Tuning Optical Cavities with Liquid-Crystalline Networks

Metal-insulator-metal (MIM) Fabry-Pérot optical cavities find a wide range of applications in optics, including perfect absorbers[1] and color filters.[2] The growing need for novel sensing, imaging and display applications has prompted interest in dynamically tunable Fabry-Pérot cavities that incorporate an active dielectric layer. However, controlling optical resonances in real time using tunable materials poses a significant engineering challenge. Current approaches that rely on refractive-index modulation suffer from low dynamic tunability, high losses and limited spectral ranges and require liquid and hazardous materials for operation.

In recent work, we showed how to dynamically tune Fabry-Pérot resonances without the need for liquids by embedding a nematic liquid-crystalline network (LCN) as the active layer of a MIM cavity.[3] We prepared optical microcavities by incorporating a polymer network with liquid-crystalline order between aluminum (Al) mirrors. The liquid-crystalline network is formed by molecules in the nematic mesophase (like those found in liquid-crystal displays) that are “frozen” into a polymer network by cross-linking.

By thermally inducing mechanical adaptations in the nematic polymer network, we can reversibly change the resonant reflectance of these Al–LCN–Al optical cavities. The tuning mechanism exploits fully reversible temperature-induced mechanical shape adaptations in the cross-linked polymer network.[4,5] We demonstrated reversible and linear dynamic tuning of the resonant wavelength over 150 cycles of thermo-mechanical actuation and relaxation. We also showed control over optical resonances with sub-nanometer precision over 100 cycles.

In particular, we obtained a large modulation of reflectance in a several-micrometer-thick cavities due to the high optical transparency of the LCN. The active microcavities exhibited a large reversible and continuous spectral tuning across the entire visible and near-infrared spectral ranges, reaching wavelength shifts of up to 40 nm and absolute modulation efficiencies up to 79%. OPN

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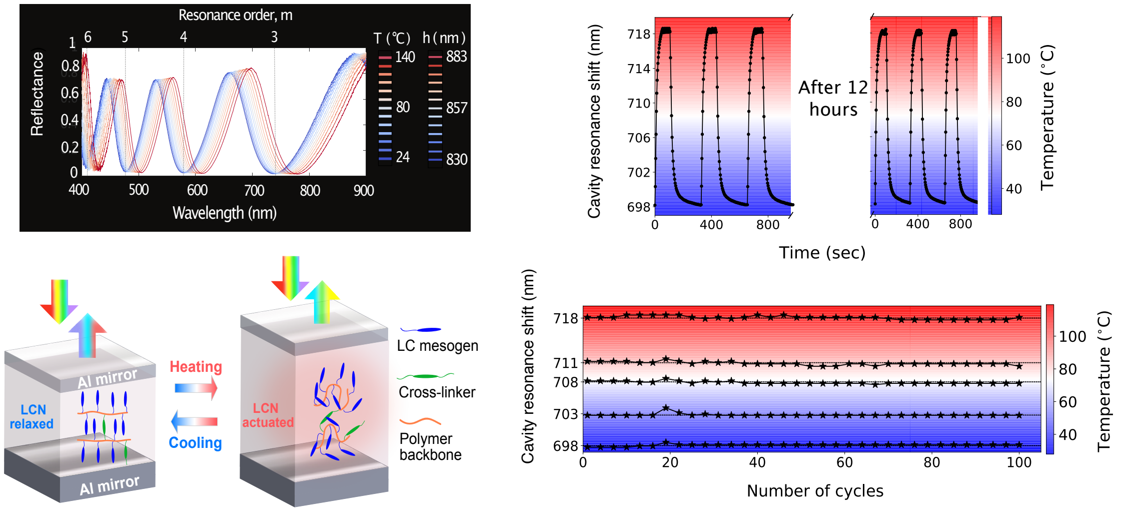
REFERENCES

1. F. Kusunoki et al. Opt. Express **14**, 5651 (2006).
2. Z. Li et al. ACS Photon. **2**, 183 (2015).
3. I. Zubritskaya et al. Adv. Mater. **35**, 2209152 (2023).
4. M. Warner and E.M. Terentjev. *Liquid Crystal Elastomers*, Oxford Univ. Press (2007).
5. C. Ohm et al. Adv. Mater. **22**, 3366 (2010).



Top left: Resonant reflectance obtained for different temperatures and corresponding thicknesses of LCN layer. Bottom left: Mechanism of tuning of resonant optical properties in optical Fabry-Pérot cavity with embedded LCN layer, showing the molecular structure and thermally induced changes in the molecular order and thickness. Top right: Tuning of a selected resonance during 150 thermoelastic cycles. Bottom right: Cavity resonance shifts obtained at different set temperatures during 100 cycles. Background colors in charts reflect accompanying temperature scale.