• indirect optical torque

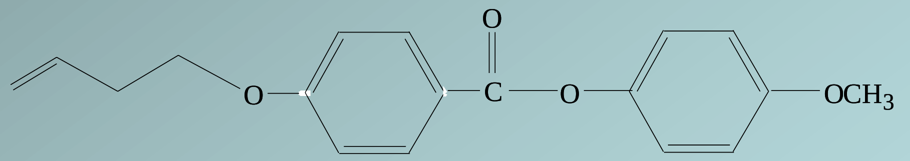
All these mechanisms could be contributing.

LCE Composition

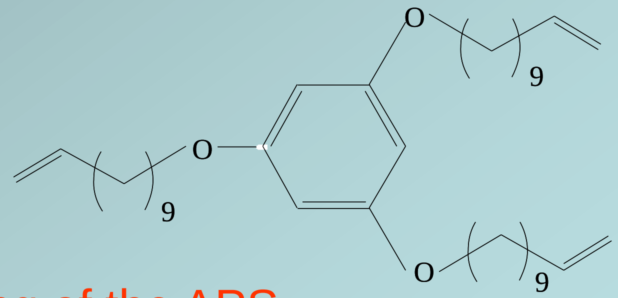
- methylsiloxane monomer
  (main chain)



- mesogenic biphenyl
  (side group)



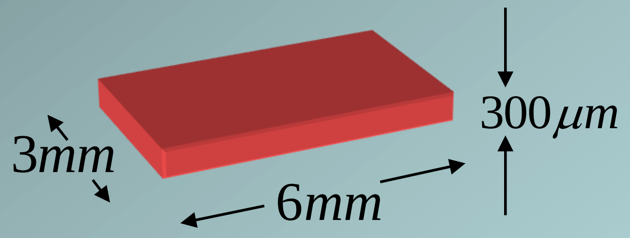
- trifunctional crosslinker



Our LCE Materials

samples have the following properties:

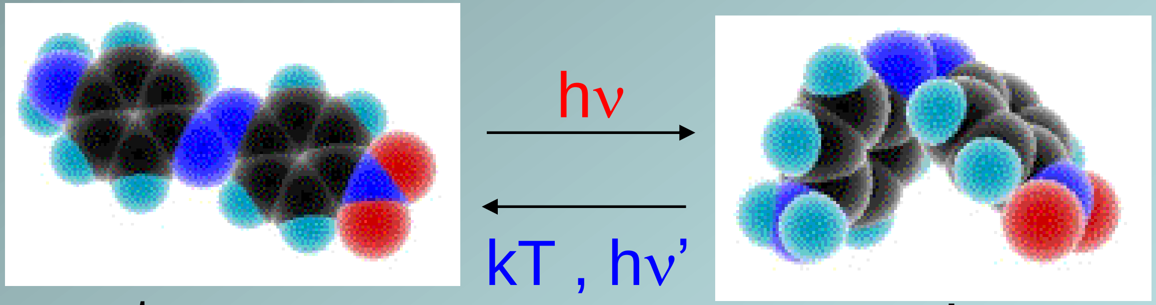
- nematic monodomain
- 8 – 12% cross-linking
- 0.1% dissolved azo-dye



Typical LCE sample size.

Azo-Dyes

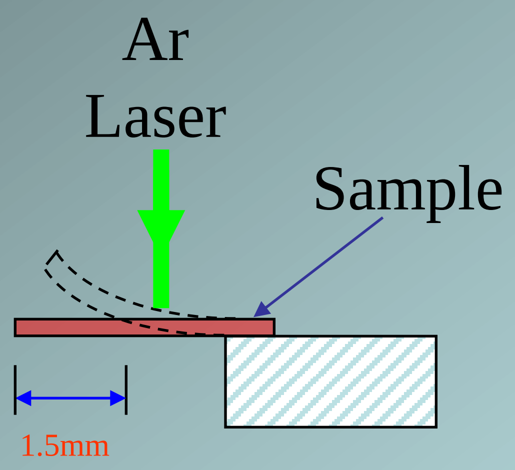
- contain a N = N double bond connecting aromatic benzene rings
- undergo photoisomerization, from the trans- to cis-configuration on absorption of a photon
- align with the nematic director
- are dissolved in our LCEs to aid in light absorption

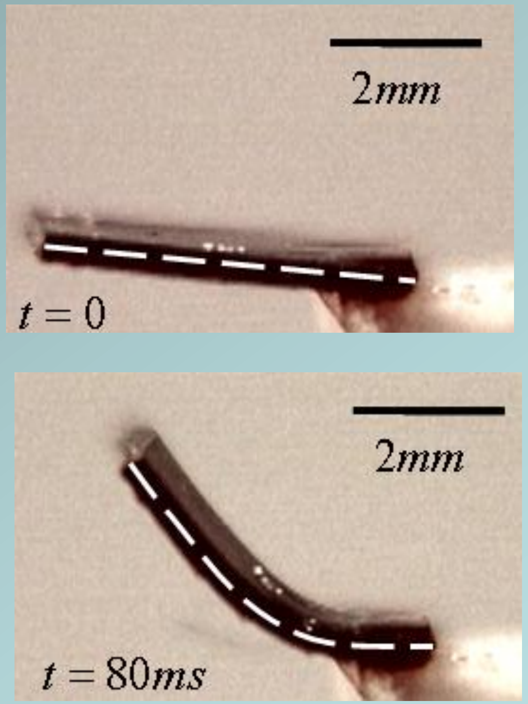


trans- cis-

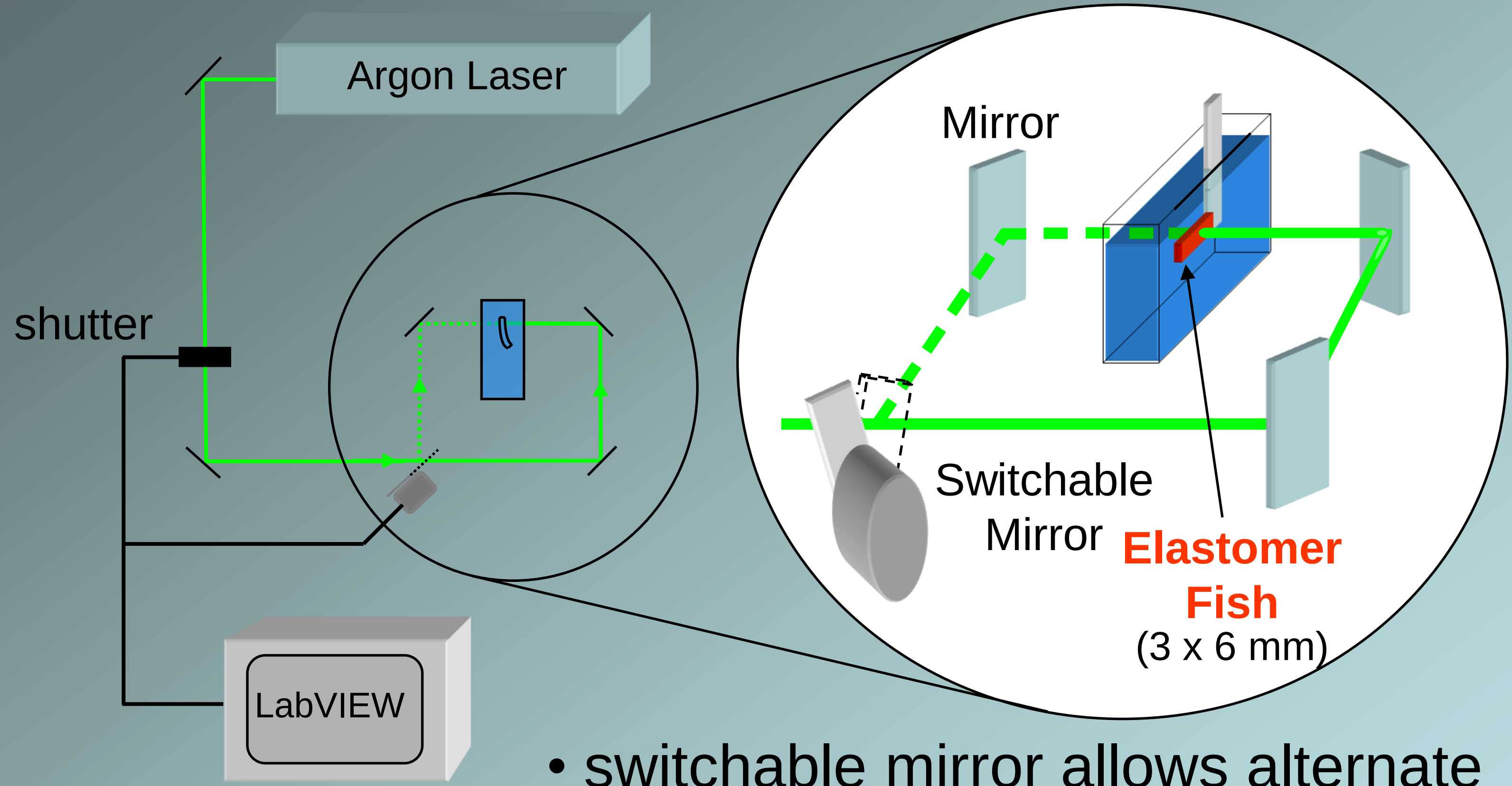
Light Induced Bending of LCEs

• laser illumination causes the elastomer to bend towards the beam, as shown





Experiment

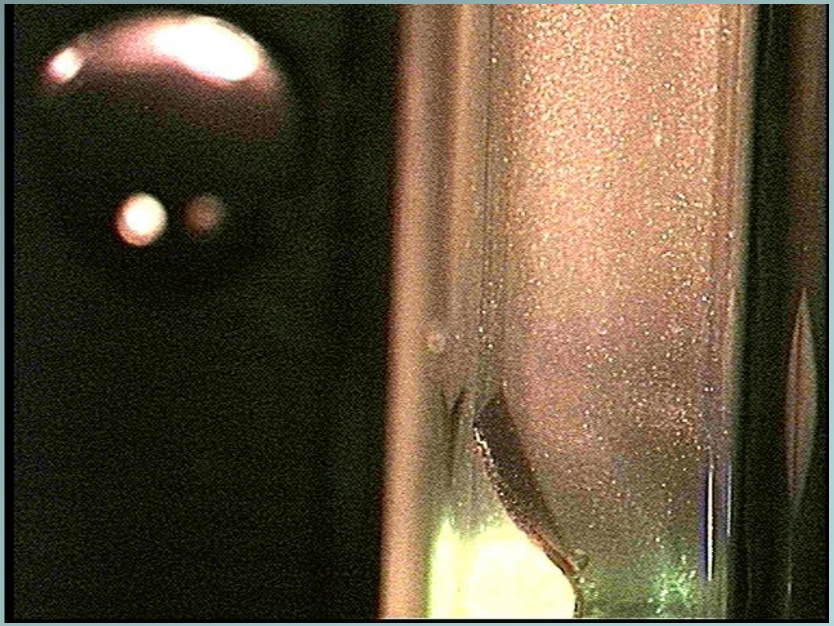


- switchable mirror allows alternate illumination of each side of LCE sample

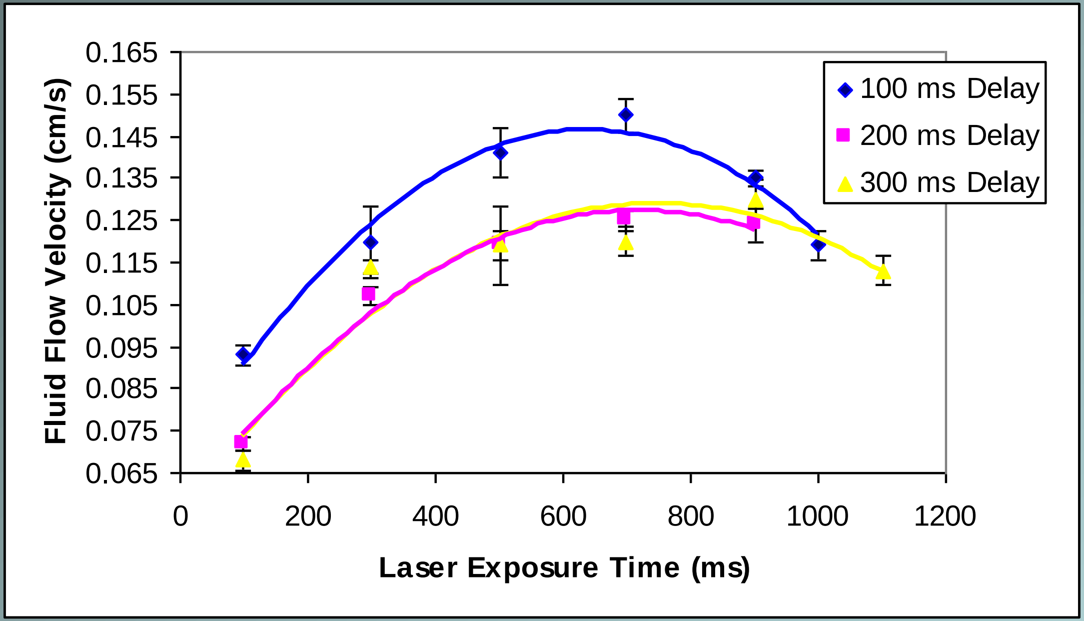
Experiment

• sample immersed in rheoscopic fluid, which allows for flow visualization

• sample is illuminated alternately on both sides by light at 514nm from Ar laser



Experimental Results



Fluid velocities for various elastomer driving excitations

- highest pumping rates are achieved with the shortest delay time between laser pulses

- all curves peak near the same exposure time of 700 ms

Momentum Transfer

- laser light provides energy to the LCE, but not momentum
- energy transfer induces a stress in the LCE sample, causing it to bend.
- bending of the elastomer sample transfers momentum to the surrounding fluid
- fluid transfers momentum to the LCE sample
- This is similar to a conventional motor, where energy is used to cause momentum transfer.

Drag Reduction

Grey's Paradox: actively swimming fish experience a significant drag reduction through the swimming process*

- possibly due to
  - viscous damping by fluid cells under the skin
  - swimming motion
- we would like to determine if soft active materials can lead to a drag reduction
- could lead to new applications such as
  - soft active materials to coat boats for reduced energy consumption

* Gray, J. Studies in animal locomotion, *J. Exp. Biol.* 13, pp. 192-199 (1936).

Conclusions

- laser supplies energy to the system which results in momentum transfer between fish & surrounding fluid
- fluid is pumped backwards
- results of this experiment will be compared with modeling
- expect new insight into soft active materials

Future work

- design experiment to determine if drag reduction is present in our system