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Layered Structure of Plural Phononic Crystals
複数のフォノニック結晶からなる層状構造体

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1. Introductions

Phononic crystals have various characteristics, like band gap, group delay, and negative refraction. Among them, we regard the negative refraction. Focused ultrasounds using negative refraction by phononic crystals has been investigated by many researchers[1)]. Acoustical lenses generally have curved surfaces to converge the ultrasound. However, by using negative refraction by phononic crystals, acoustical flat lenses become possible. These acoustical lenses are expected to be utilized in the medical field, underwater acoustics, and so on. In our previous research, we have proposed a layer structured phononic crystal with variable focal length[2)]. In this paper, we pay attention to that the ultrasound with specific incident angles can only propagate with negative refraction in the phononic crystal. With that, the spherical wave is generally used for focusing ultrasound using negative refraction. However, in many cases, we need to converge the plane wave. The plane wave has only a certain incident angle to the phononic crystal. Consequently, it is not so easy to converge the plane wave using negative refraction. Therefore, we propose the layered structure of plural phononic crystals. We design one crystal for expanding the beam of sound, and another for converging the wave and we analyze the structure by FEM.

2. Simulation Conditions

The proposal layered structure and simulation area are shown in **Fig. 1(a)**, we assume that the area of 40×100 (mm^2) is filled with water and the sound source is at origin. The sound source is a 20 mm in width and the driving frequency is 550 kHz. The proposal structure consists of two phononic crystals. Crystal(I) is a square lattice consisting of three layers, and crystal(II) is a rectangular lattice consisting of seven layers. The layers in both crystals are parallel to *x* plane. Crystal(I) works to expand the sound beam from the sound source and the crystal(II) works to converge the sound beam. Crystal (I) and (II) locate at a distance of 8 and 17.5 mm from the sound source, respectively, as shown in Fig. 1(a). The distance between the lattices of two crystals is 6.5 mm. The simulation area is divided by two dimensional triangular elements whose number is about 1,700,000.

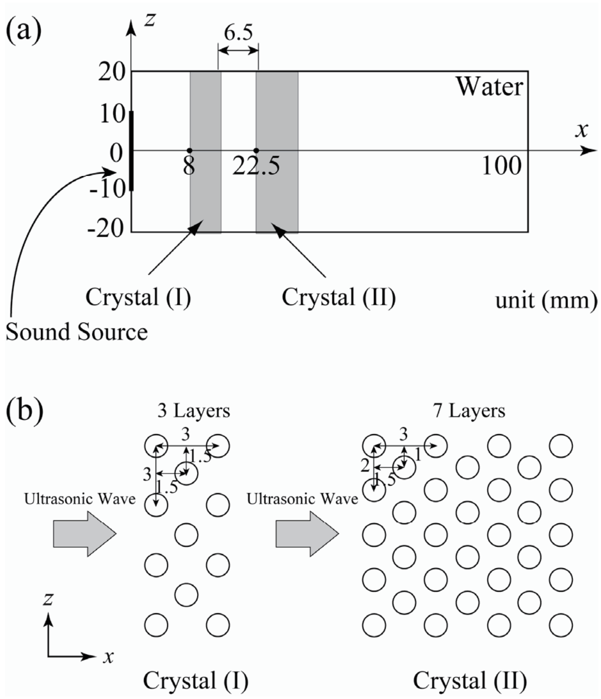

Fig. 1 Proposal layered structure and simulation setup.

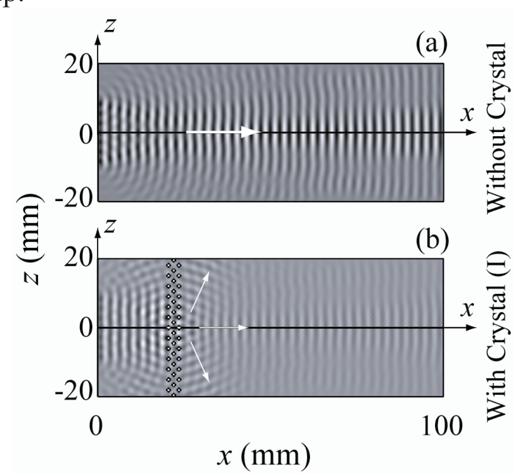

Fig. 2 Ultrasonic propagation in simulation without and with crystal(I).

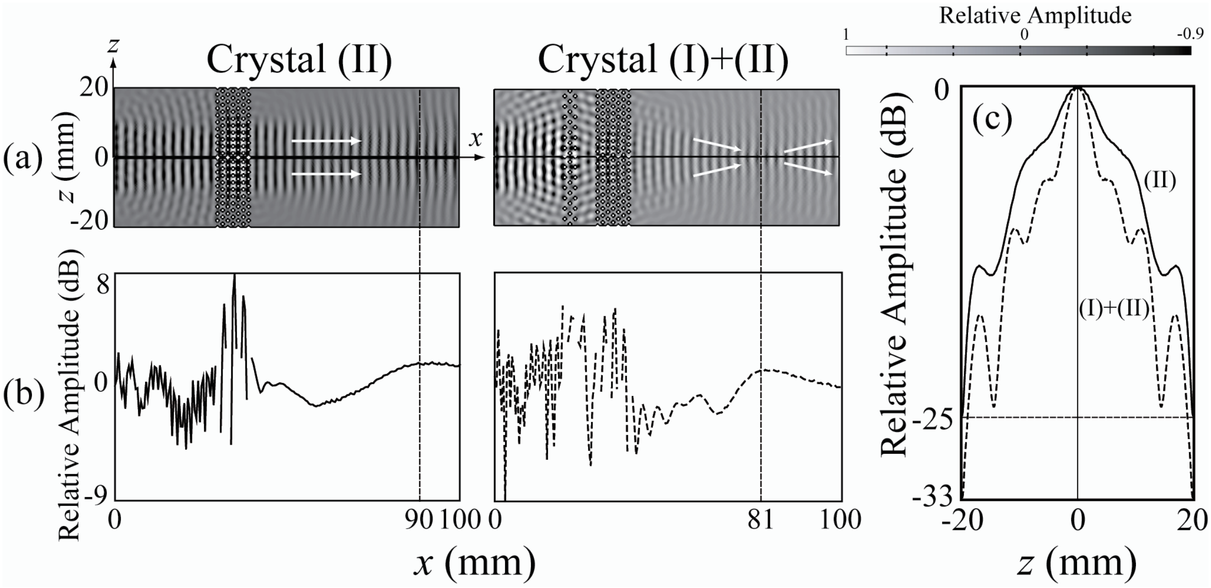

Fig. 3 Ultrasound propagation through the conventional and the proposal phononic crystal.

3. Simulation Results

Figure 2 shows the wave propagation in the case with crystal(II) and the case with crystals (I) and (II). Without crystal(I), the sound wave propagates as a plane wave. With crystal(I), after the sound wave propagates through the crystal(I), the wave is separated into the plural waves with different propagation directions. Next, we show the focused ultrasound by the plane wave in **Fig. 3**. Brightness indicates the relative amplitude of sound pressure in Fig. 3(a). Crystal(II) is the structure for converging the wave by negative refraction at least when the incident wave is spherical. However, when the incident wave is the plane wave in the case indicated as "Crystal (II)", the transmitted wave hardly converges. In contrast, in the case with layered crystal (I), indicated as "Crystal (I) and (II)", the convergence becomes more distinct. The sound pressure levels on x axis are plotted in Fig. 3(b), and the sound pressure levels at each focal plane are plotted in Fig. 3(c). In the case without the crystal (I), we can verify that the peak at focal point is not so distinct. This reason why slight convergence is observed is originated from the scattering waves generated at the surface of crystal(II), which not flat. Thus, a part of the scattering waves propagates in the crystal(II) with negative refraction. In the case with crystal(I), the focal point was at 81 mm from the sound source. We can verify that the plane wave converges well in the case with crystal(I)＋(II) in comparison with the case with crystal(II) only. However, the focusing of the sound waves is still not good in comparison with the conventional case using the spherical wave. This is because the waves propagated through crystal(I) may not have the proper incident angle for the negative refraction of crystal(II). Therefore, theoretical investigations about the proper incident angle for the negative refraction of crystal(II) are required. The structure for expanding the beam is designed to have the proper incident angle to the crystal(II). However, in this research, we can show the possibility of the focused ultrasound to the plane wave.

3. Conclusions

In this paper, we aim to design the structure for converging the plane wave with plural phononic crystals. A structure of a crystal is adopted to expand the beam of the plane wave in addition to the crystal for converging the wave. The convergence by the proposed structure is analyzed by FEM. As results, we confirmed that the plane wave can be converged using proposal structure, while the convergence is hardly observed in the structure with only conventional phononic crystal. However, we have a problem that the wave propagated through the crystal for expanding the beam may not have the proper incident angle for negative refraction of the phononic crystal. As future works, more detailed investigation of the structure for expanding the beam of sound wave is planned.

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References

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