Photonic Crystals for on-off Switching of Sub-terahertz Electromagnetic Waves

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***Abstract*—We present a sub-terahertz wave on-off switch based on a two-dimensional photonic crystal (PC). The PC consists of a triangular hole array in high density polyethylene (HDPE). The holes are infiltrated with the nematic liquid crystal 5CB. The transmission of sub-terahertz electromagnetic waves is controlled by an electric field-induced rotation of the nematic axis of the 5CB molecules. The measured extinction ratio of the switch is 13.3 dB at 91GHz. Experimental results are in good agreement with simulations.**

I. Introduction And Background

OVER the past few decades, liquid crystal (LC) based devices have experienced great growth for use in displays, modulators, and other optical communication components. Despite their widespread applications in optics, they have not been well investigated in the sub-terahertz frequency range.

By combining the optical properties of LCs with those of photonic crystals (PCs) one can realize modulators and switches for electromagnetic (EM) waves. PCs composed of periodic dielectrics or metallo-dielectric materials possess a photonic band gap (PBG) region, i.e., a frequency range in which EM waves cannot propagate through the PC[1].

By utilizing LCs in PC structures, the PBG frequency region can be tuned[2]. The optical properties of LCs change with the variation of temperature on the one hand and by applying electric or magnetic fields on the other hand[3].

Here, we demonstrate a sub-terahertz on-off switch based on a two-dimensional PC in HDPE whose holes are infiltrated with the nematic LC 5CB. The transmittivity through the bandgap region is controlled via an electric field.

II. Results

The PC switch consists of a triangular array of air holes in an HDPE background having a refractive index of $n_{\mathrm{HDPE}} = 1.5$ (see[4]). The lattice constant is $a = 1.346$ mm, and the radius of the holes is $r = 0.26a$. The air holes are infiltrated with 5CB (4-cyano-4'-pentylbiphenyl).

We have simulated the switch behavior with the help of the transmission line method[5] for EM waves of TM polarization, i.e., with an electric field along with the axis of the rods. For the simulation, the ordinary and extraordinary refractive index of 5CB have been taken as $n_o = 1.67$ and $n_e = 1.77$, respectively. If an external electric field is applied in the direction parallel to the rod axis, there is a PBG in the Γ-K direction for $0.4 < a/\lambda < 0.43$. When an external electric field is applied in the direction perpendicular to the rod axis, the structure has a PBG in the Γ-K direction for $0.415 < a/\lambda < 0.43$. Comparing the PBG regions of the two cases, a band gap shift is recognizable that can be used for realizing an on-off switch. In the next step the transmission profile for our structure has been calculated using the Finite Element Method (FEM) implemented in the Comsol software. The simulation data are presented in Fig. 1. The graph presents the transmission spectrum for two cases: i) applying the external electric field parallel to the rod axis, and ii) applying the external electric field perpendicular to the rod axis. For the two cases, the band structure is determined by the refractive index of 5CB seen by an electromagnetic wave with an electric field vector in the z direction (n_z). Therefore, if the external electric field is applied perpendicular to the rod axis, the refractive index seen by electromagnetic wave is $n_z = n_o = 1.67$. In the case where the electric field is applied parallel to the rod axis, $n_z = n_e = 1.77$. The simulation results show that there is a difference in the transmission, reaching 19 dB at a frequency of 91 GHz for two different external field polarizations.

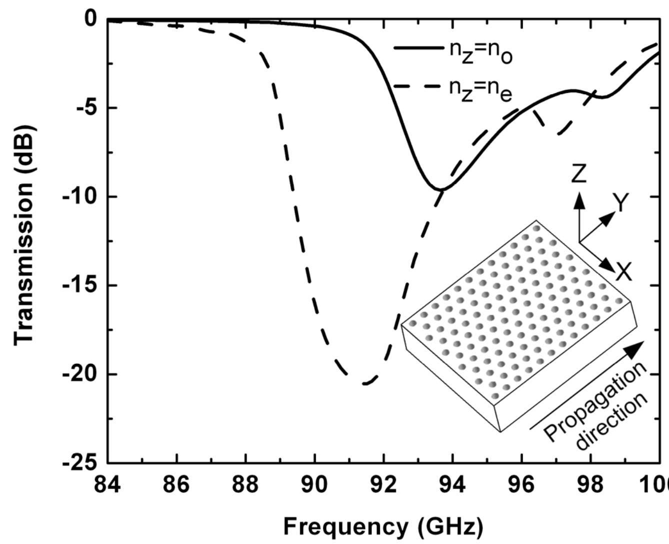

Fig. 1: Simulated transmission of the electromagnetic waves for applying the electric field perpendicular to the rod axis (solid line) and parallel to the rod axis (dashed line). The inset shows the switch structure.

The properties of the PC switch were measured using a Network Analyzer (Agilent E8361A) equipped with transmitter/receiver modules B5260-60004 in the frequency range 70 - 110 GHz. The setup is presented in Fig. 2. Two plano-convex lenses made of HDPE are used to focus the sub-terahertz waves onto the structure. For the employed lenses with a focal length of 50 mm, the beam diameter at the focus is 7 mm.

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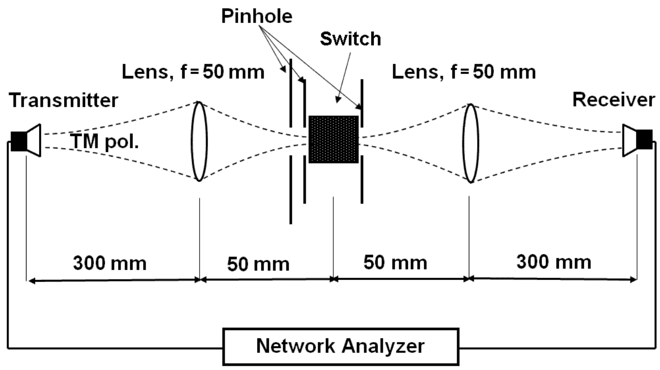

Fig. 2: Experimental setup.

To ensure, that the sub-terahertz propagate exclusively through the switch, additional pinholes are attached to the structure. After filling each air hole with 5CB, the electrodes consisting of indium tin oxide (ITO) evaporated-on-glass are glued to the PC structure. The molecules are driven by a self-made high voltage AC generator running at the frequency of 1 kHz. The electric field with strength of 70 kV/m is applied only to the one of two pair of electrodes at the same time.

The experimental data are shown in Fig. 3. Since the raw data are influenced by distortions originating from Fabry-Perot resonances, the data presented in Fig. 3 are smoothed using a FFT Filter. The graph presents the transmission spectrum for two cases: i) applying the external electric field parallel to the rod axis, where $n_z = n_e$, and ii) applying the external electric field perpendicular to the rod axis, where $n_z = n_o$. After applying the voltage to the side electrodes, that is perpendicular to the rod axis, the attenuation at the frequency of 91 GHz is 9.1 dB. Applying the external field to the top and bottom electrodes, that is parallel to the rod axis, increases the PBG depth to 22.4 dB at the observed frequency. Hence the extinction ratio of 13.3 dB has been achieved by changing the external electric field orientation.

These experimental data are in good agreement with simulations performed with Comsol, however some discrepancies are observed. We attribute them to the fact that the simulation was performed for a 2D model (x-y plane), disregarding the extension in the third plane. Another source of discrepancy is limited accuracy of the fabrication process.

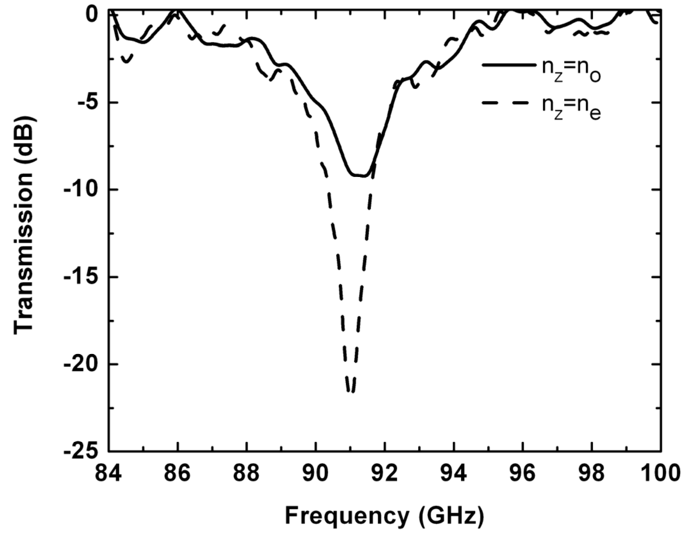

Fig. 3: Measured transmission of the electromagnetic waves for applying the electric field perpendicular to the rod axis (solid line) and parallel to the rod axis (dashed line).

III. Summary

In conclusion, we have demonstrated an on-off switch based on the PC infiltrated with the 5CB LC. By applying an external electric field to the switch, the transmission of the sub-terahertz electromagnetic waves with TM polarization can be controlled.

Acknowledgements

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References

[1] C. M. Soukoulis, “Photonic Band Gap Materials”, Kluwer Academic, Dordrecht, 1996.

[2] K. Busch and S. John, “Liquid-Crystal Photonic-Band-Gap Materials: The Tunable Electromagnetic Vacuum,” Phys. Rev. Lett 83, 1999, pp. 967-970.

[3] J. Collings and M. Hird, Introduction to Liquid Crystals Chemistry and Physics, Taylor & Francis, London, 2004.

[4] H. Han, H. Park, M. Cho, and J. Kim, “Terahertz pulse propagation in a plastic photonic crystal fiber”, Appl. Phys. Lett. 80, 2002, pp. 2634-2636.

[5] M. Shahabadi, S. Atakaramians and N. Hojjat, “Transmission line formulation for the full-wave analysis of two-dimensional dielectric photonic crystals”, IEEE Proc. Sci. Meas. Tech. 151, 2004, pp. 327-334.