Designing resonant cavity made up of photonic crystal

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Defect is built as that in the semiconductor when some metal posts are withdrawn regularly from the two-dimensional (2D) photonic crystal (PC) formed by triangular arrays of metal posts. Such defect can be used to design cavity. The relation among the lattice, the radius of post, the mode and frequency of this kind of cavity is researched in this paper. The design of this kind of cavity is introduced.

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The photonic crystal (PC) material operating in microwave is oversized and therefore easier to fabricate. PC material consisting of metal rod lattice is of great interest for high power microwave recently. A defect mode of the lattice is used as an operating mode. The PC cavity supports a TM_{010}-like mode at 140 GHz and is applied to resonator gyrotron[1]. The 17 GHz PC cavity supports a TM_{010}-like mode and is applied to line accelerator[2]. The two kinds of PC cavities are both built of triangular array of metal rods. One of key works of those applications is to design different cavity operating in different mode and frequency.

We run the software High Frequency Structure Simulator (HFSS), a 3D electromagnetic code, to model the experiment. The cylindrical metal wall surrounds the lattice, and the rods are placed between two metal plates. Four rows of rods are utilized to localize the defect mode. From Fig. 1, We can find its operating frequency and mode. The defect mode is used as an operating mode. This defect mode is analogous to the TM_{010} mode of a pillbox cavity. Only the operating mode is localized in the vicinity of the defect, whereas higher-order high-frequency modes penetrate through the row of metal rods.

The propagation of microwave in PC is governed by the Maxwell equations. When we use $r' = sr$, we can get $\omega' = \omega/s$. This is scaling law[4]. We can apply this law to design different cavity, after finding the operating point.

We discuss three cases as follows, when missing seven rods in the center.

First, let the rod radius $r = 0.78$ mm and change the metal lattice a. Withdrawing seven rods in the center forms a defect and the cavity is built. The simulation results are shown in Table 1.

It is obvious that operating frequency increases following the decrease of metal lattice a when keeping radius of rod unchanged.

We find the relation between operating frequency and metal lattice (see Fig. 2) fits well to the function

$$f = 33.73\mathrm{e}^{(-\frac{a}{2.55})} + 25.45\mathrm{e}^{(-\frac{a}{1.94})} + 307.04\mathrm{e}^{(-\frac{a}{0.55})}. \quad (1)$$

Second, let metal lattice $a = 2.94$ mm unchanged and change the radius of metal rod r. The simulation results are shown in Table 2.

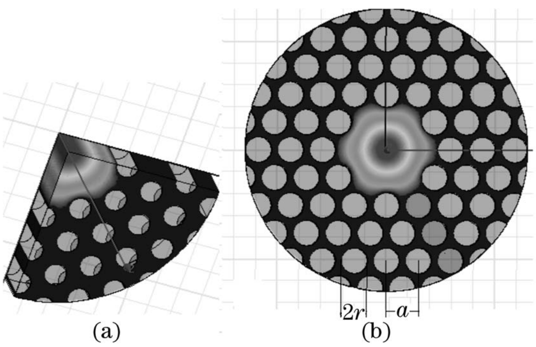

Fig. 1. Photonic band-gap (PBG) cavity geometry used in the HFSS simulations: cavity is formed of metal rod lattice with a defect in the center. The contours of constant E-field are plotted. (a) longitudinal E-field; (b) transverse E-field.

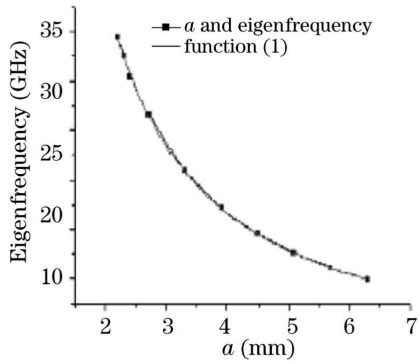

Fig. 2. Eigenfrequency versus metal lattice spacing a.

Table 1. Parameters of the Photonic Crystal Cavity with r= 0.78 mm and Various Values of a

	A	B	C							
Lattice Spacing a (mm)	2.4	2.3	2.2	2.7	3.3	3.9	4.5	5.1	5.7	6.3
Eigenfrequency (GHz)	30.402	32.483	34.396	26.579	20.843	17.123	14.515	12.583	11.108	9.945
r/a	0.325	0.339	0.355	0.289	0.236	0.2	0.173	0.153	0.136	0.124
Normalized Frequency $\omega a/(2\pi c)$	0.243	0.249	0.252	0.239	0.229	0.223	0.217	0.214	0.211	0.209

c is the velocity of light in vacuum, ω is oscillation frequency.

Table 2. Parameters of Photonic Crystal Cavity, with a= 2.94 mm and Various Values of r

	D		E			F				
Radius of Metal Rod r (mm)	1.176	1.020	0.882	0.820	0.730	0.588	0.530	0.440	0.290	0.110
Eigenfrequency (GHz)	26.719	25.574	24.520	24.217	23.636	22.715	22.357	21.787	20.813	19.187
r/a	0.400	0.346	0.300	0.278	0.248	0.200	0.180	0.150	0.099	0.037
Normalized Frequency $\omega a/(2\pi c)$	0.262	0.251	0.240	0.237	0.232	0.226	0.219	0.214	0.204	0.188

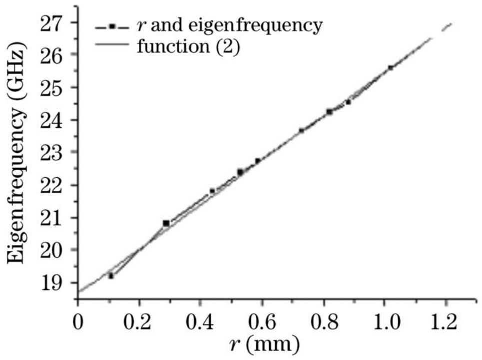

Fig. 3. Eigenfrequency versus radius of metal rod r.

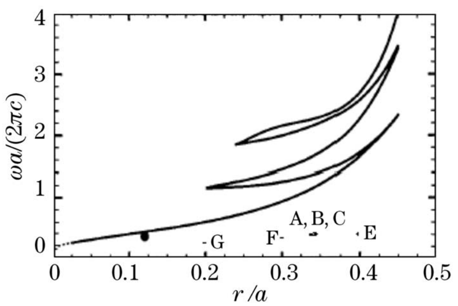

Fig. 4. Plots of global frequency band gap for TM mode as functions of r/a. The solid dots represent the operating point of different cavities.

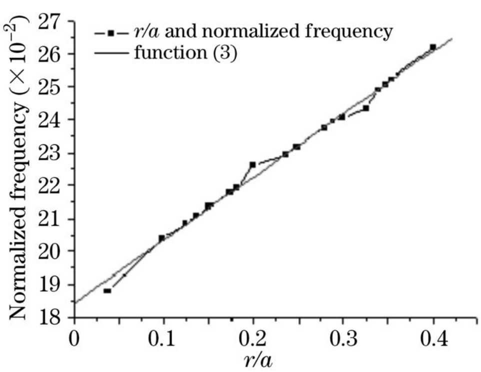

Fig. 5. Plots of normalized frequency versus r/a. The solid curve represents the function (3).

In the x-y coordinates, we plot the all points in table 2. It is obvious that operating frequency increases linearly with rod radius r increasing. The function

$$y = 18.67 + 6.8x, \tag{2}$$

fits very well to them (Fig. 3).

In the same way, we plot operating point of three cavities E, F, and G in the global frequency band gaps[3], as shown in Fig. 4.

Summing up all the simulation results, x coordinate is r/a and y coordinate is normalized frequency $\omega a/2\pi c$, we can plot the graph of operating points (Fig. 5). The curve fits well to function

Table 3. Parameters of Photonic Crystal Cavity Using the Sealing Properties

	G	H	I
Lattice Spacing a (mm)	2.6	3	3.33
Rod Radius r (mm)	0.78	0.9	1
Eigenfrequency (GHz)	27.868	24.134	21.754
Operating Mode	TM_{010}	TM_{010}	TM_{010}
r/a	0.3	0.3	0.3
Normalized Frequency $\omega a/(2\pi c)$	0.2415	0.2413	0.2415

$$y = 0.185 + 0.19x. \tag{3}$$

Utilizing the scaling properties to design different cavity, we get the simulation results as shown in Table 3.

We know that three cavities operate at the same operating point in the global band gap (Fig. 4).

The law can be applied to design different cavity. We change r and keep the same operating point unchanged. Then different cavity can be designed to operate at the same operating point.

In conclusion, we find that operating frequency decreases exponentially as the metal lattice spacing a increases when keeping the value of radius r unchanged. The operating frequency increases linearly as metal lattice is unchanged and radius of rods increases. Normalized frequency increases linearly as r/a increases. In additional, when we find operating point in the global band gap, we utilize the scaling properties to design different operating frequency and different cavity operating at the same operating point. These works are useful to design different cavity formed by photonic crystal.

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