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Influence of Refractive Index by Structure Parameter of Phononic Crystal and Analysis of Focusing Acoustic Field

フォノニック結晶の構造パラメータによる屈折率の変化とレンズの集束場解析

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1. Introduction

The imaging system with acoustic lens have been to develop in the underwater field [1,2]. Authers reported the characteristics of planar and rhomboidal acoustic lens constructed with phononic crystal tructures (PhC) [3,4]. Acoustic lens constructed with PhC has negative refractive index [5]. It was possible to focussing a sound wave when a shape of lens are flat or rhomboid. However, the influence of refractive index by structure parameter of PhC was not clearly. For the designing of a high gain lens, we examinate to the influence of refractive index by structure parameter of PhC. In previous study, we measured the characteristics of negative refractive index at the plate of PhC [6].

In this study, we describe the influence by structure parameters of PhC to a refractive index of the planer acoustic lens constructed with PhC. Furthermore, the influence by structure parameters of phononic crystal to the focusing sound field by planar lens is examined by numerical analysis.

2. Calculation of negative refractive index at PhC

Figure 1 shows the simulation model for calculation of the negative refractive index at the plate of PhC. PhC is configured at triangular lattices constructed with stainless steel rod. The diameter of rod and lattice constant are define d=2r and a as shown in Fig. 1. Layer's number of PhC to the propagation direction z has nine. Number of rod to x-direction is sixty. Pore fluid around stainless steel rods assume the pure water or silicone rubber. Sound velocity and density of water, silicone rubber and stainless steel rods is shown in **Table I.** Sound source array was constructed by point source as shown in Fig. 1. Pitch of array equal to grid side of simulation, such as assume the plane source.

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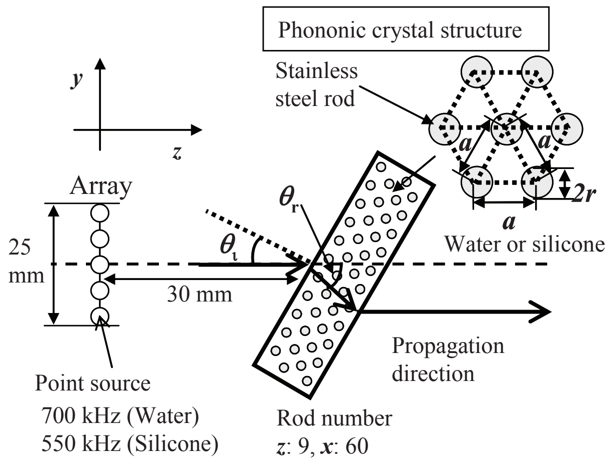

Fig. 1 Simulation model of sound propagation pass-through a PhC structure for obtaining of its negative index.

A plane wave incident to the plate constructed with PhC rotated at the angle at θ_i. The sound wave refract at the angle θ_r in the boundary of first plane of the plate. Transmitted wave in PhC refract at the angle θ_r in the boundary of second plane of plate. Refractive index n of PhC is obtained by eq. (1),

$$n = \frac{\sin\theta_i}{\sin\theta_r} \quad (1)$$

where, θ_r has a negative value. We determine the propagation direction by simulation result to obtain the value of refractive angle θ_r.

Table 1 Acoustic parameter of media composed by PhC.

Parameter	Sound velocity [m/s]		Density
	Longitudinal	Shear	[g/cm^3]
Stainless steel	5780	3200	7.93
Silicone rubber	1000	—	1.3
Water	1500	—	1

3. Simulation results

To obtain the influence by structure parameters of PhC to a refractive index, we simulate sound pressure distribution in z-x plane. **Figures 2** (a) and (b) show the calculation results of sound pressure field at frequency f = 700 kHz when pore fluid around rods is assumed the pure water. It is found that propagation direction of transmitted wave shift to the center axis caused by negative refraction at the PhC. **Figures 3** (a) and (b) show the relationship between diameter of rod d at a PhC structure and its refractive index n. As shown in Fig. 3 (a), refractive index has about -0.55 when incident angle are 10 and 15 degrees. When incident angle is larger than 20 degrees, refractive index has about -0.6. As shown in Fig. 3 (b), when pore fluid around rods assumed the silicone rubber, refractive index has about -0.4. In both cases of Fig. 3 (a) and (b), refractive index do not influence by diameter of rod.

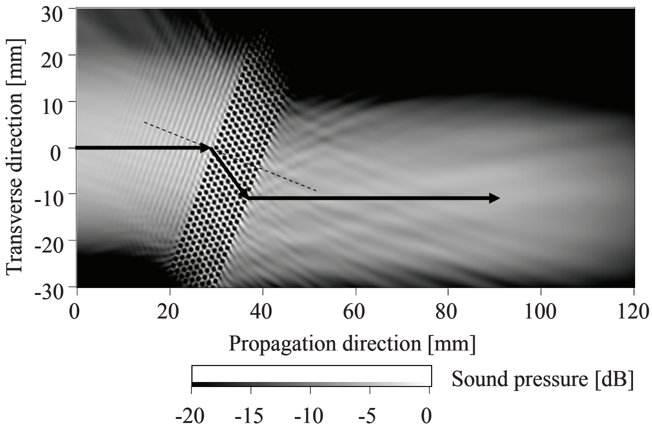

Fig. 2 Calculation results of sound pressure field at frequency f = 700 kHz when pore fluid around rods assumed the pure water.

4. Focusing sound field by planer acoustic lens

The influence by structure parameters of phononic crystal to the focusing sound field at planar lens is examined by numerical analysis. **Figures 4** (a) and (b) shows the sound pressure distribution on the center axis propagation direction z and transverse direction x at focal point when diameter of rod d is changed from 0.8 mm to 1.2 mm. It is clearly shown that the range of focal point and the beam width is slightly influenced by diameter of rod d in PhC.

5. Conclusions

In this study, we calculated the negative refractive index at the plate of PhC. Refractive index is slightly influenced by diameter of rod. And, the influence by structure parameters of phononic crystal to the focusing sound field at planar lens is describe.

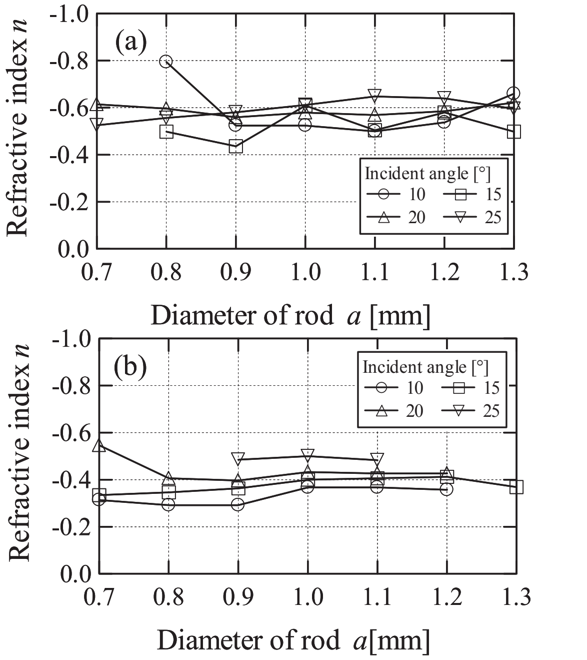

Fig. 3 The relationship between diameter of rod d at a PhC structure and its refractive index n.

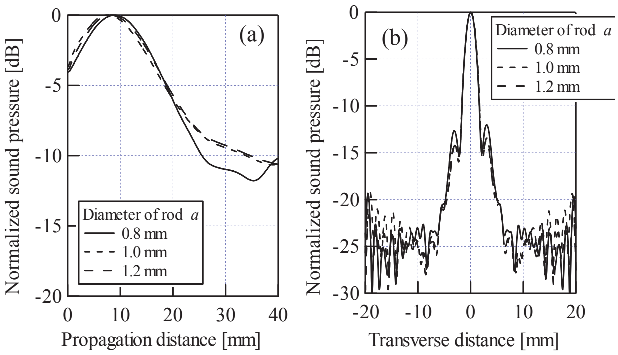

Fig. 4 Sound pressure distribution. (a) is propagation direction z, (b) is transverse direction x at focal point.

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