Fractional Lifetime Change vs. Wavelength

JTuC3 Fig. 2. Dots: Fractional lifetime change vs. wavelength Dash: normalized transmission for Erbium doped FBG.

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JTuC4/3:15 pm

Photonic band gap effect and localization in two-dimensional Penrose lattice

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Photonic crystals are artificial periodic structures in which the refractive index modulation gives rise to stop bands for electromagnetic waves (EM) within a certain frequency range in all directions.¹ Recently it was recognized that the photonic gaps can exist in two-dimensional (2D) octagonal quasicrystals.² A quasiperiodic system is characterized by a lack of long range periodic translational order. But the quasiperiodic system has long-range band orientational order, so that it can be considered as an intermediate between periodic and random systems.³

In this work, we report on observation of the photonic band gap effect in a 2D Penrose quasicrystal consisting of dielectric rods. Defect char-

acteristics of various inequivalent sites of the crystal were investigated. The Penrose tiles are composed of fat and skinny rhombic unit cells and fill the 2D plane nonperiodically as illustrated in Fig. 1. The 2D Penrose lattice was constructed by placing square shaped alumina rods, having refractive index 3.1 at the microwave frequencies and dimensions $0.32 \text{ cm} \times 0.32 \text{ cm} \times 15.25 \text{ cm}$, at each vertices of the skinny and fat rhombic cells (Fig. 1). The side of each rhombus is $a = 1.2 \text{ cm}$. The experimental set-up consists of a HP 8510C network analyzer and microwave horn antennas to measure the transmission-amplitude spectrum. The electric field polarization vector of the incident EM field was parallel to the rods.

We first performed transmission measurements through the perfect Penrose crystal by varying angle of incidence of the EM waves (see the inset in Fig. 2). The crystal consisted of 236

JTuC4 Fig. 1. Schematic drawing of a two-dimensional Penrose photonic crystal. The dielectric rods are placed at all vertices of fat and skinny rhombic cells.

JTuC4 Fig. 2. Transmission characteristics of a Penrose dielectric crystal for various incidence angles. A stop band extending from 9.9 to 13.2 GHz was observed irrespective of the incidence angle. Inset: The (●) symbols denoted vertices of the Penrose lattice.

rods, and had a square shape with dimensions $13 \text{ cm} \times 13 \text{ cm}$. As shown in Fig. 2, there is a strong attenuation, around 50 dB, in transmission of EM wave through the crystal. The photonic band gap extends from 9.9 to 13.2 GHz. The same photonic band gap spectra were observed for different values of incidence angle between 0° and 90° . We performed the measurements up to 40 GHz, and we did not observe any other gaps in the transmission spectrum.

The defect characteristics of quasiperiodic photonic crystals can be different from the periodic case as pointed out in Ref. 2. Localization properties of the defect modes in quasicrystals depend on the position of the removed rod, since local environment of each site can be different from other sites. Therefore, we can get different defect frequencies within the band gap by removing rods from various positions. This feature might be important for certain applications. To demonstrate the localization phenomena in quasicrystals, we measured the transmission spectrum through a Penrose crystal, which consisted of 98 rods, with a single rod removed defect as labeled in the inset of Fig. 3. Each defect has different local properties, i.e., number and arrange-

JTuC4 Fig. 3. Defect characteristics of a Penrose crystal consisting of 98 dielectric rods obtained by removing a single rod from various locations. Highly localized defect modes were observed. Since the crystal has many inequivalent defect sites, we can change the defect frequency within the stop band. The inset shows location of the defects. Here, the point B is positioned at the center of the crystal.

ment of neighboring rods. As shown in Fig. 3, we observed strongly localized cavity modes within the stop band of the crystal. The corresponding defect frequencies were $f_A = 11.436$ GHz, $f_B = 11.301$ GHz, and $f_C = 10.679$ GHz. The quality factors, defined as center frequency divided by the peak's full width at half-maximum, of these cavities were measured to be $Q_A = 817$, $Q_B = 513$, and $Q_C = 305$.

In conclusion, we have experimentally observed that the EM waves can not propagate within a certain frequency range through a 2D quasicrystal that was composed of the Penrose tiling of dielectric rods. It was demonstrated that by removing a single rod from an otherwise perfect Penrose lattice, we could create a highly localized cavity mode. Since the crystal had many inequivalent sites, we achieved different defect frequencies within the photonic band gap.⁴

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JTuC5

3:30 pm

Optical measurement of trapped acoustic mode at defect in square-lattice photonic crystal fiber preform

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1. Introduction

Photonic crystal fibers (PCFs) were first demonstrated in 1996.¹ They are all-silica fibers in which the cladding consists of a two-dimensional array of microscopic air holes running along their length. The central hole of the structure is missing, leaving a solid silica core to guide the light.

The periodic nature of the cladding makes also possible the existence of acoustic band gaps. Moreover, the core can also act as a defect of the phononic crystal and so elastic defect modes can be confined in this region.²

Here we present the first experimental demonstration of an acoustic defect mode trapped at the solid core in a square-lattice PCF preform.

2. Experimental results

A transverse mode lithium niobate piezoelectric transducer was attached to one side of a square PCF preform, which is shown in Fig. 1. The change in phase induced by the acoustic wave on the light traveling along the core was measured for different frequencies by inserting the preform

JTuC5 Fig. 1. SEM image of the cross-section of the preform used in the experiments. The pitch is $\Lambda \sim 75$ μm and the diameter of the holes is $d \sim 53$ μm .

in one arm of a Michelson interferometer. A second Michelson interferometer, in which the transducer was used as one of the mirrors, was set up to monitor the amplitude of the transducer's vibration and to keep it constant for all the frequencies.

Fig. 2 shows the change in phase as a function of frequency, of the light propagating along the core of the preform, due to the acoustic perturbation. A sharp peak is observed at a frequency of 24.4 MHz, which we believe corresponds to an acoustic resonance at the defect. A two-dimensional theoretical model confirms this experimental behavior.

3. Conclusions

We have observed, for the first time, the presence of an acoustic defect mode trapped at the solid core in a square-lattice PCF preform. Since a photonic crystal fiber is a scaled down preform, we expect to find the same acoustic effects at higher frequencies in the PCF. This can lead to high efficient acousto-optic devices based on PCF.

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JTuC6

3:45 pm

Multipole method for efficient microstructured optical fiber calculations

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Microstructured optical fibers (MOFs) are among the most exciting recent developments in fiber optics.¹ Typically these consist of a glass core surrounded by circular airholes running parallel to the fiber. MOFs have properties that can differ substantially from conventional step-index fibers, such as unusual dispersion characteristics, low or high effective nonlinearities, and many others. The number of air holes can be as small as six, in which case the energy confinement is imperfect and the modes are leaky. More generally, all modes of MOFs with a finite number of holes and no other confinement mechanism, are leaky.

A number of different methods for MOF calculations have been developed. The plane wave decomposition method² can deal with any refractive index profile but requires large matrices. The decomposition using Hermite-Gaussian functions³ has an adjustable parameter, the value of which is not a priori known, and which may differ for different modes of the same fiber. Both methods use periodic boundary conditions and the modes' leakiness is thus unattainable. The Beam Propagation Method (BPM)⁴ lets one calculate the evolution of an initial field profile upon propagation. Though propagating over a sufficient distance allows one to separate the modes, this distance is very large if two modes have similar propagation constants.

Here we report a multipole expansion method for full-vector modal calculations of MOFs with circular holes. Since this is the natural type of expansion for structures with circular inclusions, it is very efficient. In the neighbourhood of an air hole (labeled by i), E_z is written using local coordinates (r_i, ϕ_i) in terms of Bessel (J_m) and Hankel ($H_m^{(1)}$) functions as⁵

$$E_z = \sum_{m=-\infty}^{\infty} [a_m^{(i)} J_m(k_{\perp} r_i) + b_m^{(i)} H_m^{(1)}(k_{\perp} r_i)] e^{im\phi_i}, \quad (1)$$

where $k_{\perp}$ is the transverse wavevector component. When used with the corresponding expansion inside the cylinder, the boundary conditions at the surface can be satisfied analytically. This leads to a matrix M , that expresses the $a_m^{(i)}$ in terms of the $b_m^{(i)}$ for cylinder i . The relation between the $b_m^{(i)}$ for different cylinders is derived from the observation that the source free or J_m parts of expansion (1) in the neighbourhood of cylinder i must be due to $H_m^{(1)}$ fields radiated from cylinders $j \neq i$, and uses Graf's addition theorem. This leads to a matrix equation of the form

$$[M + S] b = 0. \quad (2)$$