Determination of Photonic Band Gaps and Dispersion in Two-Dimensional Dielectric Arrays with Ultrafast Electromagnetic Transients

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Coherent scattering of radiation in periodic dielectric structures results in an electromagnetic dispersion relation which exhibits novel features such as new propagation modes and photonic band gaps. The latter topic has received much current attention for a variety of fundamental and practical reasons [1,2]. Furthermore, the theoretical calculation of the electromagnetic dispersion relation in such structures has become relatively sophisticated. However, experimental verification using traditional microwave techniques has been limited to determining the frequencies which define the gaps and to study localized defect modes. Here, we present the dispersion relation of a periodic dielectric array measured explicitly using the coherent microwave transient spectroscopy (COMITS) technique [3,4]. The experimental results are compared with theoretical predictions obtained using the plane-wave expansion technique [5].

The experimental setup is shown schematically in figure 1. The exponentially tapered coplanar stripline antennas are fabricated on implanted silicon-on-saphhire substrates. Optical pulses from a mode-locked, pulse-compressed, and frequency-doubled, Nd:YLF laser are used in a standard pump/probe configuration to excite the dc-biased transmitter and photoconductively sample the received waveforms. Hemispherical fused silica lenses collimate the radiation diverging from the transmitter and focus it onto the receiver. The freely-propagating ultrashort electromagnetic transient is polarized with the E-field in the plane of the antennas. The measured signal has a 7 ps wide central peak, and frequency components from 0

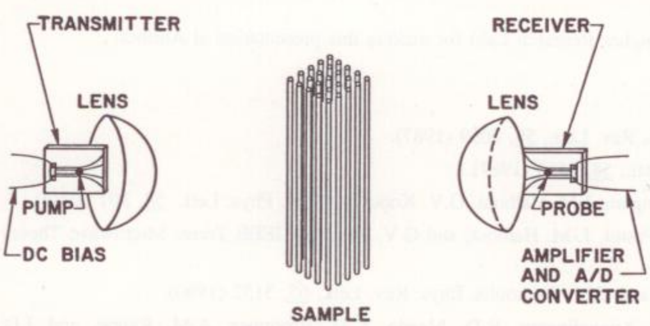

Figure 1. Schematic of the coherent microwave transient spectroscopy experimental set up. The photonic crystal is made of 100 mm long 0.74mm diameter alumina ceramic rods arranged in a square array with 1.87 mm lattice constant.

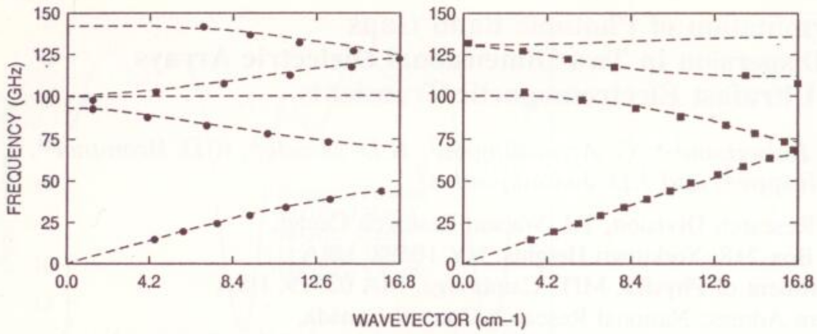

Figure 2. The electromagnetic dispersion along the <10> direction with polarization (left) parallel and (right) perpendicular to the rod axis. The points are experimental values and the lines are theoretical predictions.

GHz to 150 GHz. Since it is proportional to the time-dependent field incident on the receiver, phase information is preserved [4].

The two-dimensional photonic crystal consists of 0.74 mm diameter alumina ceramic rods arranged in a square array of lattice constant 1.87 mm. Time-domain waveforms are recorded with and without the array in the beam path. The waveforms are numerically Fourier transformed and the corresponding spectra are divided to obtain the frequency-dependent complex transmission function of the sample. Much like results obtained with traditional microwave techniques, the amplitude transmission (not shown) clearly shows the frequency regions in which electromagnetic-wave propagation is inhibited. In addition, using the phase data and the known thickness of the array we derive an effective dielectric constant at each frequency point [4]. Hence, the frequency-dependent dispersion relation is determined explicitly. The dispersion relation for propagation along the <10> direction of the array, with the E-field oriented parallel and perpendicular to the rod axis, is shown in figure 2. The points are experimental results while the lines are predicted theoretically using the plane-wave expansion technique [6]. The agreement between theory and experiment is generally good. However, the theoretical calculations also predict modes which are not observed experimentally (Fig 2). Further investigations reveal that the unobserved modes have opposite symmetry to that of the incoming plane wave. Hence, even though these modes may exist in the photonic crystal they cannot be observed with plane-wave radiation. Similar results were obtained for other propagation directions and crystal structures &lbt7].

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REFERENCES

1. E. Yablonovitch, Phys. Rev. Lett., 58, 2059 (1987).
2. S. John, Phys. Rev. Lett., 58, 2486 (1987).
3. Y. Pastol, G. Arjavalingam, J-M. Halbout, G.V. Kopcsay, Appl. Phys. Lett. 54, 307 (1989).
4. G. Arjavalingam, Y. Pastol, J.-M. Halbout, and G.V. Kopcsay, IEEE Trans. Microwave Theory Tech., 38, 615 (1990).
5. K.M. Ho, C.T. Chan, and C.M. Soukoulis, Phys. Rev. Lett., 65, 3152 (1990).
6. W.M. Robertson, G. Arjavalingam, R.D. Meade, K.D. Brommer, A.M. Rappe, and J.D. Joannopoulos, Phys. Rev. Lett, 68, 2023, (1992).
7. W.M. Robertson, G. Arjavalingam, R.D. Meade, K.D. Brommer, A.M. Rappe, and J.D. Joannopoulos, to be published.