

Article

Optically Tunable Terahertz Metasurfaces Using Liquid Crystal Cells Coated with Photoalignment Layers

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Abstract: An optically tunable terahertz filter was fabricated using a metasurface-imbedded liquid crystal (LC) cell with photoalignment layers in this work. The LC director in the cell is aligned by a pump beam and makes angles θ of 0, 30, 60 and 90° with respect to the gaps of the splitting resonators (SRRs) of the metasurface under various polarized directions of the pump beam. Experimental results display that the resonance frequency of the metasurface in the cell increases with an increase in θ , and the cell has a frequency tuning region of 15 GHz. Simulated results reveal that the increase in the resonance frequency arises from the birefringence of the LC, and the LC has a birefringence of 0.13 in the terahertz region. The resonance frequency of the metasurface is shifted using the pump beam, so the metasurface-imbedded LC cell with the photoalignment layers is an optically tunable terahertz filter. The optically tunable terahertz filter is promising for applications in terahertz telecommunication, biosensing and terahertz imaging.



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Keywords: liquid crystals; metasurface; terahertz telecommunication

1. Introduction

Photoalignment has attracted much attention due to its controllability on the orientations of liquid crystals (LCs) [1–6]. Photoalignment can be achieved by doping methyl red dyes into LCs [1–3] or coating SD1 dyes onto the substrates of LC cells [4–6]. The methyl red molecules in a dye-doped LC cell sequentially undergo absorption, photoisomerization, diffusion, desorption and adsorption on the irradiated surface of the cell after the cell is irradiated with a linearly polarized green light. The competition between the desorption and the adsorption determines the orientation of the LC director in the cell. The LC director is parallel (perpendicular) to the polarized direction of the light as the desorption (adsorption) prevails over the adsorption (desorption) at a high (low) intensity of the light [1]. Methyl red dyes will be bleached by ambient light because their absorption is in green-light wavelengths. Therefore, the reliability of methyl red dyes hinders the development of methyl red dye doped LC cells. The SD1 molecules in an LC cell that is coated with SD1 dye layers sequentially undergo absorption and photoisomerization on the irradiated surface of the cell after the cell is irradiated with a linearly polarized UV light [4–6]. The LC director in the cell is perpendicular to the polarized direction of the UV light following the photoisomerization of the SD1 molecules and can be reoriented by changing the polarized direction [4–6]. SD1 dyes are more reliable than methyl red dyes because a UV component has a smaller intensity than a green component in ambient light. LC cells that are coated with SD1 dye layers have been used to develop optically controllable optical devices such as rewritable E-papers, polarization rotators, switchable optical gratings and variable optical attenuators [5,6].

Metasurfaces, which consist of arrays of split-ring resonators (SRRs), have been used to manipulate the phases, intensities and frequencies of incident lights due to their sensitivities to the refractive indices of the media that surround them [3,7–12]. The resonance

frequencies of metasurfaces can be tuned using liquid crystals (LCs) because their refractive indices are changed by voltages, heat and magnetic fields. Wu et al. reported a review of tunable metasurfaces with anisotropic LCs and showed that LC-tunable metasurfaces have potential in developing advanced optical devices [13].

Chen et al. fabricated a terahertz metasurface that is imbedded into a dual-frequency LC cell. The switch of the frequency of a specific voltage tunes the resonance frequency of the terahertz metasurface by a frequency tuning range of 15 GHz. Therefore, the dual-frequency LC cell with the terahertz metasurface is an electrically controllable filter. Liu et al. deposited an LC layer on a terahertz metasurface [11]. The resonance frequency of the terahertz metasurface is tuned by heating the LC because its refractive index is changed at the heating of a thermal stage. As a result, the terahertz metasurface that is deposited with the LC layer is a thermally controllable filter. Zhang et al. made an omega-type metasurface that is imbedded into an LC cell [12]. The resonance frequency of the omega-type metasurface can be tuned by applying a magnetic field to the LC, and the omega-type metasurface has a frequency tuning range of 0.22 GHz. Therefore, the omega-type metasurface is a magnetically controllable filter. Optically tunable terahertz filters based on metasurfaces that are imbedded into LC cells have not yet been developed, and exhibit many advantages such as free electrode-patterning, ease addressability and high potential for remote control in various ambient environments. Therefore, it is of great interest to researchers to develop optically tunable terahertz filters using metasurfaces that are imbedded into LC cells. Some latest works reported that LCs can be used to fabricate advanced optical devices, such as lenses [14], beam steerer [15] and antennas [16].

This work presents the fabrication of a terahertz metasurface that is imbedded into an LC cell with photoalignment layers. The irradiation of a pump light with various polarized directions on the photoalignment layers causes the director reorientation, tuning the resonance frequency of the terahertz metasurface by a frequency tuning range of 15 GHz. A simulation reveals that the tuning of the resonance frequency is caused by the birefringence of the LC, and the LC has a birefringence of 0.13 in the terahertz region. The terahertz metasurface that is imbedded into the LC cell with the photoalignment layers is an optically tunable terahertz filter and has potential in terahertz imaging, biosensing and terahertz telecommunication.

2. Materials and Methods

Figure 1a presents the schematic configuration of a metasurface-imbedded liquid crystal (LC) cell with photoalignment layers. The LC cell was fabricated using two 188 μm thick polyethylene terephthalate (PET) substrates, which were separated by two plastic spacers with a thickness of 100 μm . A 200 nm thick silver split-ring resonator (SRR) array was deposited on one of the PET substrates using photolithography, metal evaporation and lift-off process. Figure 1b presents the dimensions of one of the SRRs in the array. The SRR has a split gap (g), inner radius (r_i), outer radius (r_o), period in the x direction and period in the y direction of 20, 26.5, 32.5, 85 and 85 μm , respectively. One of two photoalignment layers (SD1 dye, DIC Corp, Tokyo, Japan) with a thickness of 30 nm was coated on the top substrate, and the other was coated on the metasurface of the bottom substrate. A nematic LC (HTW114300-100, Fusol Material, Tainan, Taiwan) was used in the cell. The top substrate with the dye layer, LC layer, and the bottom substrate with the dye-coated metasurface compose the metasurface-imbedded LC cell. Although the silver metasurface is easily oxidized in ambient environment, it is imbedded into the LC cell. Therefore, the metasurface was reliable in this work.

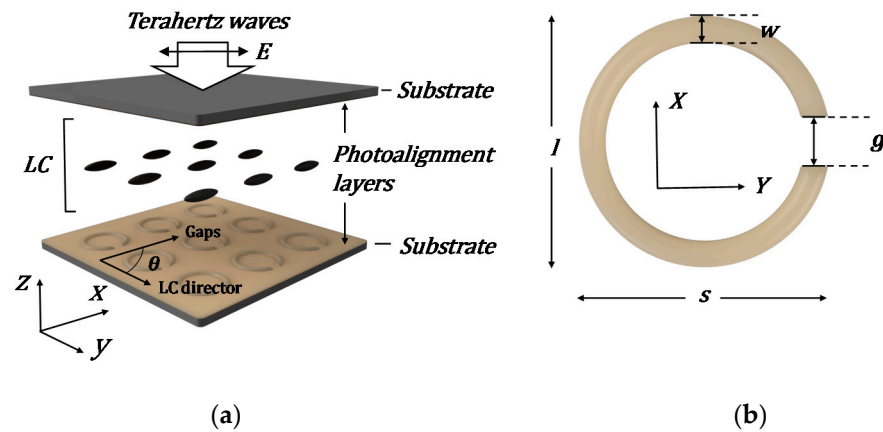


Figure 1. (a) Schematic configuration of metasurface-imbedded LC cell with photoalignment layers. (b) Dimensions of SRR.

A linearly polarized pump beam (center wavelength = 365 nm) was incident to the metasurface-imbedded LC cell from the top substrate. The pump beam with an intensity of 0.3 mW/cm^2 irradiated the photoalignment layers for 100 s, aligning the LC director in the cell. The LC director made angles θ of 0° , 30° , 60° and 90° with respect to the gaps of the SRRs of the metasurface by changing the polarized direction of the pump beam via a polarizer. The metasurface-imbedded LC cell was placed in the chamber of a terahertz spectrometer (TPS 3000, TeraView) for studying the effect of the polarized direction of the pump beam on the resonance frequency of the metasurface. Terahertz waves that were polarized in a direction parallel to the x axis of Figure 1a were normally incident to this cell. TPS 3000 had a frequency resolution of 3 GHz in this work.

3. Results and Discussion

Figure 2 displays the experimental terahertz spectrum of the metasurface that is coated with the dye layer. This spectrum was obtained using the terahertz spectrometer in transmission mode, and the chamber in the spectrometer was filled with dry air to prevent terahertz waves from absorbing moisture. The polarization of incident terahertz waves was set parallel to the x axis of Figure 1a. The metasurface had a transmission peak in its terahertz spectrum due to the absorption of the electromagnetic resonance of the metasurface. The transmission peak was at a frequency of 0.688 THz.

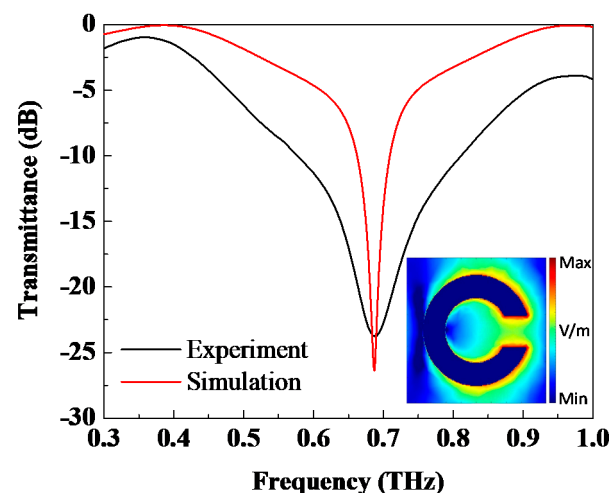


Figure 2. Experimental and simulated terahertz spectra of metasurface that is coated with dye layer. The inset presents the near-field distribution of the simulated SRR with the dye layer at 0.688 THz.

A simulation based on the finite-difference time-domain method was performed to verify the experimental spectrum of the metasurface with the dye layer. The simulated SRR had the same geometrical dimensions as the SRR of Figure 1b and was deposited on a 188 nm thick PET substrate with an area of $70\ \mu\text{m} \times 80\ \mu\text{m}$. A 30 nm thick dye layer was coated on the simulated SRR. The permittivity of the PET substrate (photoalignment) was 3.0 (1.1) in the simulation and was obtained from its time-domain spectrum. A periodical boundary condition was set in the simulation, and the conductivity of silver in the simulated SRR was $6.30 \times 10^7\ \text{S/m}$. Figure 2 displays the simulated spectrum of the metasurface with the dye layer. The metasurface had a simulated peak at 0.688 THz. Therefore, the peak frequency of the simulated spectrum verifies that of the experimental spectra. The inset in Figure 2 presents the near-field distribution of the simulated SRR with the dye layer at 0.688 THz. The near field of this SRR exhibits the maximum strength at its gap. This result depicts that the electromagnetic resonance of the metasurface with the dye layer is an inductive–capacitive mode at 0.688 THz.

The SRR can be considered as an inductor–capacitor circuit, and its resonance frequency is given by [17]

$$f = \frac{1}{2\pi\sqrt{LC}} \propto \frac{1}{n}, \quad (1)$$

where L is an inductance of the inductor and C is a capacitance of the capacitor. L is determined by the enclosed area of the SRR, and C is proportional to the permittivity of a medium that is deposited on the SRR. Equation (1) depicts that the resonance frequency of the inductive–capacitive mode of a metasurface is inversely proportional to the refractive index n of a dielectric layer that is deposited on the metasurface [17]. Therefore, the resonance frequency of the metasurface with the dye layer will be sensitive to a change in the refractive index of an LC layer that is deposited on it.

Figure 3 presents the experimental terahertz spectra of an empty cell without a metasurface, empty cell with the metasurface and LC cell without a metasurface. Figure 4 displays the experimental spectra of the metasurface-imbedded LC cell at $\theta = 0, 30, 60$ and 90° . The metasurface has resonance frequencies of 0.551, 0.557, 0.560 and 0.566 THz at $\theta = 0, 30, 60$ and 90 , respectively. The resonance frequencies of the metasurface increase with an increase in θ , and it has a frequency tuning region of 15 GHz. The increase in the resonance frequencies is caused by the birefringence of the LC. As the cell is at $\theta = 0^\circ$ (90°), the LC director is parallel (perpendicular) to the gaps of the SRRs of the metasurface. In addition, the polarized direction of the incident terahertz waves is parallel to these gaps. Therefore, the incident terahertz waves experience an extraordinary (ordinary) refractive index of the LC in the cell at $\theta = 0^\circ$ (90°). This result depicts that the LC has an extraordinary (ordinary) refractive index as the metasurface has a resonance frequency at 0.551 (0.566) THz. Therefore, the LC birefringence increases the resonance frequencies with the increase in θ . The results in Figure 4 reveal that the resonance frequencies of the metasurface can be tuned by the polarized directions of the pump beam. In other words, the metasurface-imbedded LC cell is an optically tunable terahertz filter. Therefore, this cell exhibits promise for applications in terahertz telecommunication, biosensing and terahertz imaging. The losses of the transmittances at frequencies that exceed 0.6 THz are caused by the multiple reflections of the metasurface-imbedded LC cell [18].

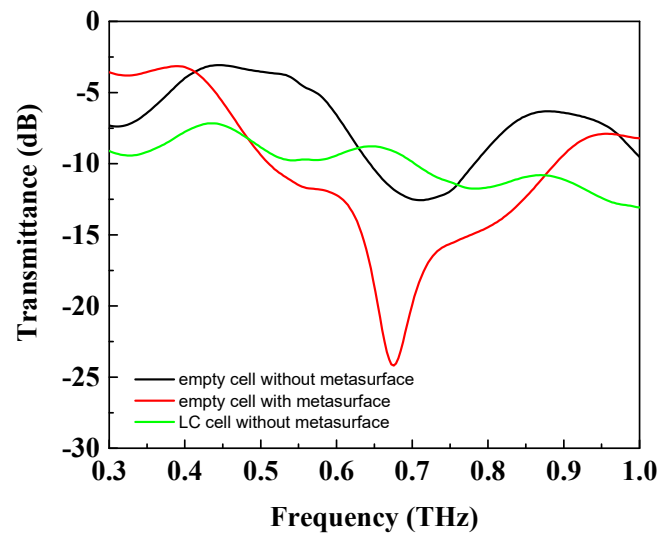


Figure 3. Experimental terahertz spectra of empty cell without a metasurface, empty cell with metasurface and LC cell without metasurface.

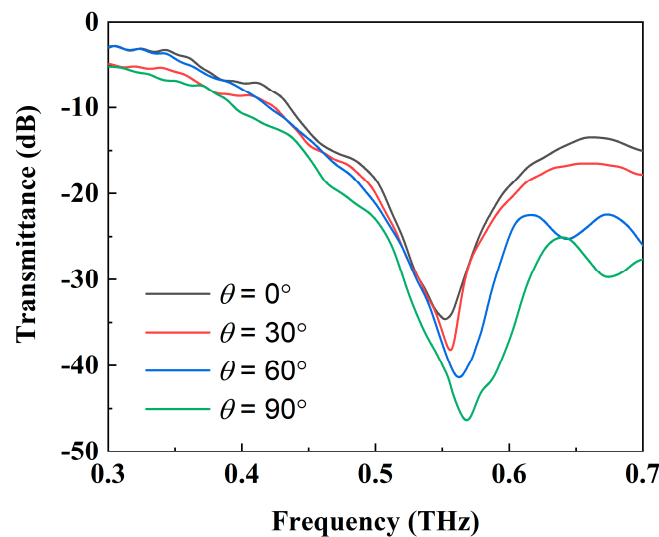


Figure 4. Experimental terahertz spectra of metasurface-imbedded LC cell at $\theta = 0, 30, 60$ and 90° .

A simulation was performed using the software to verify the experimental spectra of the metasurface-imbedded LC cell at $\theta = 0, 30, 60$ and 90° . A dielectric layer with a refractive index of n was deposited on the simulated dye-coated SRR (the inset of Figure 2). Figure 5 displays the terahertz spectra of the simulated dye-coated SRR with the dielectric layer at $n = 1.52, 1.55, 1.61$ and 1.65 . This SRR has simulated resonance frequencies of $0.551, 0.557, 0.560$ and 0.566 THz at $n = 1.65, 1.61, 1.55$ and 1.52 , respectively. The resonance frequency of the simulated dye-coated SRR with the dielectric layer at $n = 1.65$ (1.52) equals that of the metasurface-imbedded LC cell at $\theta = 0^\circ$ (90°). The polarized direction of the incident terahertz waves is parallel (perpendicular) to the LC director of the metasurface-imbedded LC cell at $\theta = 0^\circ$ (90°), so the LC has an extraordinary (ordinary) refractive index n_e (n_o) of 1.65 (1.52) in the terahertz region. This result displays that the LC exhibits a birefringence of 0.13 in the terahertz region, and the LC birefringence increases the resonance frequencies of the metasurface as the angles between the directors and the gaps of its SRRs are increased.

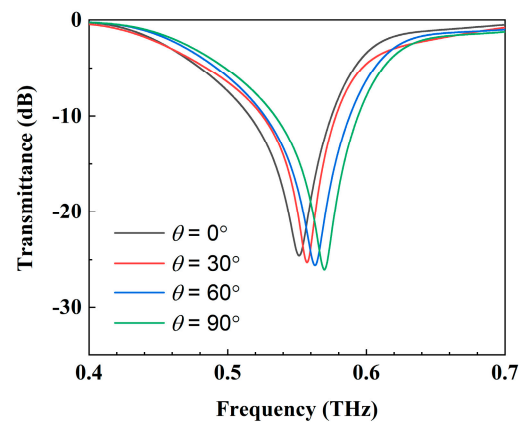


Figure 5. Simulated spectra of simulated dye-coated SRR with dielectric layer at $n = 1.55, 1.62$ and 1.70 . n is the refractive index of a dielectric layer that is deposited on the simulated dye-coated SRR.

The effective refractive indices n_{eff_θ} of the LC in the metasurface-imbedded LC cell that involves $\theta = 30$ and 60° can be determined by an equation of the index ellipse of the LC, and it is given by

$$n_{\text{eff}_\theta} = \sqrt{\frac{1}{\cos^2 \theta / n_e^2 + \sin^2 \theta / n_o^2}} \quad (2)$$

where θ is an angle between the polarized direction of the incident terahertz waves and the director of the LC. Substituting $n_e = 1.65$, $n_o = 1.52$ and $\theta = 30^\circ$ into Equation (2) yields $n_{\text{eff}_30^\circ} = 1.61$. $n_{\text{eff}_30^\circ}$ equals the refractive index of the LC in the metasurface-imbedded LC cell at $\theta = 30^\circ$. Substituting $n_e = 1.65$, $n_o = 1.52$ and $\theta = 60^\circ$ into Equation (2) yields $n_{\text{eff}_60^\circ} = 1.55$. $n_{\text{eff}_60^\circ}$ equals the refractive index of the LC in the metasurface-imbedded LC cell at $\theta = 60^\circ$. These results verify that the polarized directions of the pump beam can be used to tune the resonance frequency of the metasurface in the metasurface-imbedded LC cell.

Figure 6 is the measurement of the reliability of the metasurface-imbedded LC cell. The metasurface-imbedded LC cell was irradiated with the linearly polarized pump beam three times. The LC director made angles θ of $0, 30, 60$ and 90° with respect to the gaps of the SRRs of the metasurface by changing the polarized direction of the pump beam each of the three times, and the resonance transmittances and resonance frequencies of the metasurface-imbedded LC cell at $\theta = 0, 30, 60$ and 90° were measured by the THz spectrometer. These resonance transmittances and resonance frequencies at a given θ were the same in each of the three times. As a result, the metasurface-imbedded LC cell is reliable.

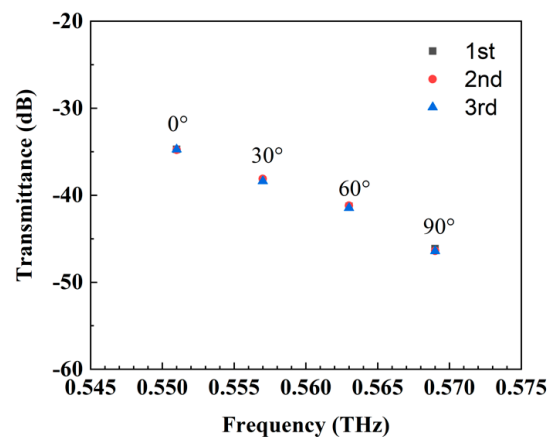


Figure 6. Measurement of reliability of metasurface-imbedded LC cell.

Atorf et al. developed an optically switchable filter using a dye-doped LC cell that is cascaded with an infrared metasurface [19]. The infrared metasurface only has two resonance frequencies before and during the irradiation of a green light. In other words, the resonance frequency of this metasurface cannot be continuously tuned by the light. Therefore, the dye-doped LC cell with the infrared metasurface is an optically switchable filter rather than an optically tunable filter. Palto et al. developed an optically switchable filter using a dye-coated visible metasurface [20]. The dye-coated visible metasurface only has two resonance frequencies at the irradiation of a blue light with two mutually orthogonal polarized directions. Therefore, the dye-coated visible metasurface is an optically switchable filter rather than an optically tunable filter. We fabricated an optically tunable filter using the dye-coated LC cell with the terahertz metasurface. The resonance frequency of this metasurface is continuously tuned by the polarized directions of the pump beam. Therefore, the dye-coated LC cell with the terahertz metasurface is an optically tunable filter. In summary, our work is different from Atorf's and Palto's works in terms of operating frequency and purpose.

4. Conclusions

This work presented the fabrication of a metasurface-imbedded LC cell with photoalignment layers. The LC director makes angles of 0, 30, 60 and 90°, and the cell has a maximum frequency tuning region of 15 GHz. The simulated results depict that the polarized direction of the pump beam reorients the LC director, tuning the resonance frequency of the metasurface. The LC has a birefringence of 0.13 in the terahertz region. The metasurface-imbedded LC cell is an optically controllable terahertz filter. The optically tunable terahertz filter can be used in biosensing, terahertz telecommunication and terahertz imaging.

Author Contributions: Conceptualization, C.-Y.H.; methodology, Y.-H.S.; software, Y.-H.S.; validation, Y.-H.S.; formal analysis, X.-Y.L., H.M.S. and C.-Y.H.; investigation, Y.-H.S., C.-R.L. and C.-Y.H.; resources, X.-Y.L., H.M.S. and C.-Y.H.; data curation, Y.-H.S. and C.-Y.H.; writing—original draft preparation, Y.-H.S. and C.-Y.H.; writing—review and editing, Y.-H.S. and C.-Y.H.; visualization, Y.-H.S. and C.-Y.H.; supervision, C.-R.L. and C.-Y.H.; project administration, C.-Y.H.; funding acquisition, C.-Y.H. All authors have read and agreed to the published version of the manuscript.

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References

1. Ouskova, E.; Fedorenko, D.; Reznikov, Y.; Shiyanovskii, S.V.; Su, L.; West, J.L.; Kuksenok, O.V.; Francescangeli, O.; Simoni, F. Hidden photoalignment of liquid crystals in the isotropic phase. *Phys. Rev. E* **2001**, *63*, 021701. [[CrossRef](#)] [[PubMed](#)]
2. Chen, W.T.; Ji, S.C.; Chen, S.H.; Huang, C.Y.; Lo, K.Y. Competitive dye adsorption-desorption on the isotropic surface at the early stage of the photoexcitation of azo dye-doped liquid crystals. *Crystals* **2020**, *10*, 802. [[CrossRef](#)]
3. Lee, C.R.; Lin, S.H.; Wang, S.M.; Lin, J.D.; Chen, Y.S.; Hsu, M.C.; Liu, J.K.; Mo, T.S.; Huang, C.Y. Optically controllable photonic crystals and passively tunable terahertz metamaterials using dye-doped liquid crystal cells. *J. Mater. Chem. C* **2018**, *6*, 4959–4966. [[CrossRef](#)]
4. Jiang, S.A.; Sun, W.J.; Lin, S.H.; Lin, J.D.; Huang, C. Optical and electro-optic properties of polymer-stabilized blue phase liquid crystal cells with photoalignment layers. *Opt. Express* **2017**, *25*, 28179–28191. [[CrossRef](#)]
5. Chigrinov, V.; Kudreyko, A.; Guo, Q. Patterned Photoalignment in Thin Films: Physics and Applications. *Crystals* **2021**, *11*, 84. [[CrossRef](#)]
6. Chigrinov, V.; Sun, J.; Wang, X. Photoaligning and photopatterning: New LC technology. *Crystals* **2020**, *10*, 323. [[CrossRef](#)]
7. Xu, R.; Xu, X.; Yang, B.-R.; Gui, X.; Qin, Z.; Lin, Y.S. Actively Logical Modulation of MEMS-Based Terahertz Metamaterial. *Photonics Res.* **2021**, *9*, 1409–1415. [[CrossRef](#)]
8. Zhang, Y.; Lin, P.; Lin, Y.S. Tunable split-disk metamaterial absorber for sensing application. *Nanomaterials* **2021**, *11*, 598. [[CrossRef](#)] [[PubMed](#)]

9. Chiang, W.F.; Silalahi, H.M.; Chiang, Y.C.; Hsu, M.C.; Zhang, Y.S.; Liu, J.H.; Yu, Y.; Lee, C.R.; Huang, C.Y. Continuously tunable intensity modulators with large switching contrasts using liquid crystal elastomer films that are deposited with terahertz metamaterials. *Opt. Express* **2020**, *28*, 27676–27687. [[CrossRef](#)] [[PubMed](#)]
10. Chen, C.C.; Chiang, W.F.; Tsai, M.C.; Jiang, S.A.; Chang, T.H.; Wang, S.H.; Huang, C.Y. Continuously tunable and fast-response terahertz metamaterials using in-plane-switching dual-frequency liquid crystal cells. *Opt. Lett.* **2015**, *40*, 2021–2024. [[CrossRef](#)] [[PubMed](#)]
11. Liu, L.; Shadrivov, I.V.; Powell, D.A.; Raihan, M.R.; Hattori, H.T.; Decker, M.; Mironov, E.; Neshev, D.N. Temperature control of terahertz metamaterials with liquid crystals. *IEEE Trans. Terahertz Sci. Technol.* **2013**, *3*, 827–831. [[CrossRef](#)]
12. Zhang, F.; Kang, L.; Zhao, Q.; Zhou, J.; Zhao, X.; Lippens, D. Magnetically tunable left handed metamaterials by liquid crystal orientation. *Opt. Express* **2009**, *17*, 4360–4366. [[CrossRef](#)] [[PubMed](#)]
13. Xu, J.; Yang, R.; Fan, Y.; Fu, Q.; Zhang, F. A review of tunable electromagnetic metamaterials with anisotropic liquid crystals. *Front. Phys.* **2021**, *9*, 633104. [[CrossRef](#)]
14. Geday, M.A.; Caño-García, M.; Otón, J.M.; Quintana, X. Adaptive Spiral Diffractive Lenses—Lenses With a Twist. *Adv. Opt. Mater.* **2020**, *8*, 2001199. [[CrossRef](#)]
15. Zhang, Y.; Qu, X.; Li, Y.; Zhang, F. A separation method of superimposed gratings in double-projector fringe projection profilometry using a color camera. *Appl. Sci.* **2021**, *11*, 890. [[CrossRef](#)]
16. Perez-Palomino, G.; Carrasco, E.; Cano-Garcia, M.; Hervas, R.; Quintana, X.; Geday, M.A. Design and evaluation of liquid crystal-based pixels for millimeter and sub-millimeter electrically addressable spatial wave modulators. In Proceedings of the 2019 International Conference on Electromagnetics in Advanced Applications (ICEAA), Granada, Spain, 9–13 September 2019; p. 19149454.
17. O'Hara, J.F.; Singh, R.; Brener, I.; Smirnova, E.; Han, J.; Taylor, A.J.; Zhang, W. Thin-film sensing with planar terahertz metamaterials: Sensitivity and limitations. *Opt. Express* **2008**, *16*, 1786–1795. [[CrossRef](#)] [[PubMed](#)]
18. Pan, R.P.; Hsieh, C.F.; Pan, C.L.; Chen, C.Y. Temperature-dependent optical constants and birefringence of nematic liquid crystal 5CB in the terahertz frequency range. *J. Appl. Phys.* **2008**, *103*, 093523. [[CrossRef](#)]
19. Atorf, B.; Mühlenbernd, H.; Zentgraf, T.; Kitzerow, H. All-optical switching of a dye-doped liquid crystal plasmonic metasurface. *Opt. Express* **2020**, *28*, 8898–8908. [[CrossRef](#)] [[PubMed](#)]
20. Palto, S.P.; Draginda, Y.A.; Artemov, V.V.; Gorkunov, M.V. Optical control of plasmonic grating transmission by photoinduced anisotropy. *J. Opt.* **2017**, *19*, 074001. [[CrossRef](#)]