Extraordinary absorption of sound in porous lamella-crystals

SUPPLEMENTARY INFORMATION

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Transfer function method (TFM) for the measurement of the reflection coefficient.

In order to experimentally characterize the reflectance and absorption of the porous lamella-crystal, we adapt the transfer function method (TFM), conventionally used in impedance tubes, to be directly applied in the anechoic chamber. We verify the use of the TFM in the anechoic chamber and select a specific range of frequencies to be compared to measurements in the impedance tube. The transfer function method used for measuring in-duct acoustic properties of materials is a well-known method for the determination of the absorption and acoustic impedances [1,2]. Using this method, the complex reflection coefficient reads as follows

$$r(\omega) = \frac{H_{12} - H_1}{H_2 - H_{12}} e^{\imath 2 k_0 l}, \tag{1}$$

where k_0 is the wave number in air and l is the distance from the last microphone position to the sample as shown in Fig. 1a. The acoustic transfer functions expressed in Eq.(1) are

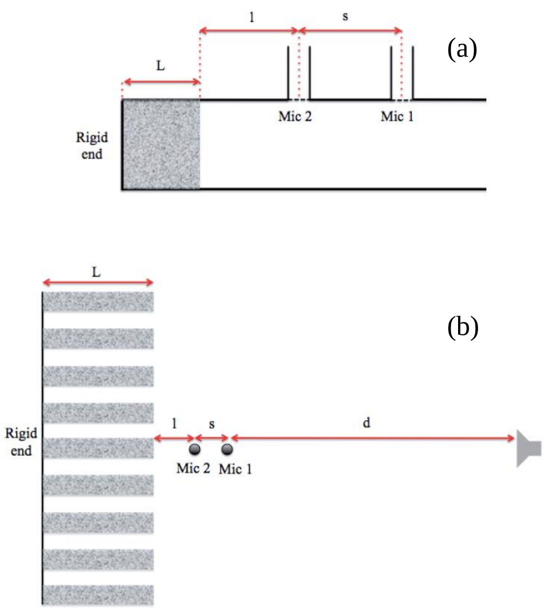

FIG. 1: Sketch for the TFM in the (a) impedance tube and (b) applied in the anechoic chamber.

written as

$$\begin{aligned} H_1 = & \ e^{-\imath k_0 s} \\ H_2 = & \ e^{\imath k_0 s} \\ H_{12} = & \ \frac{p_1 e^{\imath \theta_1}}{p_2 e^{\imath \theta_2}}, \end{aligned} \quad (2)$$

where p_i and θ_i are the amplitude and the phase respectively measured at the position i, following the scheme shown in Fig. 1a. The absorbing material is placed at the end of the tube and supported by a rigid back which leads to the simple expression for the absorption $A = 1 - |r(\omega)|^2$. This method is widely used in acoustics to characterize bulk absorbing materials. Since the lamella-crystal cannot be scaled to fit inside the impedance tube, we adapt the TFM to be used in the anechoic chamber to characterize the absorption properties of the crystal. The experimental set-up for the adapted method is illustrated in Fig. 1b. Notice that the distribution of the elements is the same as in the case of the impedance tube (Fig. 1a), hence, to ensure plane wave generation, the distance between the source and the first microphone should be long enough for the range of frequencies analysed. Moreover, to avoid the finite size effects of the sample, the distance l between the sample and the second microphone should be sufficiently small. Notice also that the periodic crystal is mounted onto a rigid end. This rigid end is a wood panel, which is characterized in the next section.

Comparing bulk measurements in the anechoic chamber and impedance tubes.

The porous lamella-crystal studied in this work is made out of sheets of a homogeneous foam, consisting of a mixture of polyurethane, polyester and polyether, compacted and compressed. The exact prediction of the effective density and dynamic modulus of the saturating fluids in real porous materials is generally rather difficult because of the very complicated pore geometries. However, in the case where the foam is considered as a porous material saturated with a Newtonian fluid that is incompressible on the scale of the pore size, several models are readily available to determine effective acoustic parameters used for the complex scattering coefficients [3]. Fig. 2a plots the reflectance $|r(\omega)|^2$ and the absorption A of a sample of foam of length $L = 4$ cm measured in the impedance tube using the TFM and predicted theoretically. The discrepancies at high frequency appear when

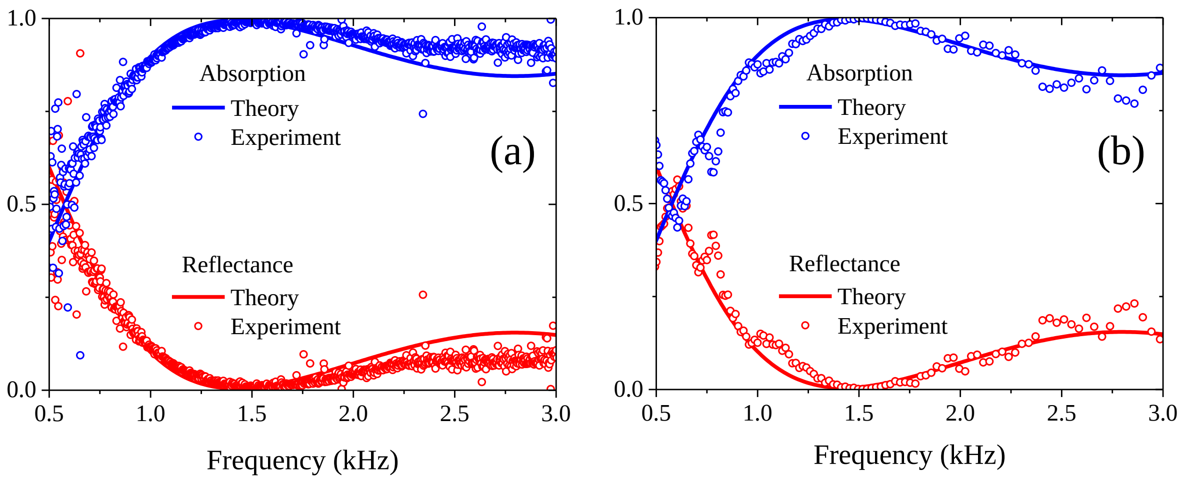

FIG. 2: Theoretical and experimental acoustic characterization of a sample of foam with length $L = 4$ cm. We present simulations and measurements obtained by the TFM in the impedance tube (a) and in the anechoic chamber (b).

approaching the cut-off of the tube. Beyond this, based on the same technique, we also conducted measurements in the anechoic chamber of a foam sheet of 1 m^2 and with a length $L = 4$ cm. This sheet is placed over the rigid end following the scheme of Fig. 1b. In Fig. 2b we plot the reflectance and absorption which are comparable with the corresponding results obtained in the impedance tube. With this comparison we have validated the feasibility of the TFM in the anechoic chamber over a selected range of frequencies. Due to the absence of a cut-off when applying the TFM in the anechoic chamber as opposed to the impedance tube, measurements for the lamella-crystal can be undertaken for an extended range of working frequencies.

We also characterize the wood panel used as a rigid support in the experimental set-ups. Frequency independent full reflectance such as zero absorption for sound irradiating the panel validate the assumption of a wood backing, behaving as a perfect rigid body as seen in Fig. 3a. Additionally, as expected, we observe no spectral phase contributions (evaluated

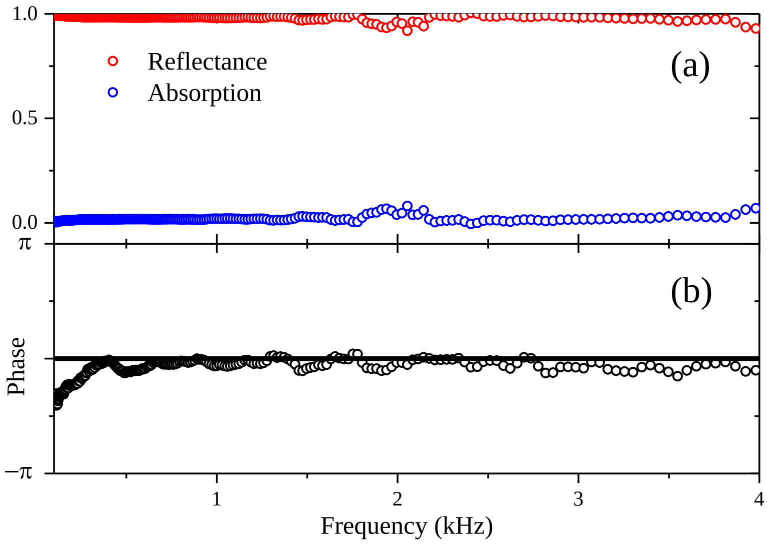

FIG. 3: Reference measurements of the rigid end. (a) Experimental data of the reflectance $|r(\omega)|^2$ and the absorption A. (b) Theoretical (continuous line) and experimental (open circles) evaluation of the phase of the complex reflection coefficient.

from the complex reflection coefficient) taking place when waves are fully reflected at the panel, Fig. 3b.

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