Realization of hyper acoustic transmission through a subwavelength hole using membrane

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Abstract

We present the first experimental realization of extraordinary acoustic transmission through a subwavelength hole using membrane resonator which has high quality factor. Our transmission efficiency normalized to the aperture area is 57times larger than the impinging at a hole opening, which is strongly enhanced result than previous studies. The key role played by membrane resonance in transferring sound efficiently from the input to the output region is presented. This knowledge is opening up exciting new opportunities in applications ranging from subwavelength acoustics to chemical sensing and biophysics.

1. Introduction

Wave phenomena shows through disparate physical realizations [1] that ranges from the nature of sound to the electromagnetic(EM) wave, for example, waveguide, diffraction, tsunami, scattering and Doppler effect. Among them, the discovery of the extraordinary optical transmission (EOT) through a lattice of subwavelength holes on a metallic film has opened a new research by Ebbesen [2]. EOT means that the light transmission can be enhanced than the area fraction of the holes.

Here, we consider how these ideas extended to electromagnetic waves can be transferred to the acoustic waves. In the case of acoustic waves, complete transmission through subwavelength aperture arrays was firstly suggested in [3,4] and fabricated for a 1D grating with narrow apertures case [5] and 2D case of Fabry-Perot resonances in [6]. Differently with the cases as mentioned above, we fabricated novel extraordinary acoustic transmission (EAT). This system is just based on aperture-factor-related resonances, because of that reason our experimental structure could be simpler than the others. In our experiment, the most important part is membrane resonator (MR), which could be a new seed for EAT.

2. Experiments and Results

In the experimental set-up shown in Fig.1, $4m$ long PVC tube was sandwiched by a sound source and an absorber. The sound source was a speaker (SE-F8100, Tech Sound) driven by an arbitrary function generator (33220A, Agilent), and the detector was a miniature condenser type microphone (MS-9600, Neosonic) inserted into the tube.

Pressure amplitudes from the tube were measured by moving the microphone. This way, the wave profile in term of the pressure as function of time and position, $p = p(z, t)$ was obtained. The PVC tube was terminated by the absorber at the right end. The absorber absorbed most of the incoming wave and allowed only small reflection, so that the acoustic wave propagating in the PVC tube behaved as if it

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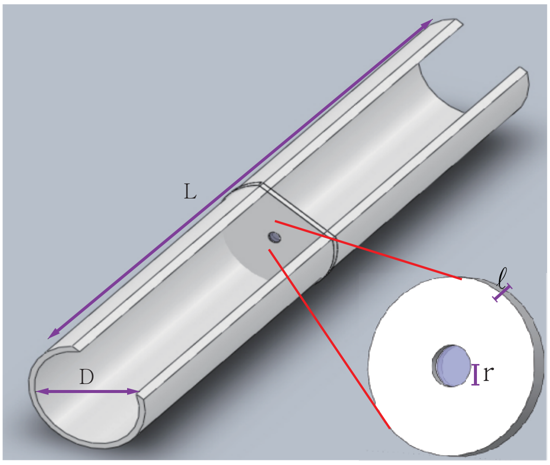

Fig. 1: (Color online) Schematic diagram of a cutoff view of experimental set up for transmission measurement. An impedance tube with radius R and length L has a slit perforated on a rigid body of thickness ℓ in the middle of tube. The hole in the slit has a radius a with a membrane resonator.

extended to infinity. The method for our absorbing was originated from impedance matching, which the size of absorber was calculated. it was 1.6times larger than the cross section of PVC tube. The reflection between the PVC tube and absorber boundary was negligible.

We first consider audio frequency range transmission through a rigid plate of thickness $\ell = 0.5cm$, inserted in PVC tube. A circular hole with radius $r = 1cm$ was milled on the circular plate with diameter $D = 20cm$. The hole was composted with membrane. A schematic picture is shown Fig. 1. From the experimental structure, very thin elastic membrane is a kind of resonator system which shows same physical characteristic such as SHO and the Helmholtz resonator. In the dynamics concept, the air in front of the membrane act like a mass and membrane is similar with spring. With this factors resonance frequency of membrane is given by [7],

$$\omega_0 = \sqrt{\frac{8\pi\tau}{r^2 d'\pi\rho_0 + M}}, \tag{1}$$

Where τ is tension per unit length, r is radius of membrane, ρ_0 is the density of air, d' is effective length and M is the weight of membrane. Our membrane resonator has high quality factor (Q-factor) that is the most important peculiarity for resonators. Transmission efficiency is dependent on the Q-factor, that means when the resonator has high quality factor, transmission efficiency is enhanced due to low energy loss of resonator.

The audio frequency was normally incident upon the sample and the transmitted amplitude was collected by the receiver, collinear with the incident wave. The audio frequency transmission measurements in the regime of 450 - 800 Hz were done in air. For control experiment, we did additional observation installed the subwavelength hole plate without membrane. Hole without membrane is same as an orifice structure which transmittance is dependent on incident wave length.

The results of the normalized to area intensity reflection coefficient and transmission coefficient measurement are shown in Fig.2. Intensity of reflectance per cross-section area shows averagely 85% when a hole smaller than sound wavelength exists. With MR, however, intensity becomes 1.2% at resonance frequency 635 Hz. The result predicts that sound wave transmit very well through the hole with membrane. As shown in Fig. 2b, intensity of transmittance per cross-section area is 57times at resonance frequency. This data means better transmittance than others.

Here, we can indicate the energy loss between reflectance and transmittance, which is base on the dissipation made by MR. Because of the strong motion of MR at resonance frequency, the transmission loss is existed. Although there is a transmission loss, the hole with membrane resonator shows magnificent transmittance which explain the important role of MR at extraordinary transmission.

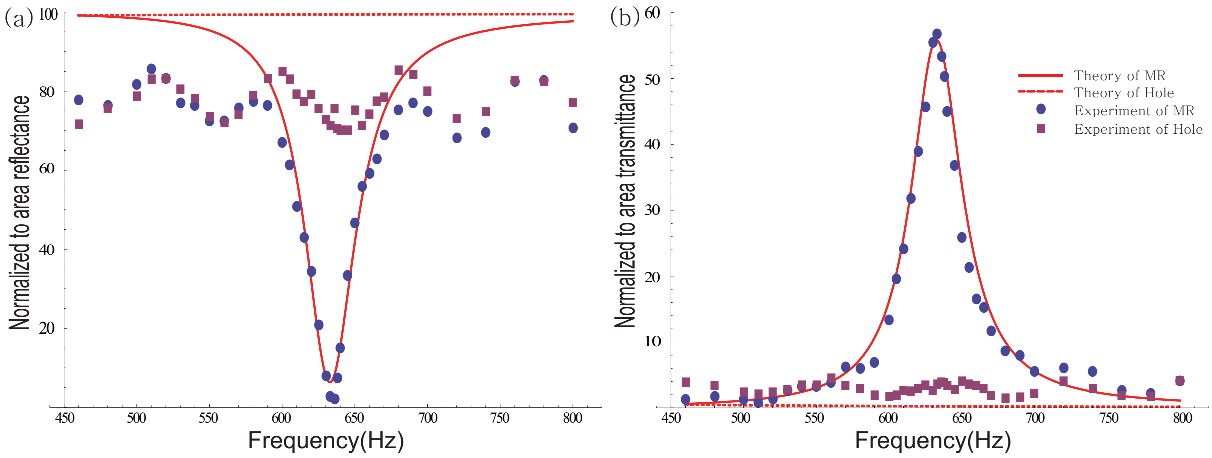

Fig. 2: (Color online) The frequency dependence of reflectance and transmittance data. The solid and dashed lines are theoretical lines of MR and a hole. The measured data are expressed as circular dots for MR and the square dots for a hole. (a) The normalized to area reflectance data between source and slit. (b) The normalized to area transmittance data between slit and absorber.

4. Conclusion

In conclusion, we present the first experimental realization of extraordinary acoustical transmission using membrane resonator which has high quality factor. The presence of membrane resonator leads to a wide variety of unexpected acoustic properties such as strongly enhanced transmission of acoustic through the hole and concentration of acoustic energy. It is great structure inserted membrane resonator for energy transmission while blocking the air flow. This knowledge is opening up exciting new opportunities in applications ranging from subwavelength acoustics to chemical sensing and biophysics. It shows novel result for wave and material physics. With great possibilities, EAT using membrane resonator can give a new way of energy and information transferring techniques.

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