rect numerical simulations that this instability appears because of resonance excitation of a field with polarization orthogonal to the soliton polarization. It was shown that for this instability the excited field propagates along the waveguide channel formed by the solitons, see figure 2 (top). Analytical results obtained for small δ are in a good agreement with numerics. If $\delta < \delta_{thr2}$ another polarization instability was found. In this case the waves excited by the instability have weakly damped tails, which results in significant radiation losses, see figure 2 (bottom). Both polarization instabilities lead to the formation of oscillating elliptical soliton.

QTuF13 **1:00 pm**

Thermal Emission From Periodic Array of Microcavities with a Different Aperture Ratio

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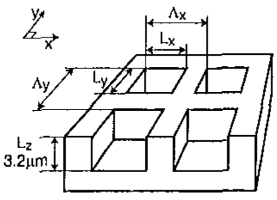
Recent studies of thermal emission control have revealed many interesting phenomena.[1,2,3] The influence of microstructures upon thermal emission, however, has not well been understood. In this paper, we report experimental results of thermal emission from a tantalum surface having a periodic array of microcavities.

In our experiment, a periodic array of microcavities was fabricated on the tantalum surface. The schematic drawing of the fabricated structure is shown in Fig. 1. Two kinds of structures were fabricated: structure-A ($\Lambda_x = \Lambda_y = 7.5$ μm, $w_x = w_y = 5.5$ μm), and structure-B ($\Lambda_x = \Lambda_y = 5.5$ μm, $w_x = w_y = 2.5$ μm). The aperture ratios are 54% for structure-A and 25% for structure-B. A relative emissivity, which is the ratio of emissivity of the surface with the periodic array to that of a flat surface, was measured at 700 K.



QTuF13 **Fig. 1.** Schematic drawing of fabricated structure.

Figure 2(a) shows the experimental result for structure-A. It is seen that the effects of the structure are enhancement in emission for the whole measured range (3 μm ~ 11 μm), and the three noticeable peaks at 4.15 μm, 7.75 μm, and 8.25 μm. It is known that absorptivity of a surface becomes large when the surface has roughness, and emissivity is equal to absorptivity. Thus this is why we have enhanced emission. The other effect, the three peaks, has been found to be attributed to electromagnetic modes in a cavity, as described below.

The electromagnetic mode $\lambda_{EM}(n_x, n_y, n_z)$ in a cavity with one open end is expressed by the following equation,

$$\lambda_{EM}(n_x, n_y, n_z) = \frac{2}{\sqrt{(\frac{n_x}{L_x})^2 + (\frac{n_y}{L_y})^2 + (\frac{n_z}{2L_z})^2}}, \quad (1)$$

where $n_x, n_y = 0,1,2,3,\ldots$, and $n_z = 0,1,3,5,\ldots$. At most one of the integers can be zero. The downward arrows indicate the calculated positions of λ_{EM}. As apparent from the result, the three noticeable peaks correspond with the following three modes: mode α with $\lambda_{EM}(1, 0, 1)$ or $\lambda_{EM}(0, 1, 1)$, mode β with $\lambda_{EM}(1, 1, 0)$, and mode γ with $\lambda_{EM}(1, 0, 3)$ or $\lambda_{EM}(0, 1, 3)$. The other modes are not so visible. The small figures on the right side of the graph show the dependence of electric fields on three axes. Since the three noticeable peaks are all low order modes, it can be concluded that enhanced peaks are more sensitive to low order modes than high order ones.

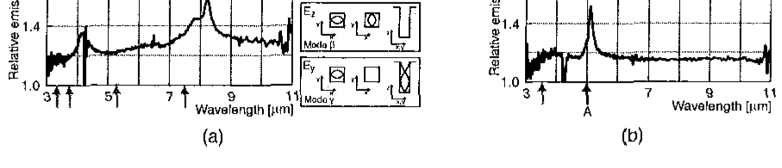
Figure 2(b) shows the experimental result for structure-B. For this structure, there is only one peak at 5.15 μm, and the peak position does not coincide with any modes in a cavity. Thus we need a different interpretation.

In the theory of diffraction grating, anomalous absorption is caused by the excitation of SPP at the wavelength λ_{SP},

$$\lambda_{SP}(m, n) = \frac{\Lambda}{\sqrt{m^2 + n^2}}, \quad (2)$$

where Λ is the period of grating, and $m, n = 0,1,2,3,\ldots$. The periodic array of microcavities can be regarded as two-dimensional grating. Thus this phenomenon is also expected to occur for our experiment. The upward arrows indicate the calculated positions of λ_{SP}. It is clear that the position of the peak corresponds with one of the wavelengths λ_{SP} indicated by the letter A with $\lambda_{SP}(1, 0)$ or $\lambda_{SP}(0, 1)$. This result suggests that the enhanced peak for the structure with a small aperture ratio is attributed to thermally excited SPP.

In summary, we have experimentally demonstrated that in the case of large aperture ratio, the effect caused by the modes in a cavity becomes dominant, while in the case of small aperture ratio, thermally excited SPP has more influence on thermal emission.



QTuF13 **Fig. 2.** Experimental results of relative emissivity for (a) structure-A, and (b) structure-B. The downward arrows indicate the calculated positions of λ_{EM} and the upwards arrows is for λ_{SP}.

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QTuF14 **1:00 pm**

Photonic Band Gap Structures for WDM Applications

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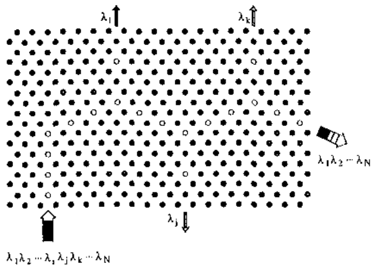
In recent years, there has been much interest in the possible realization of photonic crystals for designing optical components and circuits. Recently, we demonstrated a new type of waveguiding mechanism, which is known as coupled-cavity waveguides (CCWs), in which electromagnetic (EM) waves can propagate through an array of coupled cavities[1] without any radiation losses. In the present work, we propose a new structure by combining a single cavity and CCWs for wavelength division multiplexing (WDM) applications. Previously, various type of photonic structures have been reported for WDM applications.[2,3,4]

In order to demonstrate demultiplexing phenomena in photonic crystals, we designed a structure in which the coupling between the cavity mode and the guiding mode allows to drop a selective wavelength λ_i (See Fig. 1). The selectivity of dropping wavelength is determined by local properties of the cavity modes.

We first constructed 2D triangular photonic crystals which consist of dielectric cylindrical alumina rods having radius 1.55 mm and refractive index 3.1 at the microwave frequencies. The lattice constant and the corresponding filling fraction are $a = 1.3$ cm and $\eta \sim 0.05$, respectively. Length of the rods is 15 cm. The experimental setup consisted of a HP 8510C network analyzer and microwave horn antennas to measure the transmission-amplitude and the transmission-phase properties. The crystal exhibits a photonic band gap extending from $0.73\omega_0$ to $1.14\omega_0$ where $\omega_0 = 2a/c = 11.54$ GHz.



QTuF14 Fig. 1. Schematic drawing of the proposed demultiplexing structure in two-dimensional photonic crystals. A selective wavelength can be dropped from the guided mode inside a coupled-cavity waveguide due to coupling between the cavity mode and the waveguide mode.

We measured the transmission characteristics corresponding to the structure shown in right panel of Fig. 2. The CCW is constructed by removing 8 rods, and exhibits a waveguiding band extending from $1.03\lambda_0$ to $1.17\lambda_0$ (solid line). As shown in Fig. 2 [left panel], photons having wavelength $\lambda = 1.11\lambda_0$ is selectively dropped from guiding band (dotted line).

In conclusion, we proposed and demonstrated a method for adding and dropping of selective wavelength in photonic crystals. Our results are important for designing future ultrasmall optical circuits.

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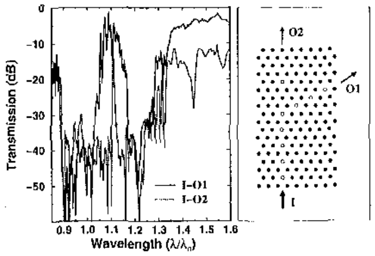

QTuF14 Fig. 2. [Left Panel] Measured transmission spectra along I-O1 (solid line) and I-O2 (dotted line). [Right Panel] Schematics, top view, of the demultiplexing structure where (O) symbols denote the removed rods.

QTuF15 1:00 pm

Measurement of Optical Tunneling Times in Double-Barrier Photonic Band Gaps

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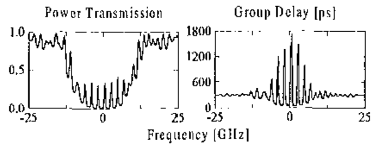
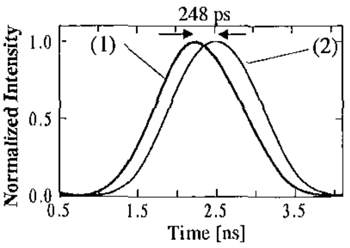
The problem of how much time does a particle spend to tunnel across a potential barrier is one of the most intriguing problems in quantum mechanics.[1] For opaque barriers, it is known that the tunneling time becomes independent of the barrier width (Hartman effect), and may hence imply superluminal propagation. Tunneling of electromagnetic pulses through photonic barriers has been considered as a convenient means for experimental investigation of tunneling owing to the analogy between quantum mechanical and optical wave phenomena. In particular, the experimental validation of the Hartmann effect has been reported in tunneling experiments at either microwave and optical wavelengths.[2,3] Tunneling through double-barrier (DB) photonic barriers shows even a more amazing phenomenon, namely the independence of the transit time not only of barrier width, but also of barrier separation (generalized Hartman effect). Measurements of tunneling times in DB structures were previously reported in microwave transmission experiments, where tunneling time measurements are more accessible, however no experiment has been performed at optical wavelengths yet.

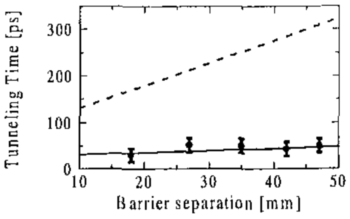
In this work we report on the measurement of tunneling times in DB photonic barriers, made by two periodic fiber Bragg gratings (FBGs), at the wavelength of optical communications (1.5 μm), providing an experimental test for the generalized Hartman effect of quantum mechanics. Five DB-FBG structures were realized with grating separation L of 18, 27, 35, 42 and 47 mm and barrier width $L_0 = 8$ mm. For such structures, both transmission spectra and group delays were measured using a phase shift technique; an example of measured transmission spectrum and group delay versus frequency for the 42-mm separation DB FBG is shown in Fig. 1. Far from the Fabry-Perot resonances (off-resonance tunneling), the group delay is superluminal, with an expected time advancement of the order of 240–250 ps. Conversely, far from the stop band of the structure the group delay corresponds to luminal propagation.



QTuF15 Fig. 1. Measured spectral power transmission and group delay for the DB-FBG structure ($L = 42$ mm).



QTuF15 Fig. 2. Oscilloscope traces of off-resonant tunneled pulses (1) and reference pulses (2).



QTuF15 Fig. 3. Tunneling time versus barrier separation.

Direct time-domain measurements of tunneling delay times were performed in transmission experiments using a 300 MHz repetition-rate 1.3-ns-duration pulse train, generated from an externally-modulated tunable semiconductor laser. Figure 2 shows a typical oscilloscope trace of off-resonance tunnelled pulses [curve (1)] and corresponding trace recorded when the laser was detuned away from the stop band of the DB FBG structure [curve (2)]; a 248 ps peak pulse advancement without appreciable pulse distortion is observed. Time delay measurements were repeated for the five DB-FBG structures, and the experimental results are summarized in Fig. 3 and compared with the theoretical predictions of tunneling times based on the group-delay analysis of the DB-FBG structure. The dashed line in the figure shows the theoretical transit time, from input to output planes, versus barrier separation L for pulses tuned far away from the band gap of the FBG (luminal transit times). The solid line is the expected transit time for off-resonance tunneling of pulses based on the group delay analysis. The experimental data (points) are in good agreement with theoretical predictions and prove that the transit time does not substantially increase with barrier separation.

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