Modelling of the Photo-Mechanical Response of Liquid-Crystal Elastomers

Giacomo Cerretti[1], Jean-Christophe Gomez-Lavocat[2], Kevin Vynck[1], Diederik S. Wiersma[3]

[1]European Laboratory for Non-Linear Spectroscopy (LENS), University of Florence, Sesto Fiorentino, Italy

[2]European Laboratory for Non-Linear Spectroscopy (LENS), University of Florence, Sesto Fiorentino, Italy; The Institute of Photonic Sciences (ICFO), Mediterranean Technology Park, Castelldefels, Spain

[3]European Laboratory for Non-Linear Spectroscopy (LENS), University of Florence, Sesto Fiorentino, Italy; Istituto Nazionale di Ottica (INO), National Research Council (CNR), Florence, Italy

Abstract

Liquid-crystal elastomers (LCEs) [1] have attracted a great attention in recent years due to their high potential in a wide range of applications, from microfluidics components [2] to artificial muscles [3]. The photo-mechanical response of LCEs is due to their constitutive photo-sensitive molecules, which change shape when absorbing part of the incident light. These microscopic deformations can cause a macroscopic contraction or expansion of the material, depending on the orientation of the molecules, the absorption coefficient of the medium and the light intensity. This phenomenon can be used, for instance, to drive a small actuator with light (see Figure 1). Towards future applications, it is important to develop an ab-initio tool able to couple in an exact way the optical response of the material and its mechanical deformation, in order to gain a deeper understanding of the behavior of LCEs when exposed to a light stimulus. Our work concerns the multi-physics finite-element modeling of the photo-mechanical response of LCEs, using COMSOL Multiphysics. The Radio Frequency package was used to solve the electromagnetic problem of the light scattering and absorption by the object. The resulting material deformation was then evaluated using the Structural Mechanics package by introducing an equation that expresses the strain in the material as a function of the retrieved light intensity. Using this approach, we modeled the macroscopic deformation of a two-dimensional LCE-based cantilever in response to a steady-state plane wave, as a function of the molecular alignment, absorption coefficient and light intensity, and compared our results with a simplified analytical model assuming the Beer-Lambert's law of absorption [4]. A very good agreement was found in the limit of a relatively strong absorption coefficient and/or thick sample, thereby validating our model. On the other hand, we found that when the wave nature of light becomes important, for instance when interferences due to multiple reflections at the interfaces of the medium cannot be neglected, the deformation of the material can deviate strongly from expectations. This illustrates clearly the relevance of our model to treat more realistic cases. In conclusion, by solving exactly the electromagnetic problem, our finite-element model completes the theoretical models known so far on the deformation of LCE-based materials. It can be easily applied

to more complex geometries and may find use in a near future in the design of actuators for lab-on-a-chip devices [5] or in the implementation of soft motors [6].

Reference

1. M. Warner and E. M. Terentjev, "Liquid Crystal Elastomers" (Clarendon Press, Oxford, 2003).
2. J. Den Toonder et al., "Artificial cilia for active micro-fluidic mixing", Lab Chip 8, 533-541 (2008).
3. T. Mirfakhrai et al., "Polymer artificial muscles", Materials Today 10, 30-38 (2007).
4. C. L. van Oosten et al., "Glassy photomechanical liquid-crystal networks actuators for microscale devices", Eur. Phys. J. E 23, 329-36 (2007).
5. S. A. Wilson et al., "New materials for micro-scale sensors and actuators. An engineering review", Materials Science and Engineering: R: 56 1-129 (2007).
6. M. Yamada et al., "Photomobile Polymer Materials: Towards Light-Driven Plastic Motors", Angewandte Chemie , 47, 4986–4988 (2008).

Figures used in the abstract

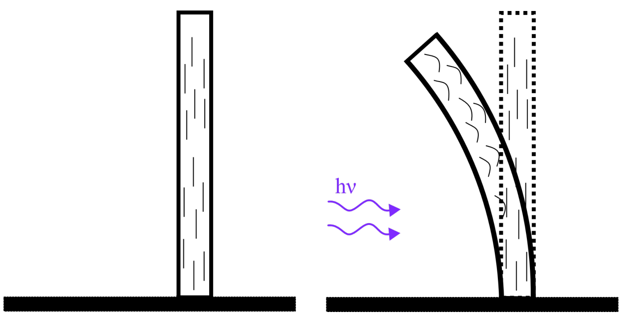

Figure 1: Macroscopic deformation of a LCE-based cantilever caused by the microscopic deformation of the molecules due to the light absorption.