Photonic Crystal Waveguides in Terahertz Regime (invited)

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Abstract: Using the finite difference time domain method, the electromagnetic field distribution of THz waves in photonic crystals (PCs) T-splitters and Y-splitters had been simulated. The simulation results show that those different T-splitters and Y-splitters can divide the power in an input wave guide equally between two output waveguides. By the improved T-splitter with a rod in the junction, we achieved the 84% amplitude-frequency characteristics consistency of pass-band from 1.12 THz to 1.22 THz, and surpass the 76% consistency of common T-splitter. The improved Y-splitter with a rod in the junction and without rod in the corners has widest -3db bandwidth 0.224 THz, and the amplitude reaches 1655.727. The improved Y-splitter has better performance than other Y-splitters. Introducing the photonic band gap structure with L-type defect composed of three defects. Three high-Q resonant frequencies appeared simultaneously in some monitor coordinates. The wavelength-add-drop properties of L-type defects may be used in multi-carrier communication and multi-frequency-monitoring for the THz regime. Also, a carefully designed PCs can be used as high Q narrowband filter in THz band. These results provide a useful guide and a theoretical basis for the developments of THz functional components.

1. Introduction

Terahertz (THz) radiation is a part of the electromagnetic spectrum. THz frequencies cannot clearly be classified to be either on the “electronic” side or on the “optics” side, commonly referred to as the “terahertz gap” (0.1-10 THz, λ=3mm-30µm). The THz frequency radiation has been proved as a fertile region in the electromagnetic spectrum and a powerful tool in scientific research and applications. Although enormous efforts have focused on the search for “THz” materials or alternative novel techniques to enable the construction of device components, much work remains [1]. THz waves have significant transmission loss in the atmosphere, so waveguide-based terahertz devices have become an important foundation for the THz transmission, as well as the bottle-neck for its practical applications.

One solution to the problem of THz manipulation is the application of photonic crystals (PCs), which is a low-loss periodic dielectric medium. With special design
and construct the PCs can control the propagation of THz wave in certain directions with specified frequencies \(^2\). In this presentation, we introduce three kinds of PCS based THz devices: splitter, add-drop filter and High Q narrow-band filter.

2. Splitters

A useful waveguide device is a splitter, which divides the power in an input waveguide equally between two output waveguides \(^3\). Like the bend waveguide, the photonic band gap eliminates radiation loss and we need only deal with the possibility of reflection. Unlike the bend waveguide, it turns out that we cannot eliminate reflections by a symmetry argument, and must do something counterintuitive. We need to obstruct the output waveguides in order to increase transmission. In this paragraph, we demonstrate an improved method for guiding wave around T-splitter and Y-splitter, using photonic crystal waveguides.

For simplicity, we choose to study a 2-D photonic crystal of long dielectric rods in air on a square array with lattice constant of \(a\). The lattice constant \(a\) is set to be 100\(\mu m\), since it remains unchanged under rescaling for a photonic band gap (PBG) material, it can easily assure that the guided light will be in the infrared or THz region \(^3\). For example, if we choose a lattice constant \(a\) of 0.58 \(\mu m\), the wavelength corresponding to the mid gap frequency will be 1.55 \(\mu m\). Their 2D photonic crystals composed of long dielectric rods in air can be realized in a practicable form by incorporating the same lattice pattern in the thin space between the two metal plates of a parallel-plate waveguide, as discussed and demonstrated in References \(^2, 4\).

According to Grischkowsky’s work \(^5\), High-resistivity and high-purity Silicon (Si) with the index of refraction (n) of 3.4176 is excellent for THz transmission due to its non-dispersive nature and low absorption in THz region. So here we choose Si rods for simulation. We had calculated the TE band gap structure for the square PCs with \(R = 18\ \mu m\) for relatively wilder transverse-electric (TE) gap \(^6\), two TE band gaps namely \(\Gamma\) and \(\Delta\) exist in two different frequency regions. Gap \(\Gamma\) is wider with a frequency range from 0.91 to 1.33 THz, while gap \(\Delta\) is much narrower with a frequency range from 2.23 to 2.28 THz. So we mainly focus on the transmission properties in Gap \(\Gamma\).

In Figure 1, it shows four different T-splitter configurations, (a) is the common T-splitter called T0, (b) is the T-splitter that has one rod in junction called T1, (c) is the T-splitter that has four rods in junction called T2 and (d) is the T-splitter that has nine rods in junction called T3. The field pattern of the propagating mode can be observed by a continuous wave (CW) excitation of the guided mode. According to the previous results \(^6\), we set the CW excitation frequency to be 1.12 THz, and the corresponding electric field distribution pattern was simulated and shown in Figure 1. As can be clearly seen that, the mode is completely confined inside the guides, and the wave travels smoothly around the sharp bend, even though the radius of curvature of the bend is on the order of the wavelength \(^3\).

In order to monitor the field amplitude that travels after T-splitter, we set a monitor point after the T-splitters at the position of (-400, 0, 0), labeled as point A in Figure 1. We study the transmission properties of waveguide splitters using a vector
finite-difference time-domain program with quartic perfectly matched layer boundaries \([7]\). In our simulation, a dipole located at the entrance of the waveguide creates a pulse with a Gaussian envelope in time. Figure 1 shows the frequency dependence of field amplitude, which is monitored inside the T-splitters guides at point A. As can be seen that, four curves have the similar features that, field amplitude increases sharply at 0.843 THz and decreases quickly at 1.50 THz. The amplitude reaches its highest point near the frequency 1.12 THz and 1.22 THz, those features are decided by the structure of photonic crystals. But obviously the four curves are different. For example, T0 firstly reach to its sub-peak value of 785 at 1.12 THz and increase to its peak value of 1035 at 1.22 THz. For T1 its sub-peak is 810 at 1.12 THz and increasing to the highest point of 965 at 1.22 THz. T2 and T3 are more special than T0 and T1 curves. That is, T2 firstly reaches to its highest point of 905 at 1.12 THz and then decreases to the sub-peak point of 835 at 1.22 THz. Similarly, T3 firstly reaches to its highest point of 755 at 1.12 THz and decreases to the sub-peak value of 465 at 1.22 THz. Those differences are decided by the bend structure of T-splitters \([8]\).

From figure 1 we can also see that the pass-band of T-splitters is from 1.12 THz to 1.22 THz. We define the amplitude-frequency characteristics consistency of pass-band as \(\delta\), its value is the ratio of the sub-peak amplitude comparing with that of the highest peak. So the value of \(\delta\) implies the consistency of the pass-band. Considering the practical fact in signal propagation, that the loss at higher frequency is a little larger than that at lower frequency, higher transparency at higher frequency is prefect. This is the case of T1 curve. Thus considering the consistency quality as well as the demand in signal propagation, T1 is the best choice comparing with other configuration \([6]\).

![Fig.1](image)

**Fig.1** The electric field pattern in the vicinity of the T-splitter at frequency of 1.12 THz and field amplitude is monitored inside the T-splitters waveguides.

The amplitude-frequency characteristics of improved T-splitter were superior to the common T-splitter's. But the output and input direction of T-splitter are vertical position, and the T-splitter can not output the EM wave parallel to the input direction. In this paragraph, the different Y-splitters with a junction and two corners are studied.
Y-splitters are composed of a junction and two corners. The different Y-splitters with same junction structure and different corners structure are investigated. In Figure 2, it shows four different Y-splitter configurations, (a) is the conventional Y-splitter called Y00 without rod in the junction and corners, (b) is the Y-splitter that has no rod in the junction and one rod in the corners called Y01, (c) is the Y-splitter that has no rod in the junction and three rods in the corners called Y02 and (d) is the Y-splitter that has no rod in junction and six rods in the corners called Y03. The field pattern of the propagating mode can be observed by a CW excitation of the guided mode. According to the previous results [6], we set the CW excitation frequency to be 1.12 THz, and the corresponding electric field distribution pattern was simulated and shown in Figure 2. As can be clearly seen that, the mode is completely confined inside the guides, and the wave travels smoothly around the junction and corner, even though the radius of curvature of the bend is on the order of the wavelength. The observation can be explicited by the PCs' basic feature that preventing light from propagating in certain directions with specified frequencies [3].

In order to monitor the field amplitude that travels after those Y-splitters, a monitor point after the Y-splitters was set at the position of (900, 400), labeled as point M in Figure 2. We study the amplitude-frequency transmission properties of waveguide splitters using a vector finite-difference time-domain program with quartic perfectly matched layer boundaries [7]. The frequency dependence of field amplitude which is monitored inside the Y-splitters guides at point M was shown in Figure 2. The curves of Y00, Y01, Y02 and Y03 reach the peak of 1577.247 at 1.219 THz, 1665.585 at 1.219 THz, 1645.622 at 1.219 THz and 1431.75 at 1.172 THz, respectively. The Y02 has highest peak amplitude and the Y03 has lowest peak amplitude. The -3db bandwidth is a key and useful evaluation index for bandpass properties. The -3db bandwidth of Y00, Y01, Y02 and Y03 are 0.216 THz, 0.211 THz, 0.209 THz and 0.215 THz, respectively. The Y00 has widest -3db bandwidth. Those differences are determined by the different corners structure of Y-splitters [9]. The
effective lengths of corners bend waveguide variation lead to the amplitude frequency characteristics change \[8\].

In Figure 3, it shows four different Y-splitter configurations, (a) is the Y-splitter called Y10 with one rod in the junction and without rod in the corners, (b) is the Y-splitter that has one rod in the junction and corners called Y11, (c) is the Y-splitter that has one rod in the junction and three rods in the corners called Y12 and (d) is the Y-splitter that has one rod in junction and six rods in the corners called Y13. The field pattern of the propagating mode also can be observed by a CW excitation of the guided mode. The CW excitation frequency was also designated to be 1.12 THz, and the corresponding electric field distribution pattern was simulated and shown in Figure 3. As can also be clearly observation that, the mode is completely confined inside the guides, and the wave travels smoothly around the junction and corner \[9\].

![Fig. 3](image)

**Fig. 3** The electric field pattern in the vicinity of the Y-splitters for frequency 1.12 THz. The field amplitude was monitored inside the Y10, Y11, Y12 and Y13 Y-splitters waveguides.

In order to monitor the field amplitude that travels after those Y-splitters, we also set a monitor point after the Y-splitters at the position of (900, 400), labeled as point M in Figure 3. The monitored conditions of the amplitude-frequency properties of the waveguide are same as the former. The frequency dependence of field amplitude which is monitored inside the Y-splitters guides at point M was shown in Figure 3. The curves of Y10, Y11, Y12 and Y13 reach the peak of 1667.727, 1676.228, 1663.664 and 1476.106 at 1.219 THz, respectively. The Y11 has highest peak magnitude and the Y13 has lowest peak magnitude. The -3db bandwidth of Y10, Y11, Y12 and Y13 are 0.224 THz, 0.208 THz, 0.207 THz and 0.211 THz, respectively. The Y10 has the widest -3db bandwidth. Those differences are determined by the different corners structure of Y-splitters \[9\].

Figure 2, 3 show that the transmission properties of the different Y-splitters. Y-splitters can divide the power in an input wave guide equally between two output waveguides. Those figures show that the Y-splitters with three rods in the corners have the highest peak amplitude at 1.219 THz. The Y-splitters with six rods in the corners have a feature that the amplitude at 1.172 THz has been increased relatively to
the amplitude at 1.219 THz. The Y-splitters without rod in the corners have the widest -3db bandwidth. Those differences are determined by the different corners structure of Y-splitters. The effective lengths of corners bend waveguide variation lead to the amplitude frequency characteristics change \(^8\).

In comparison with the property of different Y-splitters, the frequency and normalized amplitude of peak and the -3db bandwidth had been listed in Table 1. Table 1 evidently shows that only Y10, a rod in the junction and without rod in the corners, has the higher amplitude of peak and wider -3db bandwidth than the conventional Y-splitter Y00 \(^9\).

### Table 1 The comparison of different Y-splitters

| Y-splitter | Peak | -3db bandwidth |
|------------|------|----------------|
|            | Freq.(THz) | Amp. (a. u.) | (THz) |
| Y00        | 1.219 | 1577.247       | 0.216 |
| Y01        | 1.219 | 1665.585       | 0.211 |
| Y02        | 1.219 | 1645.622       | 0.209 |
| Y03        | 1.172 | 1431.75        | 0.215 |
| Y10        | 1.219 | 1655.727       | 0.224 |
| Y11        | 1.219 | 1696.228       | 0.208 |
| Y12        | 1.219 | 1663.664       | 0.207 |
| Y13        | 1.219 | 1476.106       | 0.211 |

Using the finite difference time domain method, the electromagnetic field distribution of terahertz waves in different photonic crystals Y-splitters with a junction and two corners were simulated. The simulation results show that those different Y-splitters can divide the power in an input wave guide equally between two output waveguides. The improved Y-splitter with a rod in the junction and without rod in the corners has widest -3db bandwidth 0.224 THz, and the amplitude reaches 1655.727. The improved Y-splitter has better amplitude frequency performance than other Y-splitters.

### 3. Dropped/Added filters

Terahertz waves could handle broadband signals and are expected to be applied to ultrafast wireless communications \(^1\). In a communication system, one of the most important issues is that the work frequency or narrowband signal should be selectively upload and download. Conventional components can not perform well in THz regime, but PCS is an excellent candidate \(^10\). In this work, PCs with both line- and cavity-defects are designed. By control the shape of the cavity defects, one, two, or three upload/download frequencies are realized, rendering this PCS filter a good candidate for multi-carrier communication and multi-frequency-monitoring in the THz regime.

In Figure 4, line-shaped defects designed as a straight waveguide is formed by removing one column of rods from the square PCs array, and with a single defect in the vicinity of the waveguide as illustrated in each figure. The coordinate of every single-defect are assigned as (300, 0), (300,100), (400, 0), (300,-100) and (200, 0),
respectively. Relative to the coordinate of (300, 0), those single defect are defined as center, upward, rightward, downward and leftward defect, respectively. The wavelength-add-drop properties of the waveguide are investigated using a vector finite-difference time-domain program with quartic perfectly matched layer boundaries [7]. In our simulation, a dipole located at the entrance of the waveguide creates a pulse with a Gaussian envelope. The field amplitude of monitored inside the corresponding waveguides are shown in Figure 4 as M.

![Image](https://example.com/image.png)

**Fig.4** Schematics of 2D PBG with typical square lattices composed of the Si rods in air background with a=100 um and r = 18 µm. The coordinate of single-defects are (a) (300, 0), (b) (300,100), (c) (400, 0), (d) (300,-100) and (e) (200, 0), respectively. The field amplitude of monitored of different single-defect inside PBG are shown in Figure 4.

The field amplitude of monitored of different single-defect inside PBG are shown in Figure 4. Figure 4 shows that the input pulses propagating through the linear waveguide are trapped by the single-defect. The reason is that the single-defect has strong localization state. The single-defect acted as resonator with special frequency and quality factor. The resonance peak of the center, upward, rightward, downward and leftward single-defect are 0.206 at 1.149 THZ, 0.191 at 1.149 THZ, 0.05 at 1.14 THZ, 0.217 at 1.149 THZ, and 0.764 at 1.155 THZ, respectively. It shows that the upward, center and downward single-defect have same resonance frequency. But the filed amplitude increase from 0.191 to 0.217, the obvious reason is that the much closer of the single-defect to the input port, the more energy can be obtained from line-shaped defects waveguides. Meanwhile, with the single-defect position vary from the leftward, to rightward, the resonance frequency decrease from 1.155 THz to 1.14 THz and the field amplitude decrease from 0.764 to 0.05, as shown in Figure 4. This can be understood by the fact that much more energy would be obtained from the leftward single defect nearest to the line-shaped defects. In comparison, the resonance frequency and amplitude of the single-defect in vertical direction relative to the line-shaped defects waveguide are more sensitive to its position than that of the single-defect in parallel direction, and the difference are caused by the propagation properties of the line-shaped defects waveguides [11]. According to Figure 4, the sharpest curve of leftward defect shows most quality factor Q, and the descending
trends of factor $Q$ are the downward, center, upward and rightward single defect, respectively. The reason of most quality factor $Q$ is that more energy can be obtained from the single-defect which is closer to the line-shaped defects.

![Figure 5](image1.png)  
**Fig. 5** Schematics of 2D PBG. (a) and (b) are vertical and parallel defects relatively to the line-shaped waveguides in the middle of PCs. (c), (d), (e) and (f) are L-type defects of upper-left, upper-right, lower-left, and lower-right, respectively.

The structures with three defects are shown in Figure 5. Two kinds line-defects as shown in Figure 5 (a) and (b), the line defects are named as vertical and parallel line defects relatively to the line-shaped waveguides in the middle of PCs, and four kinds L-type defects as shown in Figure 5 c-f, the four kinds L-type defects are named as upper-left, upper-right, lower-left and lower-right L-type defects, respectively. The field amplitude of monitored inside the corresponding waveguides are shown in Figure 5 as M. For comparing the amplitude of three single-defects, every single-defect was monitored. Other monitored conditions of the wavelength-add-drop properties of the waveguide are same as the former.

![Figure 6](image2.png)  
**Fig. 6** The field amplitude of monitored inside the vertical and parallel line-shape defects

Figure 6 shows the field amplitude of monitored inside the vertical line-shape...
defects relatively to the line-shaped waveguides in the middle of PCs. The amplitude of coordinate at (300, 0) have two little difference of the resonance peak of 0.162 at 1.038 THz and 0.077 at 1.173 THz. The amplitude of (200, 0) have two large difference of the resonance peak of 0.099 at 0.987 THz and 0.448 at 1.137 THz. The amplitude of (400, 0) also have two large difference of the resonance peak of 0.424 at 1.137 THz and 0.072 at 1.284 THz. Figure 6 shows that the endpoint of the vertical line-shape defects have the high amplitude and the middle of the vertical defects has little different amplitude of two resonant frequency.[11]

Figure 6 also shows the field amplitude of monitored inside the parallel line-shape defects relatively to the line-shaped waveguides in the middle of PCs. The amplitude of (300, 0) have two little difference of the resonance peak of 0.181 at 1.017 THz and 0.098 at 1.347 THz. The amplitude of (300, -100) also have two difference of the resonance peak of 0.254 at 1.122 THz and 0.085 at 1.347 THz. The amplitude of (300, 100) also have two major of the resonance peak of 0.231 at 1.14 THz and 0.097 at 1.299 THz, meanwhile, an unremarkable resonance peaks of 0.138 exist in 1.023 THz. Figure 6 shows that the endpoint of the parallel line-shape defects have the high amplitude and the middle of the parallel defects has little different amplitude of two resonant frequency.[11]

Figure 6 shows that the vertical or parallel line-shape defects, composed of three single-defects, have more than one resonance frequency. The defects structure change cause the localization state change, the result is the resonant state and mode change. The different field patterns measured could be explained by the eigenmodes of the defects and the excitations can be understood considering how the waveguide modes couple to each of the eigenmodes. The different resonant structure between the vertical and parallel line-shape defects had obtained different energy from the straight line-shape waveguide, and caused the difference peak location between Figure 6 in the same coordinate (300, 0). Figure 6 also show that the line-shape with three single-defects have the similar amplitude feature that two endpoint large and middle point small. The feature can be interpreted in accordance with Reference 3. The resonance cavity, the vertical or parallel line-shape three single-defects, that is effectively surrounded by reflected walls. The endpoint directly access to energy from three reflected walls, conversely, the middle-point directly access to energy from two reflected walls. The direct reflected walls number difference lead to the magnitude difference. From Figure 4, the amplitude peak of (200, 0) single-defect has more than (400, 0)'s, the similar reason cause the amplitude peak of (200, 0) has more than (400, 0)'s in the vertical line-shape defects. And the similar phenomenon and reason appear in the parallel line-shape defects.
Figure 7 shows the field amplitude of monitored inside the upper-left L-type defects. The amplitude of (300, 0) have three little difference of the resonance peak of 0.117 at 1.053 THz, 0.083 at 1.176 THz and 0.094 at 1.281 THz. The amplitude of (200, 0) have two large difference of the resonance peak of 0.126 at 1.014 THz and 0.409 at 1.158 THz. The amplitude of (300, 100) also have two large difference of the resonance peak of 0.084 at 1.008 THz and 0.405 at 1.161 THz. Figure 4 shows that three resonant frequency appeared simultaneously in the (300, 0) of upper-left L-type defects, and the main resonant frequency appeared in the other two monitored coordinates.

Figure 7 also shows the field amplitude of monitored inside the lower-left L-type defects. The amplitude of (300, 0) have three little difference of the resonance peak of 0.136 at 1.035 THz, 0.075 at 1.158 THz and 0.087 at 1.266 THz. The amplitude of (200, 0) have two large difference of the resonance peak of 0.399 at 1.161 THz and 0.100 at 1.287 THz. The amplitude of (300, -100) have two large difference of the resonance peak of 0.156 at 1.011 THz and 0.405 at 1.161 THz.

In Figure 7, the field amplitude of monitored inside the upper-right L-type defects is shown. The amplitude of (300, 0) have two little difference of the resonance peak of 0.102 at 1.014 THz and 0.085 at 1.326 THz. The amplitude of (400, 0) have main resonance peak of 0.097 at 1.059 THz. The amplitude of (300, 100) have three little difference of the resonance peak of 0.089 at 1.017 THz, 0.131 at 1.161 THz and
0.081 at 1.311 THz. Figure 7 shows that three resonant frequency appeared simultaneously in the (300, 100) of upper-right L-type defects, two resonant frequency appeared in the (300, 0), and one low-Q factor resonant frequency in the (400, 0).

As to the case of lower-right L-type defects, the amplitude of (300, 0) have three little difference of the resonance peak of 0.131 at 1.017 THz, 0.040 at 1.155 THz and 0.081 at 1.317 THz. The amplitude of (400, 0) also have three little difference of the resonance peak of 0.120 at 1.023 THz, 0.136 at 1.164 THz and 0.075 at 1.311 THz. The amplitude of (300, -100) also have three little difference of the resonance peak of 0.067 at 1.014 THz, 0.093 at 1.134 THz and 0.068 at 1.338 THz. Figure 7 shown that three resonant frequency appeared simultaneously in each monitor point of the lower-right L-type defects, the high-Q and small difference of amplitude of resonant appeared in (400, 0), the high-Q and large difference of amplitude of resonant appeared in (300, 0), and lower-Q resonant appeared in (300, -100).

Figure 7 show that the different L-type defects structures, composed of three single-defects, have different resonant frequency, amplitude and peak shape. But there have the similar feature that three resonant frequencies simultaneously appear in some monitored coordinates. The specific feature possible is interpreted below [3, 11, 12]. Firstly the three single-defects obtain energy from the straight line-shape waveguide, and then there exchange energy and resonate in the L-type cavity. The energy exchange and resonant inevitable had been effected by the corner with the existence of bound states localized in the vicinity of the corner. The multi-reflection will appear in the course of energy of one of single-defect reach the other two single-defect and return to the beginning coordinates. The complex reciprocity cause the resonance split to three points. In other words, the corner in the L-type defects lead to the resonant frequency split to three in some coordinates. The different field patterns measured also could be explained by the eigenmodes of the defects. The different three single-defects composed different L-type defects. Figure 4 shows the different single-defects with different resonances, and causes the different L-type defects have different resonant appeared Figure 7.

Our result provide a new way, introducing L-type defects composed of three defects, to develop the wavelength-add-drop device that three high-Q resonant frequencies appear simultaneously in one defect coordinates. The wavelength-add-drop properties of L-type defects may be used in multi-carrier communication and multi-frequency-monitoring for the THz regime.

4. Hgh-Q narrow-band filters

Also, a carefully designed PCs can be used as high Q narrowband filter in THz band. We introduce a waveguide–cavity–waveguide structure to the PC, as shown in Fig. 8, and it is found that the number and structure of cavity has very important influences on the characteristic of the filter. Our simulation results show that by control the number of the cavity we can achieve single THz narrow-band signals.
The narrow-band filter properties of the central cavity were shown in Figure 2. The transmission spectrum shows that 100% peak at cavity resonance frequency 1.161 THz, and $\Delta f$ at half-maximum (50% transmission) is about 0.0193 THz with $Q \approx 60.15$. The fractional width $\Delta f/f_0$ at half-maximum (50% transmission) is precisely equal to $1/Q$, where $Q$ is the quality factor of the cavity mode when excited internally. This sharp peak means that the device acts as a narrow-band filter. The light is transmitted for frequencies near the resonant frequency of the cavity, and is reflected for somewhat lower or higher frequencies. The existence of the resonance peak conforms to intuition: near the resonant frequency, light from the input waveguide can couple into the cavity, and the cavity in turn can couple into the output waveguide.

The field pattern for transmission at resonance is shown in Figure 8. If we shift the frequency by only 0.01 THz, the transmission drops to less than 0.3, corresponding to the fields in the middle panel. The sharp dip in the transmission at around 1.13 THz corresponds to the zero-slope band edge of the waveguide mode, where coupling light through the device is especially difficult. The oscillations at high and low frequencies correspond to frequencies outside the band gap, where energy propagates through the crystal instead of being confined to the waveguide and cavity.

5. Conclusion

The application of photonic crystal, which is a low-loss periodic dielectric medium, can solve to the problem of THz manipulation. With special design and construct the PCs can control the propagation of THz wave in certain directions with specified frequencies. Three kinds of splitter, add-drop filter and High Q narrow-band
filter had been introduced for the application of THz. These results provide a useful

guide and a theoretical basis for the developments of THz functional components.

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References:
1. Hosako, I., Sekine, N., Patrashin, M., et al. At the Dawn of a New Era in Terahertz
Technology, Proceedings of the IEEE, 95, 8,1611 – 1623, (2007)
2. A. Bingham, Yuguang Zhao, and D. Grischkowsky, THz Parallel Plate Photonic Waveguides,
Appl. Phys. Lett. 87, 051101(2005)
3. J.D. Joannopoulos, R.D. Meade, and J.N. Winn, Photonic Crystals: Molding the Flow of Light
(second edition) (Princeton, New York, 2007)
4. Yuguang Zhao and D. Grischkowsky, “Terahertz demonstrations of effectively two dimensional
photonic bandgap structures,” Optics Letters, 31, 1534-1536 (2006)
5. D. Grischkowsky, Søren Keiding, Martin van Exter and Ch Fattinger, “Far-infrared
time-domain spectroscopy with terahertz beams of dielectrics and semiconductors”, J. Opt.
Soc. Am. B, 7, 2006-2015 (1990)
6. Sheng LI, Huai-Wu ZHANG, Qi-Ye WEN, et al. Improved Amplitude- Frequency
Characteristics for T-splitter Photonic Crystal Waveguides in Terahertz Regime. Applied
Physics B:Lasers and Optics, 2009, 95:745-749
7. J. C. Chen and K. Li, Quartic Perfectly Matched Layers for Dielectric Waveguides and Gratings,
Microwave Opt. Technol. Lett. 10, 319–323 (1995).
8. Attila Mekis, J. C. Chen, I. Kurland, et al., High Transmission through Sharp Bends in Photonic
Crystal Waveguides, Phys. Rev. Lett., 77,3787,(1996)
9. Sheng LI, Huai-Wu ZHANG, Qi-Ye WEN, et al. Improved Y-splitter Photonic Crystal
Waveguides in Terahertz Regime. Applied Physics B:Lasers and Optics, 2010, 99:709-716
10. Susumu Noda, Alongkarn Chutinan and Masahiro Imada, Trapping and emission of photons
by a single defect in a photonic bandgap structure, Nature, 407, 608 (2000)
11. Sheng LI, Huai-Wu ZHANG, Qi-Ye WEN, et al. Wavelength-drop properties of L-type
defects in photonic bandgap structure for the terahertz regime. Opt. Quant. Electron. 2009,
41:159–168
12. Attila Mekis, Shanhui Fan, and J. D. Joannopoulos, Bound states in photonic crystal
waveguides and waveguide bends, Phys. Rev. B, 58, 4809 (1998)