Multichanneled filter based on a branchy defect in microstrip photonic crystal

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(Received 15 August 2005; accepted 4 January 2006; published online 22 February 2006)

A multichanneled filter based on a branchy defect in a microstrip photonic crystal is proposed. By introducing a branchy structure across the defect region, multiple defect modes will appear inside the photonic gap, leading to the multichanneled filtering phenomenon. In comparison with the conventional multichanneled filters, the proposed structure is more compact and tunable as far as the device volume and fabrication are concerned. The microwave experiment results are found in agreement with simulation results. © *2006 American Institute of Physics*.
[DOI: 10.1063/1.2176851]

Since the original work of Yablonovitch and John, photonic crystal (PC) with periodic modulation of the dielectric constant has attracted much attention.[1,2] Since PCs possess photonic band gaps (PBGs) within which the propagation of electromagnetic (EM) waves is forbidden; they are utilized to manipulate the flow of EM waves. Up to now, PCs have found many applications in microwave and optical systems. Based on microstrip technology, many applications of PCs in microwave fields such as microwave filters, antennas, couplers, etc. are proposed.[3–5]

Recently, a defect mode in the PC has been investigated for its application in wavelength division multiplexed systems that play an important role in modern optical and microwave communication systems.[6–9] A defect mode will appear inside the PBG when the periodicity of the PC is broken. By increasing the size or the number of the defect, more and more defect modes with different frequencies will emerge inside the PBG as a result of the Bragg resonant, leading to the multichanneled filtering phenomenon.[10–16] However, this conventional method has a prominent shortcoming, i.e., it increases the volume of the device. In this letter, we demonstrated that multiple defect modes could be realized by introducing a branchy defect, almost without increasing the volume of the device.

Now we give a schematic shown in Fig. 1 to illustrate our method. Instead of increasing the number of the defects as shown in Fig. 1(a), we introduce a complex defect with different paths along propagation direction, i.e., a branchy microstrip geometry, as shown in Fig. 1(b). In the traditional method for a multichanneled filter, there is only *one* microstrip line through the defect region. However, in our present design, *several* microstrip lines with different lengths are added across the same region. Each of these microstrip lines plays the role of one defect in the microstrip PC. Therefore, multiple defect modes with different frequencies will appear inside the PBG, leading to the multichanneled filtering. The number of channels, in general, depends simply on the number of microstrip lines in the defect, without enlarging the longitudinal volume of the structure as employed by the conventional method. In this way, we can make the filter more compact.

To test the earlier analysis, we fabricate a multichanneled filter based on a branchy defect in the microstrip PC. The microstrip PC is made by etching circles periodically on the ground plane of a 50 Ω microstrip line. The 1 mm height substrate used is FR4, which has a dielectric constant of 2.5 and a loss tangent of 0.02. The S21 parameters (transmission characters) of our structure are calculated by a finite-integration-technique (FIT) simulator (CST Microwave Studio), and measured by Angilent 8722ES network analyzer. The period a of PBG structure is 20 mm and the circles have a radius r of 4.5 mm, which are chosen to get a band gap in the region of 3.5–7.2 GHz. By introducing a defect with length $d1=20$ mm in the periodical structure, a one-channeled filter based on the microstip PC is realized, as shown in Fig. 2(a). The simulation result given in Fig. 2(b) clearly shows a defect mode inside the PBG.

To introduce two defect modes inside the PBG, the conventional method is to increase the number or the longitudinal length of the defect. However, in our design as shown in Fig. 3(a), an extra microstrip line with a total length (both the vertical part and the parallel part) $d2=34.1$ mm is added across the defect region, compared to the one channeled filter described in Fig. 2(a). Two defect modes inside the PBG have been observed experimentally and confirmed theoretically by the FIT simulation as shown in Fig. 3(b). The thin solid line and the dotted line present the simulation result with and without the dielectric loss, respectively. The thick solid line is the experimental result. It is seen that, when the dielectric loss is considered, the simulation result coincides well with the experimental result.

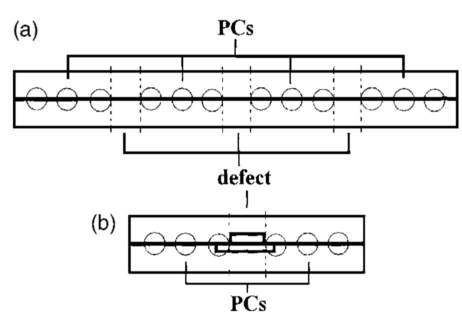

FIG. 1. Schematic of multichanneled filter: (a) traditional multichanneled filter and (b) multichanneled filter based on a branchy defect.

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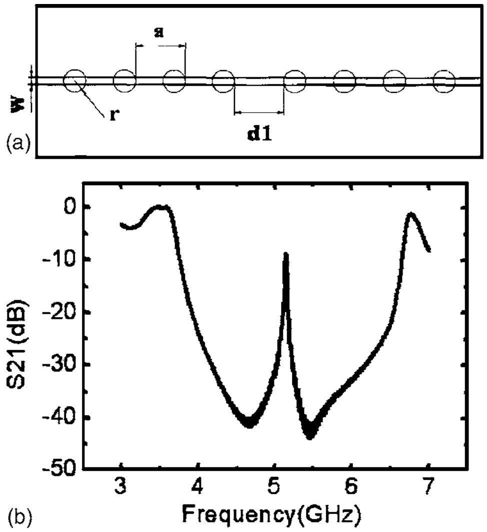

FIG. 2. One-channeled filter in a microstrip photonic crystal: (a) the model used in simulation and (b) the simulated S21 parameter.

Next, a three-channeled filter, as shown in Fig. 4(a), is considered. Based on the two-channeled configuration shown in Fig. 3(b), another microstrip with a different length across the defect region is added. From the simulation and experimental results in Fig. 4(b), it is seen that there are three defect modes appearing inside the PBG. The thin solid line and the dotted line indicate the simulation result with and without the dielectric loss, respectively. The thick solid line is the experimental result. Again, good agreement is found between the simulation and experimental results when the dielectric loss is included. Therefore, we have shown that a multichanneled filter could be achieved by introducing a branchy defect without increasing the longitudinal length of the defect.

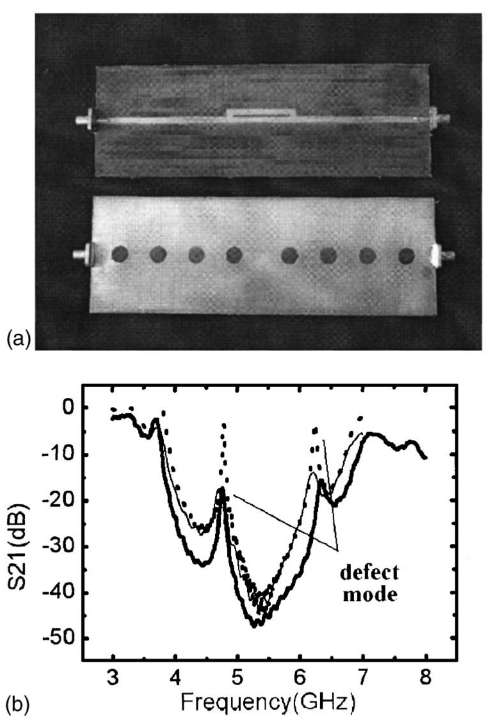

FIG. 3. Two-channeled filter based on a branchy defect: (a) the model used in experiment and (b) the thin solid (dotted) line is the simulated result with (without) the loss of substrate and the thick solid line is the experimental result.

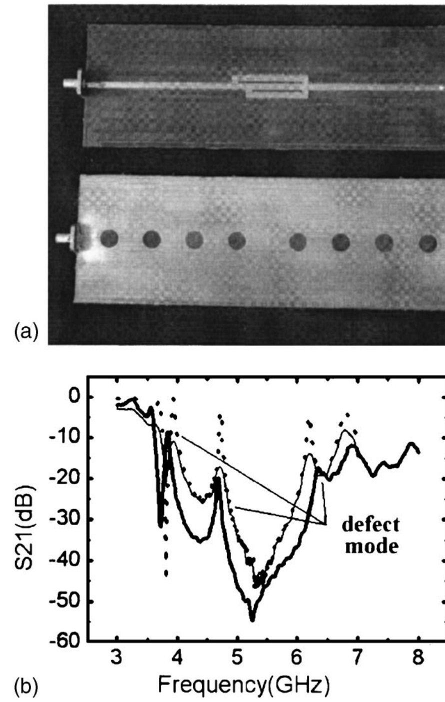

FIG. 4. Three-channeled filter based on a branchy defect: (a) the model used in experiment and (b) the thin solid (dotted) line is the simulated result with (without) the loss of substrate and the thick solid line is the experimental result.

Furthermore, the energy flows at resonant frequency of three-channeled filter is calculated, as shown in Fig. 5. The size and direction of the arrows present the amplitude and the direction of energy flow. Figures 5(a)–5(c) show the energy flows when the resonance frequencies are 3.93, 4.73, and 6.20 GHz, respectively. These results illustrate that EM waves with different resonant frequency will pass through different paths across the defect region, namely through the up path for 3.93 GHz, the middle path for 4.73 GHz, and the down path for 6.20 GHz. As mentioned before, the resonant frequency of the defect mode depends on the length of the microstrip line in the defect. So only the EM waves with a frequency matching the resonant condition can transmit the corresponding path in the defect. For example, when the EM wave with frequency 4.73 GHz transmits the defect region, only the middle path matches the resonance condition, thus most energy flow will pass through this path as shown in Fig. 5(b). The other paths, which do not match the resonance condition, will greatly reflect such an EM wave due to the PBG effects.

Before giving a conclusion, we would like to discuss the extension of our idea, demonstrated in a microstrip PC for microwave frequency, to a two-dimensional PC for optical frequencies. In the latter case, the resonant cavity should be located in the waveguide channels. By extension and modification of the cavity in the lateral direction, different geometries along the lateral direction of the cavity, or a branchy defect, would be achieved. When EM waves pass through this cavity, different resonant modes will be selected by corresponding geometries along the lateral direction, as in the case of the microstrip PC we discussed previously. Moreover, our idea could also be extended to a slab PC although it might be hard to be realized in a three-dimensional PC.

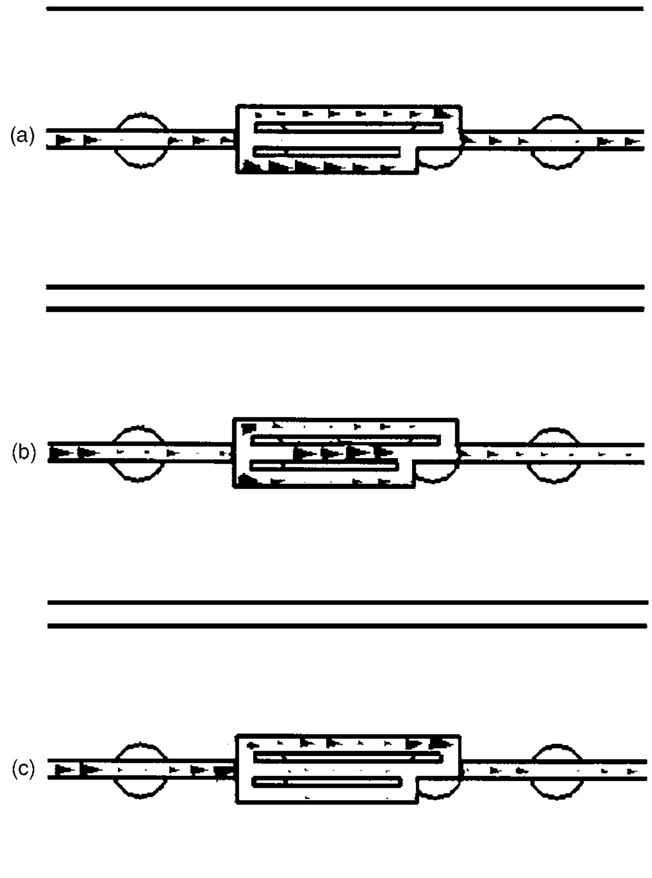

FIG. 5. The energy flows for a three-channeled filter based on a branchy defect at different resonance frequencies: (a) 3.93, (b) 4.73, and (c) 6.20 GHz.

In conclusion, a multichanneled filter based on a branchy defect in microstrip photonic crystal is proposed. By simply adding some extra microstrip lines across the defect region, corresponding defect modes will appear inside the photonic band gap, leading to the multichanneled filtering phenomenon. The simulation result coincides well with the experiment result. Compared to the traditional methods by increasing the longitudinal length of the defect, the present design can make the device more compact.

This research was supported by the National Key Basic Research Program of China under Grant No. 2001CB610406, by the National Natural Science Foundation of China under Grant Nos. 10474072, 50477048, and 10574099, and by the Shanghai Science and Technology Committee.

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