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STUDY ON X-SHAPED PHOTONIC CRYSTAL WAVEGUIDE IN 2D TRIANGULAR LATTICE FOR WDM SYSTEM

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For wavelength division multiplexing system, X-shaped waveguide situated in two dimensional pillar type photonic crystal structure was studied in this paper. Propagation and filtering characteristics of some types of the waveguide were experimentally investigated. Measurement was done by using a model in microwave frequency around 4 GHz with lattice period P=26.5 mm, diameter of pillar ϕ=7.5 mm and its dielectric constant ε_r=36.0. First, symmetric X waveguide was measured to show its basic transmission characteristics. After the measurement, three cavities with a pair of dielectric rods were situated in each output waveguide to perform a filtering function. Next, asymmetric X waveguide with cavities was examined to improve filtering characteristics in each output port. For the asymmetric structure, higher extinction ratio and higher Q-factor were obtained, compared to symmetric structure. Finally, filtering characteristics of the asymmetric X-shaped waveguide was compared with the result of Y-shaped cascaded waveguide with 4 outputs. The asymmetric X-shaped waveguide showed better results with higher resonant peak amplitude than that of Y-shaped waveguide. Applying good resolution characteristics of 40MHz with respect to input frequency, proposed asymmetric X-branch circuit is available for signal add/drop device for wavelength division multiplexing (WDM) system.

Keywords: microwave; periodic structure; photonic crystal; wavelength division multiplexing; X-shaped branch waveguide; Y-shaped branch waveguide
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1 Introduction

Photonic crystal structure or electromagnetic band gap structure are expected to play important roles not only in microwave communication component but also in optical signal processing and optical fiber communications, because of its unique and sensitive characteristics for wavelength, based on photonic band gap theory[1]-[4]. In such signal processing, high density multiplexing in wavelength domain is expected due to its sensitiveness with respect

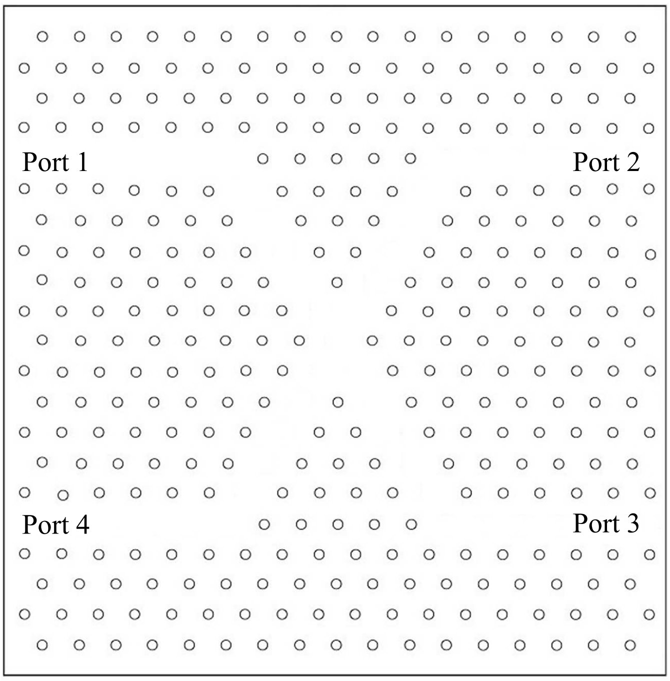

Fig. 1. Top view of illustration of two dimensional photonic crystal waveguide with symmetric X-shaped branch.

to optical wavelength or frequency. This is important to improve capacity of information transmission in the future photonic network.

In this paper, measurement result of transmission and reflection of X-shaped waveguide with one input and three output ports are presented. In the measurement, symmetric and asymmetric X waveguide with cavities were measured. The measurement result was that the asymmetric X waveguide showed higher resonant peak amplitude and quite good Q-factor of the resonance in the cavities, compared with results of Y-shaped waveguide[5]. This result is applicable for an add/drop component of signal in wavelength division multiplexing(WDM) system.

2 Measurement of Two Dimensional Photonic Crystal Waveguide

2.1 Design of waveguide and experimental setup

Top view of two dimensional photonic crystal waveguide with symmetric X-shaped branch is illustrated in Fig. 1. The measurements are done by referring to Refs. [5], [6] and [7]. Ceramic dielectric rods with diameter ϕ=7.5 mm and height h=29.5 mm are situated as triangular lattice with period P=26.5 mm, as is depicted in Fig. 2. The ceramic rods were provided by Kyocera co. ltd. in Japan and the dielectric constant $\varepsilon_r = 36.0 \pm 0.2$ at 4.0 GHz was reported. Also, the loss tangent is order of 10^{-6}, thus loss by the material can be negligible. The array of rods are supported by a pair of aluminum plates. On surface of the

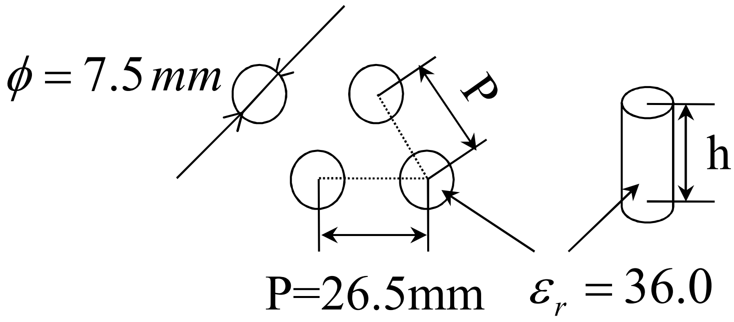

Fig. 2. Schematic of triangular periodic array of ceramic rods.

bottom plate, periodic shallow holes with diameter of 7.6 mm and depth of 0.5 mm were mechanically fabricated for precise arrangement of the rods. The design of periodic structure, or in other word, period P was determined by the finite difference time domain (FDTD) method[8] for under restriction of actual material parameter and mechanical fabrication, so that the line defect operates as a waveguide for measured frequency range between 3.6 and 4.2 GHz [5], [9]-[12]. Transverse electric (TE) wave is supposed as electromagnetic field profile for the two dimensional structure. The structure is surrounded by aluminum walls which are electrically grounded to assume two dimensional structure by principle of mirror image. By removing a line of rods, the defect in the periodic structure operates as a photonic crystal waveguide. The waveguide is excited by a microwave in range of 3.6 to 4.2 GHz by attached coaxial-to-waveguide adapter. Height of dielectric rods h=29.5 mm corresponds to height of rectangular waveguide of the adapter. The transmission and reflection of the waveguide were measured by vector network analyzer Agilent Technologies E5071C, after calibration in measurement frequency range.

2.2 Measurement of symmetric X-shaped waveguide

A symmetrical X-shaped waveguide with input/output ports is depicted in Fig. 1. The structure is composed of 11 vertical and 18 horizontal rows of ceramic rods. Here, dimension of the whole waveguide structure is width L_0=485.5 mm and the height W_0=477.0 mm, respectively. For measurement between an input and one of output ports, an anti-reflection termination adapters were loaded at output ports which were not under measurement. For confirmation of transmission to each output port and reflection to input port, measured S-parameters were depicted in Fig. 3. In the figure, it is obvious that transmission to port 2, 3 and 4 are observed, however, transmission to port 3 and 4 are lower than that to port 2 and unstable for variation of input signal frequency.

Next, cavities are situated in each output waveguide, as is shown in Fig.4. The rods of cavities which are closer to outputs are placed right on regular lattice, however, another rod of cavities were placed on irregular position to make difference of length of each cavity. This type of cavity situation is referred to as “Type-I ”. The transmission characteristics to

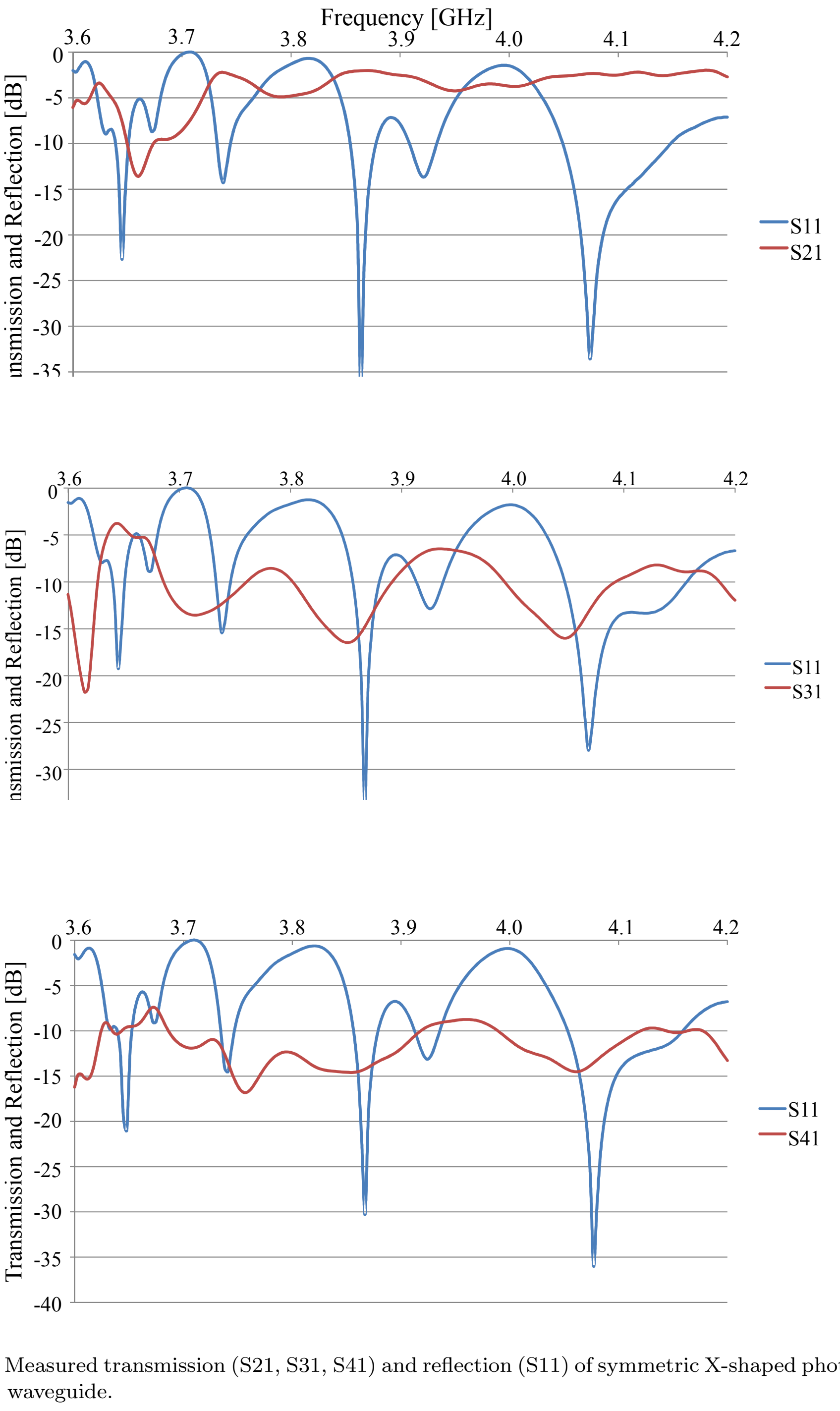

Fig. 3. Measured transmission (S21, S31, S41) and reflection (S11) of symmetric X-shaped photonic crystal waveguide.

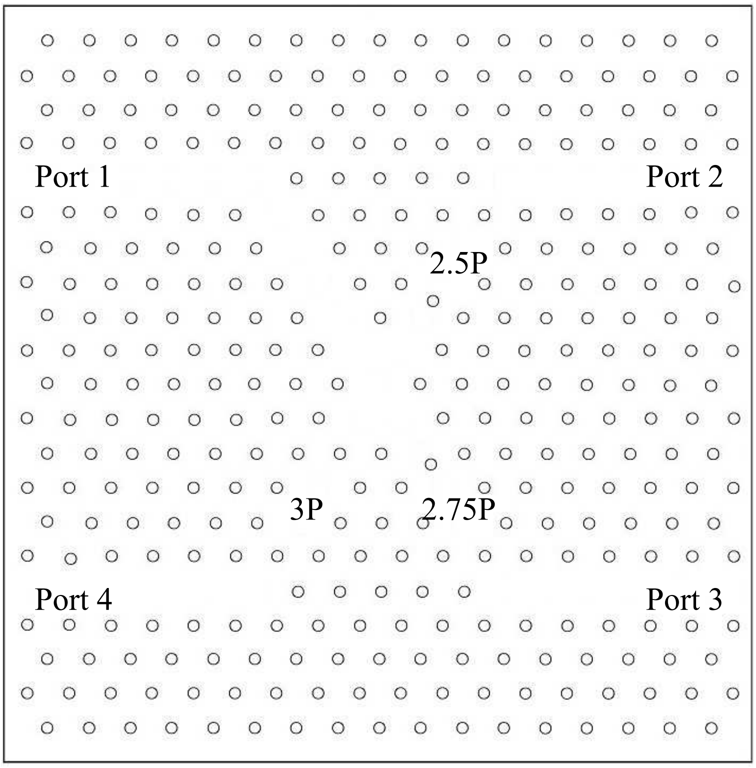

Fig. 4. Illustration of symmetric X branch waveguide with three pairs of cavity, which is called Type-I.

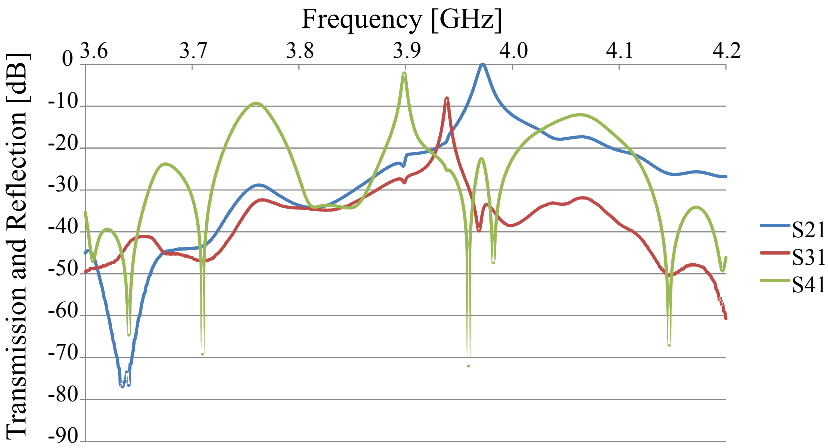

Fig. 5. Transmission characteristics of waveguide Type-I.

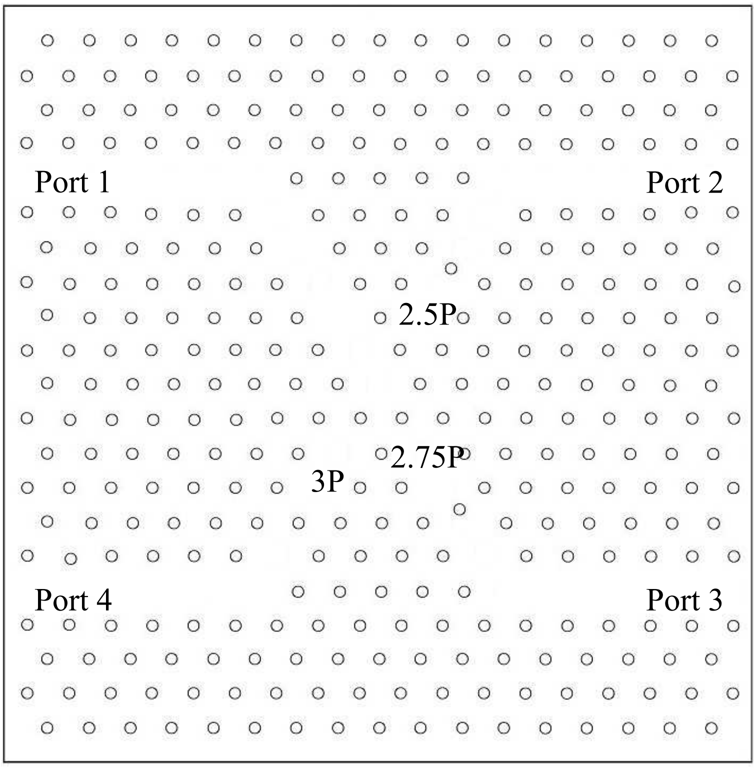

Fig. 6. Illustration of symmetric X branch waveguide with three pairs of cavity, which is called Type-II.

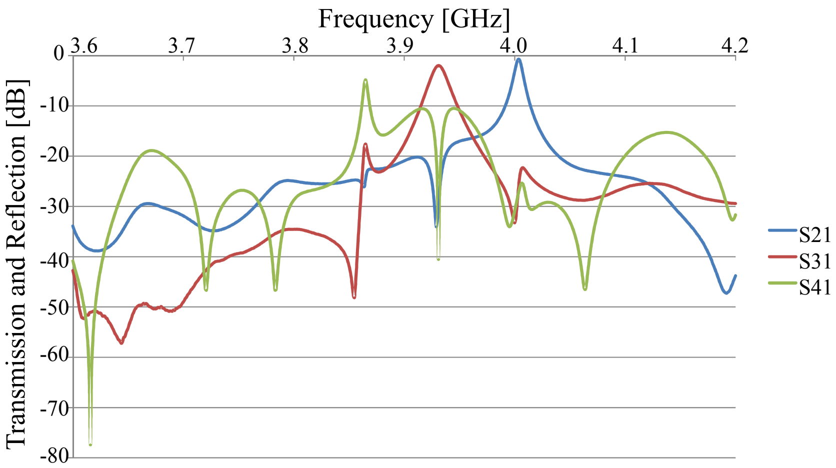

Fig. 7. Transmission characteristics of waveguide Type-II.

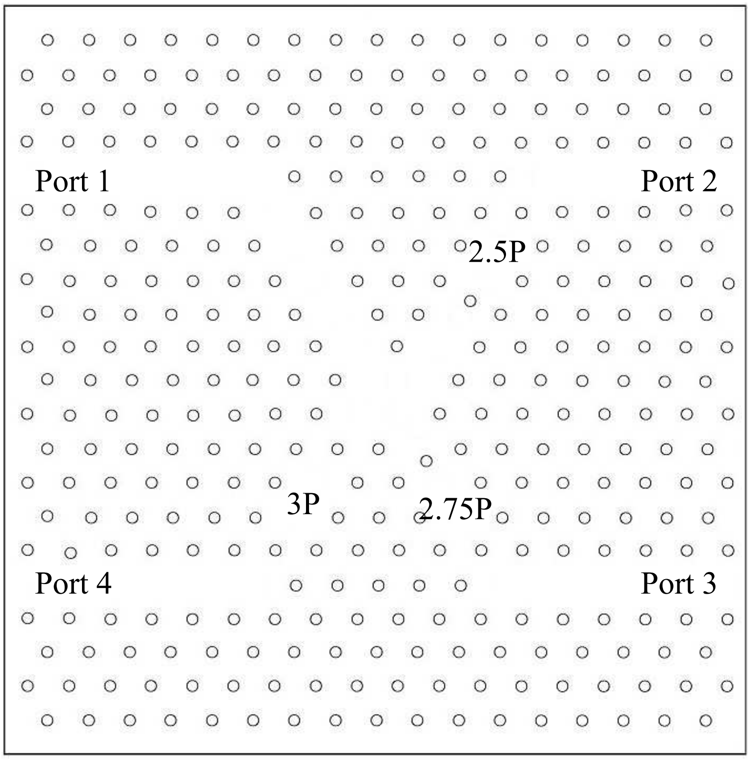

Fig. 8. Illustration of asymmetric X branch waveguide with three pairs of cavity, which is called Type-III.

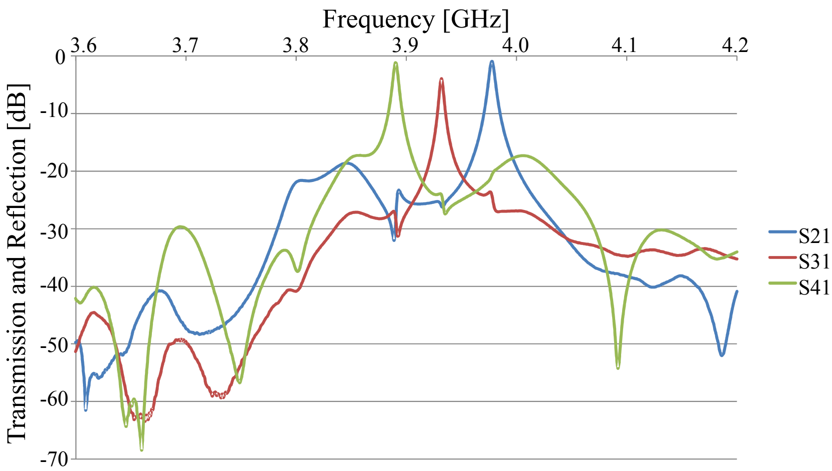

Fig. 9. Transmission characteristics of waveguide Type-III.

port 2, 3 and 4 are shown together in Fig.5. In this figure, the resonant peak amplitude of transmission to S31 is smaller than the other outputs.

In Fig.6, the rods of cavities which are closer to center of X-shape are placed on regular lattice, as "Type-II ". In this experiment, as shown in Fig.7, the resonance peak of S31 was improved. However, extinction ratio of S41 is not large enough and resonance of S31 is quite broad. These points are to be improved in symmetrical structure.

2.3 Measurement of asymmetric X-shaped waveguide

Finally, to improve filtering characteristics, asymmetric X-shaped waveguide was examined, as in Fig.8, which have cavities in each output. As seen in the figure, waveguides to port 2 and port 4 are situated off-axis, which is called "Type-III ". In symmetric X waveguide, the power division to three output ports was unstable and tend to show maximum at port 2, the first and closest branch to input waveguide. Therefore, we improved the power transmission to outputs by using asymmetric X-shaped structure to deliver input power intensively to port 4 and 3. In an asymmetric branch waveguide removing three pairs of cavity from Fig.8, we could successfully observe almost equal power division in measurement frequency range.

The transmission to port 2, 3 and 4 with cavities are shown in Fig. 9. The figure indicates that each resonance became sharper and extinction ratio among output ports are over 20dB. The Q-factor were summarized in Table 1. As shown in Fig.9 and Table 1, sharpest resonance are obtained among measured structure in this paper. Especially, in the figure and table, it is noted that quite sharp resonant peaks are obtained with separation of about 40MHz.

Table 1. Transmission to each output port in asymmetric X-shaped waveguide Type-III.

Port No.	Cavity Length	Peak Freq.	Q factor	Ext. Ratio
Port 2	$2.50P$	3.978 GHz	796	19.49 dB
Port 3	$2.75P$	3.932 GHz	983	20.14 dB
Port 4	$3.00P$	3.890 GHz	778	26.50 dB

2.4 Comparison with cascaded Y-shaped waveguide with 4 outputs

In our previous work[5], we proposed Y-shaped branch waveguide for WDM signal drop circuit. The measurement result of cascaded Y-branch waveguide with 4 outputs showed higher Q-factors in output ports.

In the proposed structure in 2.3, the Q-factors are all over 700 and well separated each other. We can conclude that asymmetric X-shaped waveguide is needed to improve Q-factor for purpose of drop circuit in dense-multiplexed WDM system. However, resonant peaks of cascaded Y-shaped waveguide is less than -10 to -20 dB. From point of signal attenuation after branching, there exist advantage in X-shaped waveguide, because amplitude of resonant peaks are over -5dB in all of outputs, depicted in Fig. 9.

Table 2. Summary of improved resonance in Y-shaped four-branching waveguide with stabs.

Length of Cavity	Peak Freq.	Q factor	Extinction Ratio
2.1P	4.138 GHz	1034.5	31.91 dB
2.3P	4.083 GHz	453.7	32.06 dB
2.5P	4.018 GHz	1337.7	27.64 dB
2.7P	3.914 GHz	1957.0	18.13 dB

3 Concluding Remarks

In microwave model of pillar type two dimensional photonic crystal waveguide with triangular lattice, transmission and reflection characteristics of X-shaped waveguides were measured near frequency of 4 GHz. After confirming transmission of symmetric X waveguide, filtering characteristics of cavities in outputs were measured. As an improvement of filtering function, we concluded that asymmetric X waveguide with cavities has advantages because it showed sharpest, well-separated and generally high extinction ratio among proposed structures. This result is compared with Y-shaped waveguide to show filtering characteristics with larger amplitude of X waveguide. For an application of proposed X-shaped waveguide, signal drop circuit to one of output port for typical career frequency was proposed. The measurement result is, of course, directly applicable for optical circuits, based on scaling rule, as far as material constant and normalized frequency remains same with this experiment.

Our future subject is to design and fabricate cascaded X-shaped waveguide for dropping multiplexed signal with more carrier frequencies. Also, improvement of Q-factor and extinction ratio among output ports are our theme to challenge.

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