Enhancement of sound absorption by periodic partitions embedded in a hard-backed porous layer

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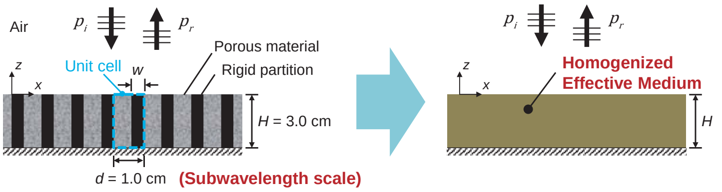
Abstract

Porous materials are widely used in acoustic systems for noise reduction but their acoustic performance is prominent mainly in a high-frequency region. There were many earlier efforts to increase the performance over a broad frequency range, including multi-layering and shaping of porous materials and periodic insertion of rigid inclusions in a porous layer. In this work, an alternative strategy to locate periodic rigid partitions inside a hard-backed porous layer is proposed for sound absorption enhancement. The proposed porous layer system is shown to enhance sound absorption capability considerably over a wide range of frequency and the physics behind new peaks appearing in the sound absorption curve will be also discussed. The geometric influence of the periodic rigid partitions on the absorption performance is also investigated, especially at thickness resonant frequencies.

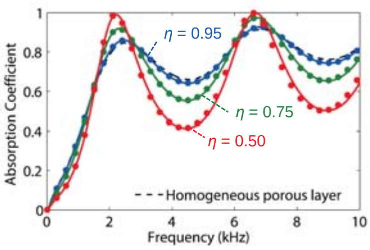
1. Influence of partitions embedded in a porous layer



Material properties of

- Rigid-framed porous material: ρ_1, κ_1 (Johnson-Champoux-Allard model)
- Rigid material: $\rho_2, \kappa_2 \to \infty$

Porosity $\phi = 0.95$
Tortuosity $\alpha_\infty = 1.42$
Viscous characteristic length $\Lambda = 180\ \mu m$
Thermal characteristic length $\Lambda' = 360\ \mu m$
Static airflow viscosity $\sigma = 8900\ N \cdot s \cdot m^{-4}$



Effective density $\rho_{e,x} = \infty,\ \rho_{e,z} = \rho_1/\eta$

Effective bulk modulus $\kappa_e = \kappa_1/\eta$

Effective surface impedance

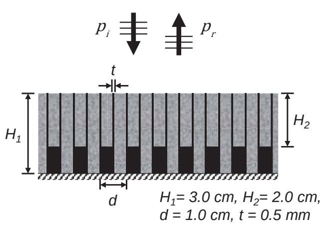
$$Z_e^s = -j\frac{\rho_1 c_1}{\eta}\cot(k_1 H)$$

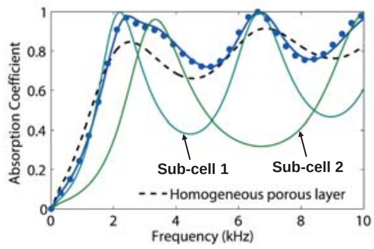
$$\eta = 1 - \frac{w}{d}$$ (Volume fraction of porous material in a unit cell)

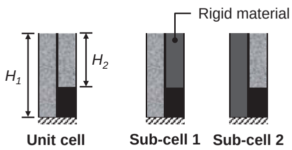
Absorption capabilities are considerably enhanced at thickness-resonant frequencies

→ **Could it be applied to broadband sound absorption?**

2. Parallel array of partitions







$$(\eta' = 1 - \frac{(t+d/2)}{d} = 0.45)$$

Effective surface impedance of each sub-cell

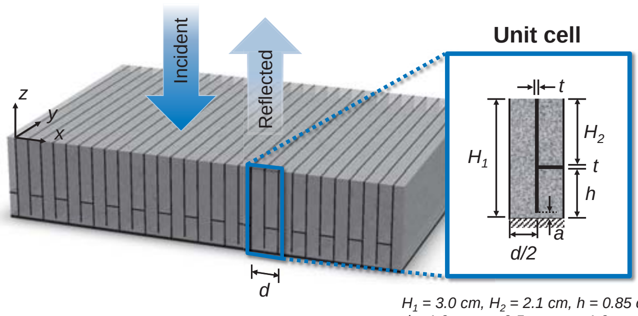
$$Z_{SC1}^s = -j\frac{\rho_1 c_1}{\eta'}\cot(k_1 H_1)$$

$$Z_{SC2}^s = -j\frac{\rho_1 c_1}{\eta'}\cot(k_1 H_2)$$

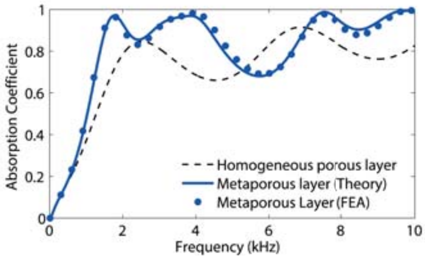
Total eff. surface impedance

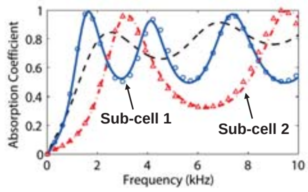
$$\frac{1}{Z_e^s} = \frac{1}{Z_{SC1}^s} + \frac{1}{Z_{SC2}^s}$$

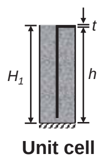
3. Effective thickness elongation for low frequency

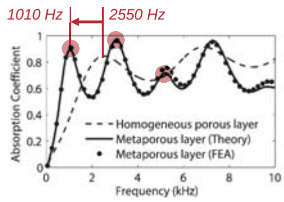


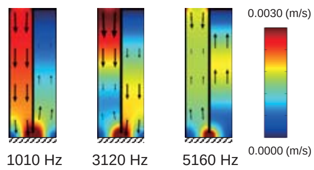
H_1 = 3.0 cm, H_2 = 2.1 cm, h = 0.85 cm, d = 1.0 cm, t = 0.5 mm, a = 1.0 mm

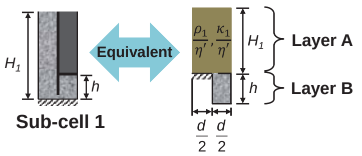












Eff. surface impedance of sub-cell 1

$$Z_{SC1}^s = z_A\frac{Z_B^s\cot(k_1 H_1) + jz_A}{jZ_B^s + z_A\cot(k_1 H_1)}$$

Layer A: Effective medium

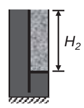
$$z_A = \rho_1 c_1/\eta'$$

Layer B: Porous chamber

$$Z_B^s = \frac{j}{\eta'}[\omega m - \rho_1 c_1 \cot(k_1 h)]$$

$$m = \frac{\rho_1}{a}\frac{d}{2}(t + 2\delta a),$$

δ: end correction factor

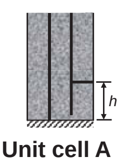


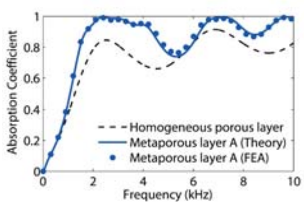
Eff. surface impedance of sub-cell 2

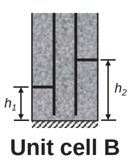
$$Z_{SC2}^s = -j\frac{\rho_1 c_1}{\eta'}\cot(k_1 H_2)$$

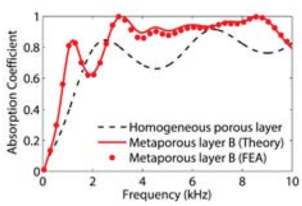
$$(\eta' = 1 - \frac{(t+d/2)}{d} = 0.45)$$

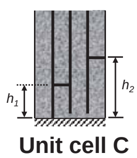
4. Various configurations for broadband sound absorption enhancement within limited thickness

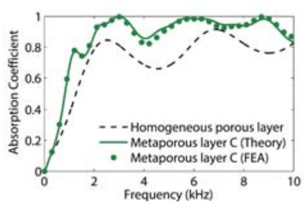












This work was supported by Samsung Research Funding Center of Samsung Electronics under Project Number SRFC-MA1401-06.