A replacement model for nonlinear dynamics of electro-active liquid crystal coatings

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Abstract. A replacement lumped-parameter model is proposed to simulate the key nonlinear dynamics of electro-responsive liquid crystal polymer networks (LCNs). LCN coatings are responsive material, which have a great potential to be integrated in functional surfaces. However, due to their complex molecular dynamics, low-order dynamic models that can describe and predict their dynamic behavior accurately, are scarce. In light of this research gap, we develop an electric circuit analogy, which in its simplest form, can capture the nonlinear phenomenon of transforming a high frequency input voltage to a relatively slow increase of height in LCN. The comparison of the simulation results and experimental data shows that the nonlinear dynamics of this height increase as a function of input frequency and voltage are captured well by our model. This model allows for the accurate design and prediction of a predefined deformation pattern in LCNs, which is vital for integrating them in application devices.

Introduction

Fabricating responsive surfaces that can generate dynamic deformations in response to remote stimuli is one of the core studies for development of smart surfaces and displays [1]. Electro-responsive LCN coatings are known as one of the great candidates in this field, which have interesting potential for generating various surface patterns [2]. In addition, the feasibility of integrating these smart surfaces in functional devices relies strongly on obtaining an accurate controlled response. However, due to the complex molecular dynamics of the surface deformation in LCN coatings, the low-order dynamic models that can accurately describe their nonlinear responsiveness based on the input parameters (stimuli) are quite scarce. Such low-order models are required for designing controllers, which is a preliminary step for integrating these material in application devices to obtain quantified and precise desired surface deformation.

Results and Discussion

According to the experimental data, when the AC voltage $V(t) = V_0 \sin(2\pi f t)$ is active with frequency f and amplitude V_0, a dynamic free volume is generated, leading to a nonlinear gradual increase of $h(t)$. Upon turning off the AC voltage, the surface will relax back to its initial state $h(0)$ (Figure 1(a)). Here, we distinguish two nonlinear characteristics of LCN actuation. Firstly, a high-frequency, 900 kHz AC voltage input leads to a relatively slow increase of $h(t)$, in the order of tens of seconds, until a quasi-equilibrium level is reached (Figure 1(b)). Secondly, the quasi-equilibrium level of LCN height increases nonlinearly with an exponential shape, by increasing the input voltage amplitude V_0 (Figure 1(c)). According to these observations, we develop a replacement model in the simplest form of an electric circuit, which is composed of constant and variable resistors (R), capacitors (C), diode (D) and an input signal source ($V(t)$), as shown in Figure 1(d). By incorporating the nonlinear diode component and variable resistors in our model, the frequency-related and amplitude-related nonlinear characteristics of LCN dynamics are captured and simulated, as illustrated in Figure 1(e-f). Our hybrid approach of modelling, which partially connects to the dielectric and physical properties of LCN, suggests an unconventional perspective on the modelling of the macro-scale dynamics of LCN coatings.

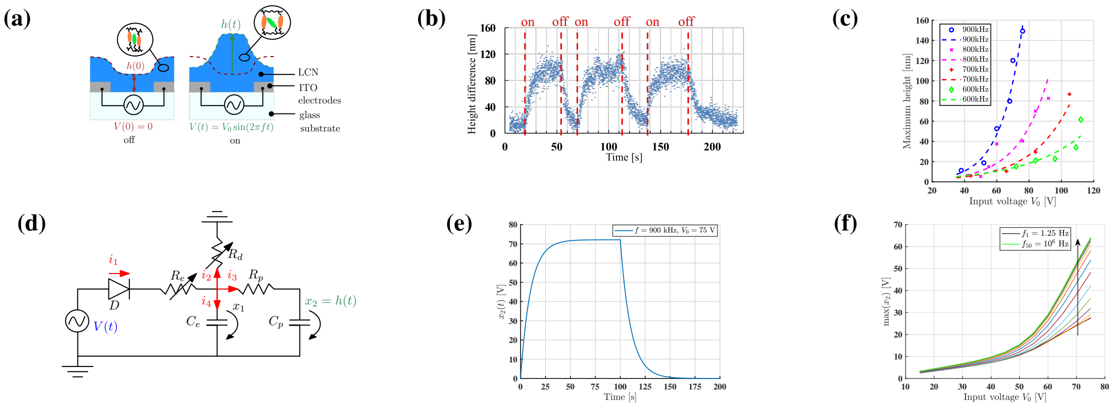

Figure 1: (a) Schematic of LCN actuation. (b) 3 cycles of LCN response at $f = 900$ kHz, $V_0 = 75$ V. (c) Nonlinear response over V_0. (d) Schematic of the model. (e) and (f) are the simulation results of model in (c).

References

[1] Liu D., Tito N., Broer D. (2017) Protruding organic surfaces triggered by in-plane electric fields. *Nat. Commun.* **8**:1526.

[2] Feng W., Broer D., Liu D. (2018) Oscillating Chiral-Nematic Fingerprints Wipe Away Dust. *Adv. Mater.* **30**:1704970.