INTRODUCTION

Applicant: Zibo Liu

My Tattoos

Born:
Shijiazhuang

1989-2007

Bachelor:
BIT, Beijing

2007-2011

Master:
NUDT, Changsha

2011-2014

PhD:
KTH, Stockholm

2014-2019

Research engineer:

- **Yiduo Co. Ltd.**
- **Tongji University**
- **SYSU**
- **Tsinghua…**

2019-2021

Next step: Postdoc at …

2021-?

Background and experiences:

- **Acoustic metamaterials, smart structure design and application;**
- **Sound insulation and absorption/NVH control;**
- **Acoustic/elastic waves;**
- **Tribology**

DESIGN OF METAMATERIAL PANELS: BACKGROUND

Turbine noise

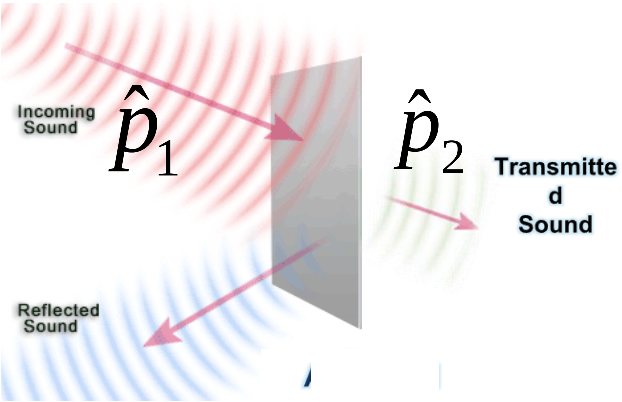
Fan noise

- Lightweight
- Bad insulation in particular frequency regions
- Limitations in traditional method

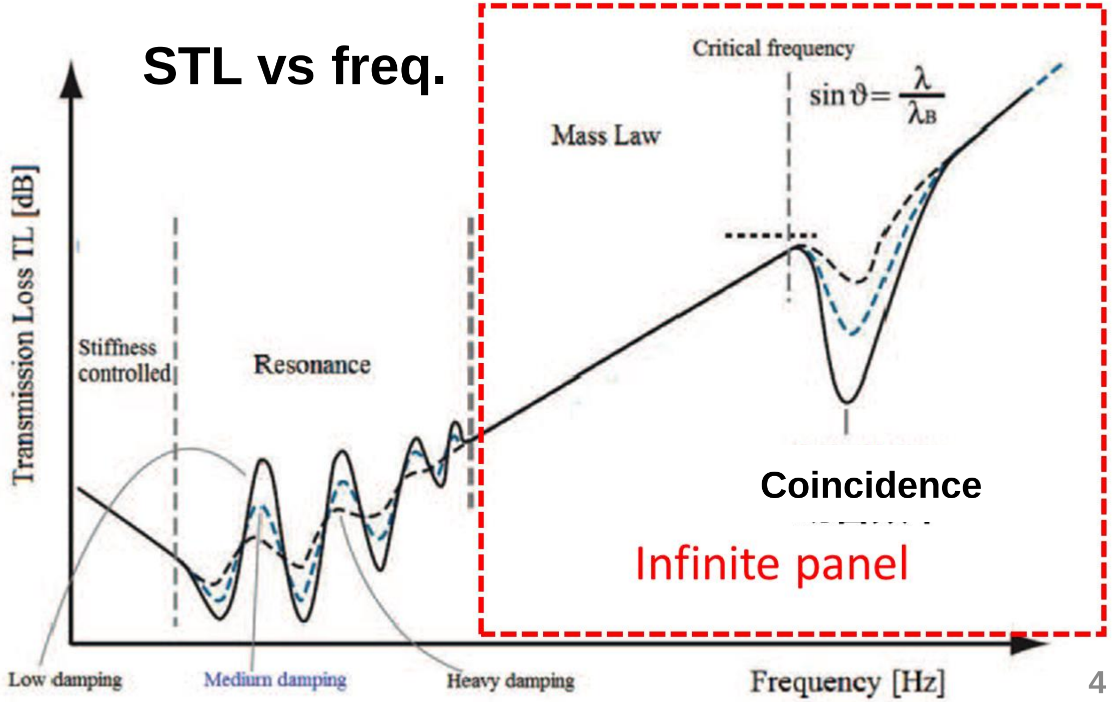
New treatment desired to improve the sound insulation properties of different types of panels

Environmental noise

Depiction of sound transmission

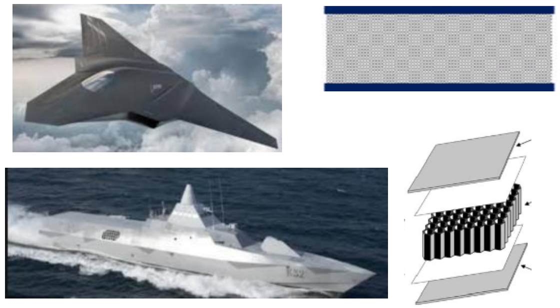


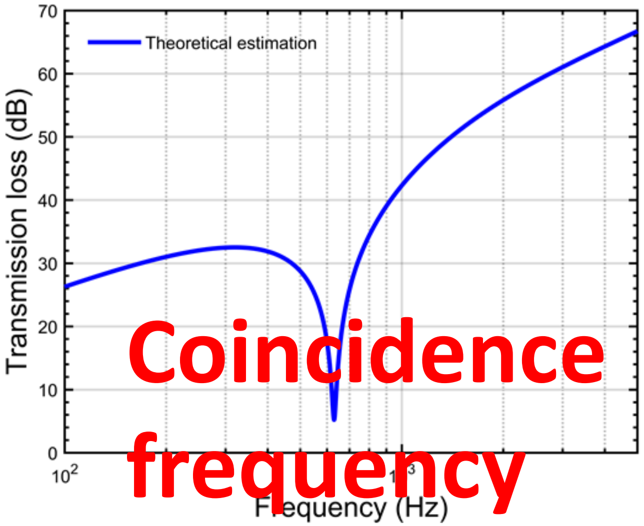
STL vs freq.



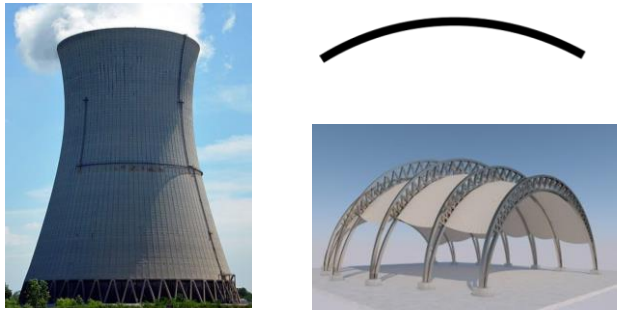
DESIGN OF METAMATERIAL PANELS: BACKGROUND

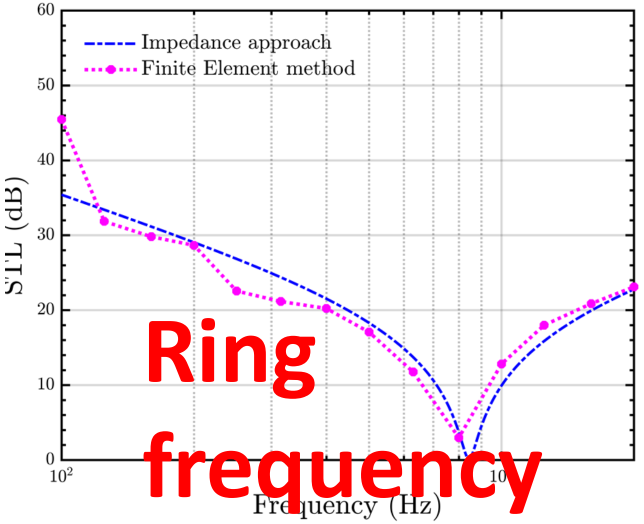
Sandwich structures



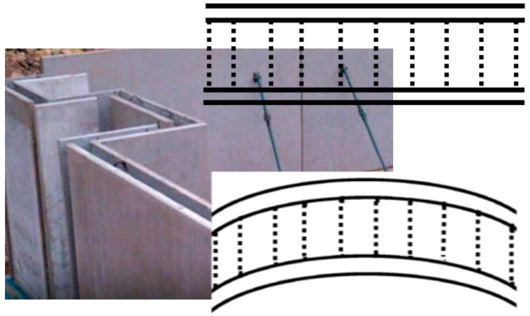


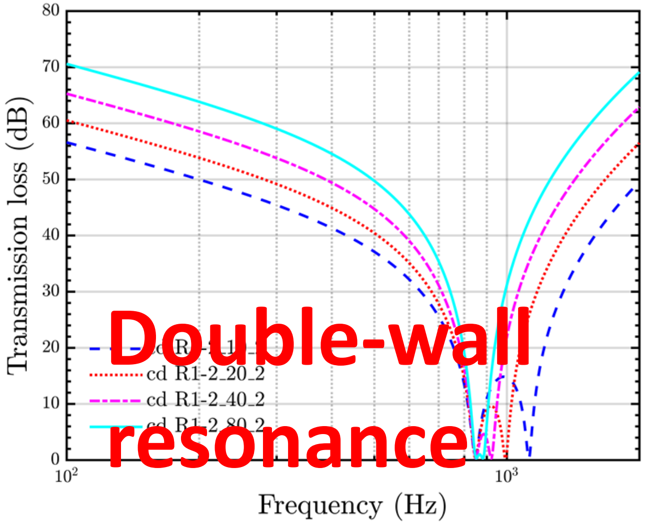
Cylindrical shells





Double walls





NEEDS:

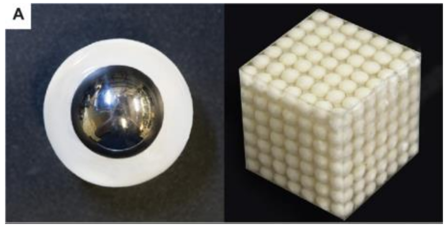
To improve

- Coincidence for sandwiches
- Ring frequency for shells
- Double-wall resonance

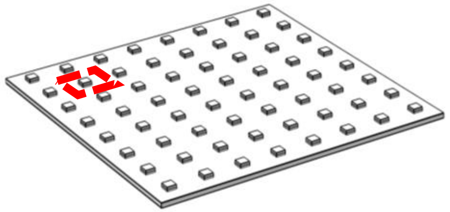
DESIGN OF METAMATERIAL PANELS: SCIENTIFIC PROBLEM

- **Acoustic metamaterials (AM)**
  - **Nontrivial behaviour**
  - **Limited working frequency region**
- **Locally resonant AM**
  - **Host panel**
  - **Resonators**

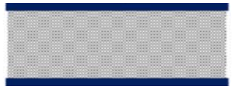
Locally resonant AM



AM panel

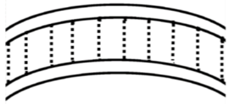


Sandwich



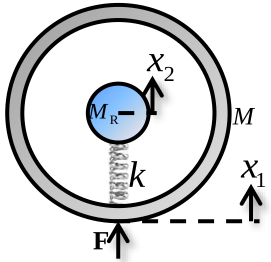
Shell

Double wall



- **Unexpected results**
- **Limited working frequency region**

Resonators

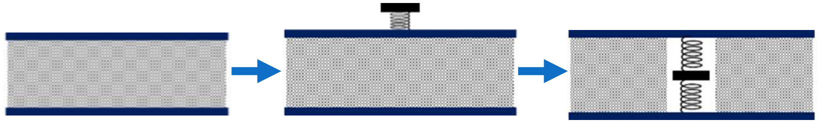
\+ 

= ?

- **Investigate the physical insights;**
- **Explore the potential ways to improve the sound insulation behavior in the relevant specific frequency regions.**

Design of metamaterial panels: Metamaterial sandwich

Metamaterial sandwich with embedded resonators:

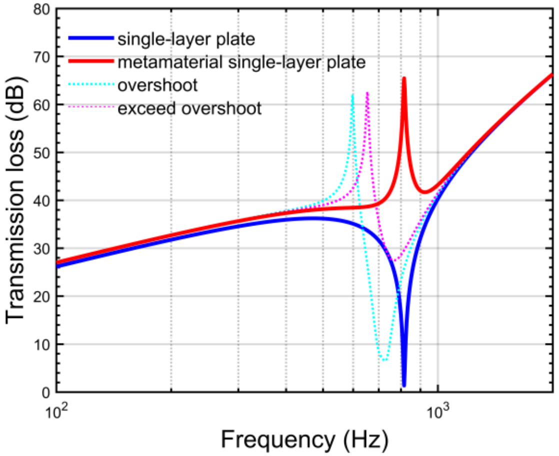


- A systematic tuning criterion

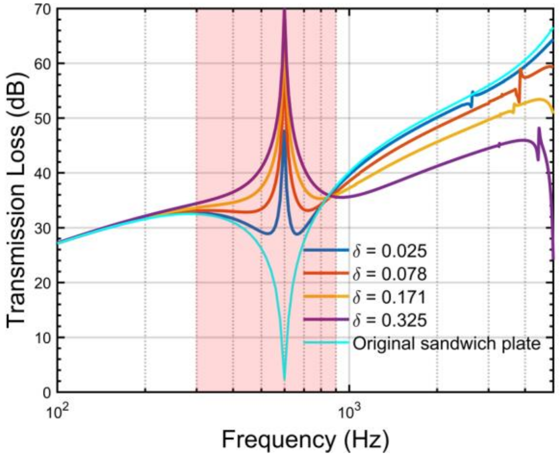
$$f_{co}\left(\sqrt{1+\frac{\delta}{2}}-\sqrt{\frac{\delta}{2}}\right) \le f_{res} \le f_{co}\left(\sqrt{1+\frac{\delta}{2}}+\sqrt{\frac{\delta}{2}}\right)$$

- where δ is the ratio of the resonator to the host panel $\delta = \frac{m_r}{m}$

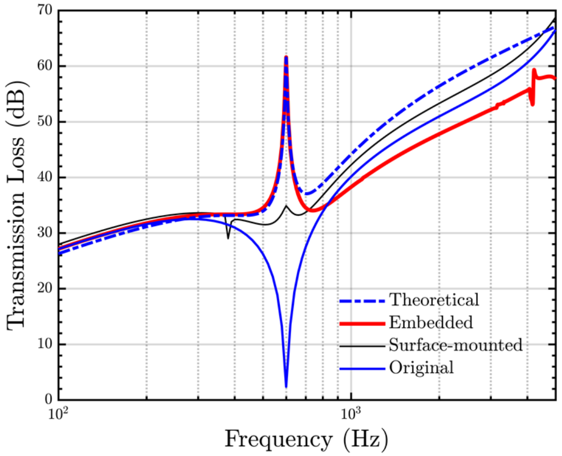
- Working frequency range: $\sim \sqrt{\delta}$



Overcome the coincidence effect



Broaden the working frequency range



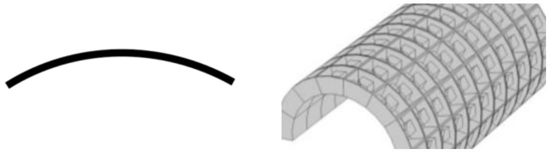
Suppress the radiation from the resonators

Advantages:

- Coincidence effect
- Radiation from the resonators
- Working frequency range
- Practicability

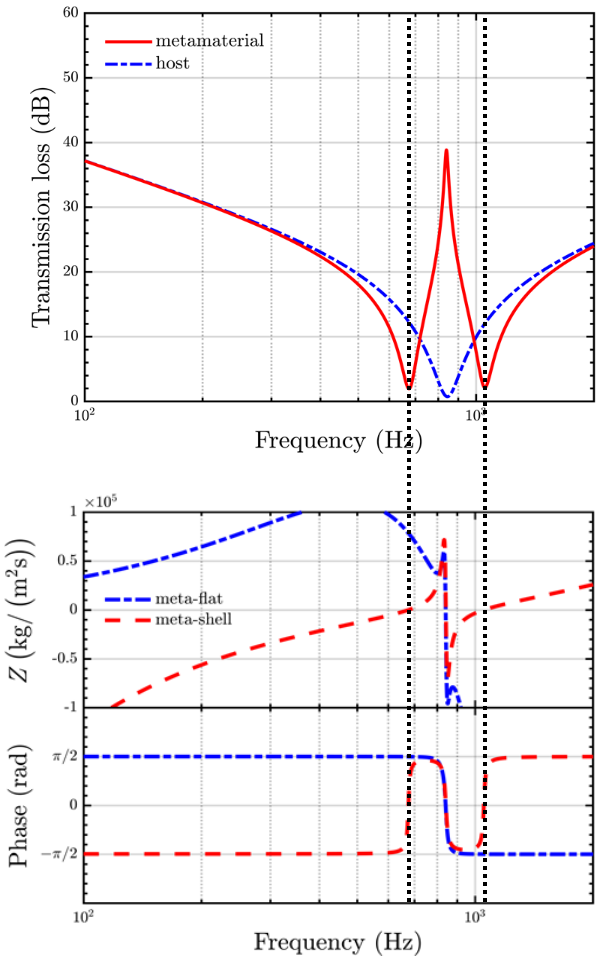
DESIGN OF METAMATERIAL PANELS: METAMATERIAL SHELL

Metamaterial cylindrical shell

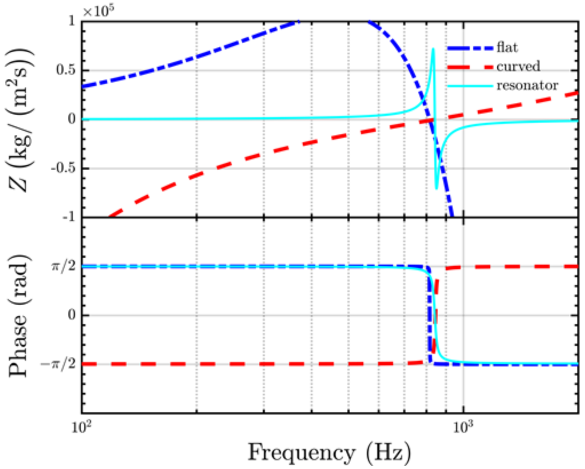


Tuning conventional resonators to the ring frequency of curved panels generates two side dips despite a sharp improvement.

Z	Resonator	Flat	Shell
Below the freq.	+	+	-
Above the freq.	-	-	+



The ‘side effects’ from the resonators



Physical insights: Phase change

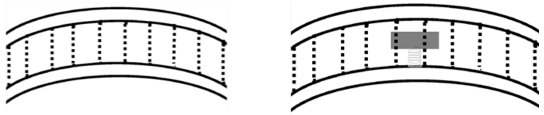
Resonators: mass- to stiffness-controlled

Shell at ring: stiffness- to mass-controlled

- **Effective impedance approach;**
- **Allow for the design of suitable resonators to resolve the ring frequency effect.**

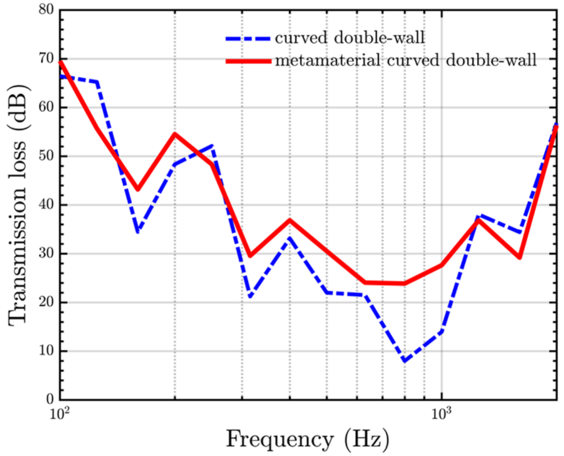
DESIGN OF METAMATERIAL PANELS: METAMATERIAL CURVED DOUBLE WALL

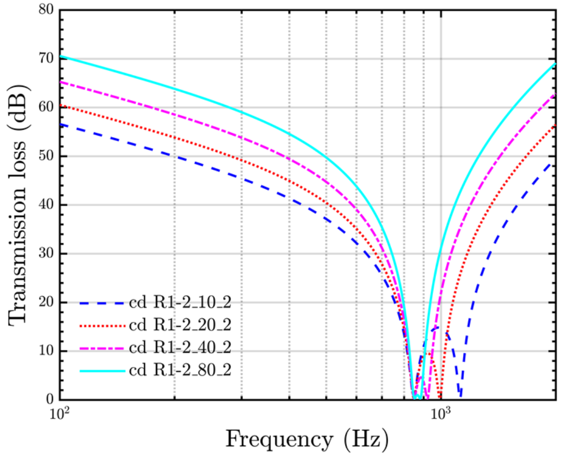
Curved double wall



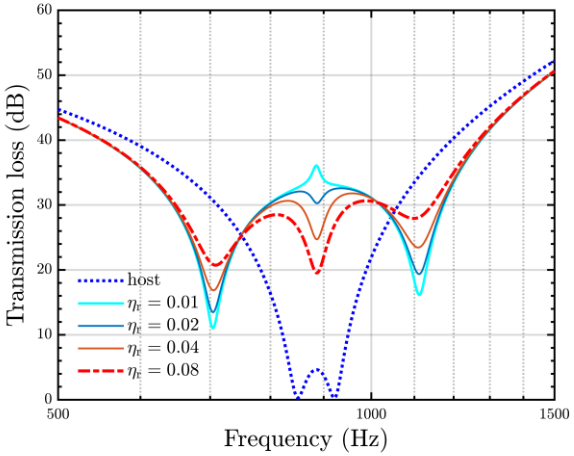
'Apparent Impedance' formula

$$Z^{\mathrm{cd}} = Z_1^{\mathrm{c}} + Z_2^{\mathrm{c}} + \frac{\mathrm{j}\omega}{s}\left(Z_1^{\mathrm{c}} + Z_{\mathrm{a}}\right)\left(Z_2^{\mathrm{c}} + Z_{\mathrm{a}}\right)$$





Step 1. Design of the host panel: narrowed 'valley'



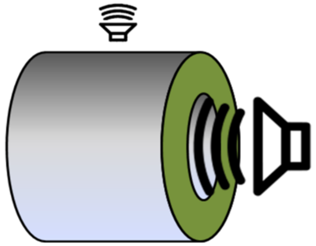
Step 2. Mounted with damped resonators

- **Apparent impedance approach introduced, validated against the Finite Element method.**
- **Improvement of sound transmission loss performance around characteristic frequencies.**

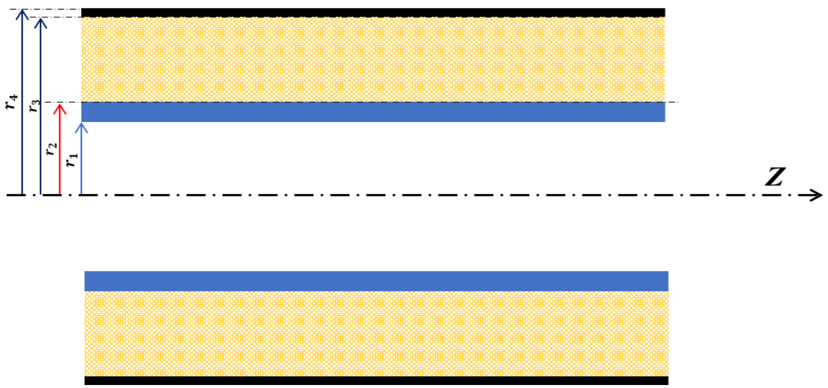
NVH-RELATED PROJECT

NOISE CONTROL OF THE PIPELINE FOR NUCLEAR POWER PLANT

Pipeline w/o jacket



Pipeline with jacket



Theoretical model:

$$p = [AJ_0(k_{rp}r) + BN_0(k_{rp}r)]e^{-jk_z z}e^{j\omega t} \quad (1)$$

$$u_r = \frac{k_{rp}}{jZ_p k_p}[AJ_1(k_{rp}r) + BN_1(k_{rp}r)]e^{-jk_z z}e^{j\omega t} \quad (2)$$

$$\boxed{Z_p} = \rho_0 c_0 \left(1 - j\frac{r_p}{\omega\rho_0}\right)^{1/2} \quad (3)$$

Impedance

$$k_p = k\left(1 - j\frac{r_p}{\omega\rho_0}\right)^{1/2} \quad (4)$$

$$\begin{bmatrix} p_2 \\ u_{r2} \end{bmatrix} = \frac{X}{det}\begin{bmatrix} J_{13}N_{02} - J_{02}N_{13} & \frac{1}{X}(J_{03}N_{02} - J_{02}N_{03}) \\ X(J_{12}N_{13} - J_{13}N_{12}) & J_{12}N_{03} - J_{03}N_{12} \end{bmatrix}\begin{bmatrix} p_3 \\ u_{r3} \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} p_1 \\ u_{r1} \end{bmatrix} = \begin{bmatrix} 1 & Z_{12} \\ 0 & 1 \end{bmatrix}\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix}\begin{bmatrix} 1 & Z_{34} \\ 0 & 1 \end{bmatrix}\begin{bmatrix} p_4 \\ u_{r4} \end{bmatrix} \quad (6)$$

Transfer Matrix

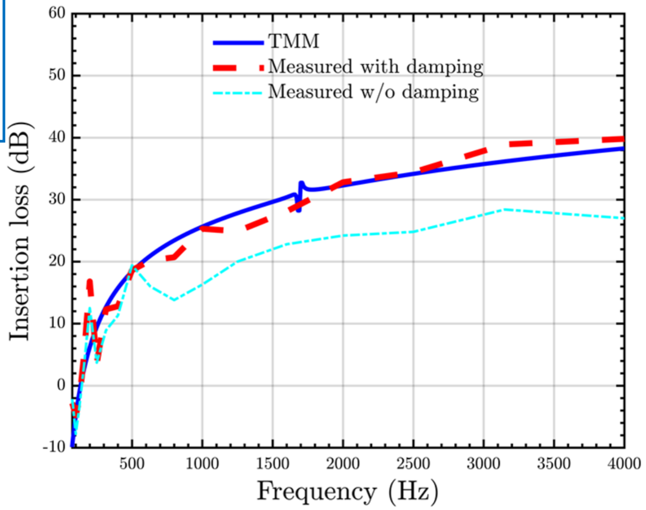
Insertion loss

$$TL_{lagged} = 10\log\left[\frac{|p_1|^2 S_1/(2\rho_0 c_0)}{\frac{1}{2}|u_{r4}|^2 Re(Z_{04})S_4}\right] \quad (7)$$

$$TL_{bare} = 10\log\left[\frac{|p_1|^2 S_1/(2\rho_0 c_0)}{\frac{1}{2}|u_{r4}|^2 Re(Z_{02})S_4}\right] \quad (8)$$

$$IL = TL_{lagged} - TL_{bare} \quad (9)$$

- **Theoretical model derived**
- **Insertion loss improved**
- **Optimization design**
- **Integrated function of both sound and thermal insulation**



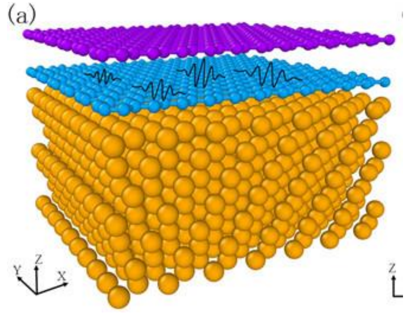
PHONONIC CRYSTALS AND ITS DESIGN

LATTER RESEARCH IN COLLABORATION WITH CHINA ACADEMIA

In collaboration with:

Tsinghua University

Research proposal:
Atomic design for nanofriction control

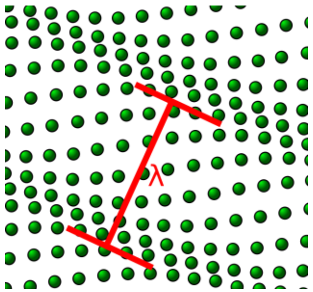


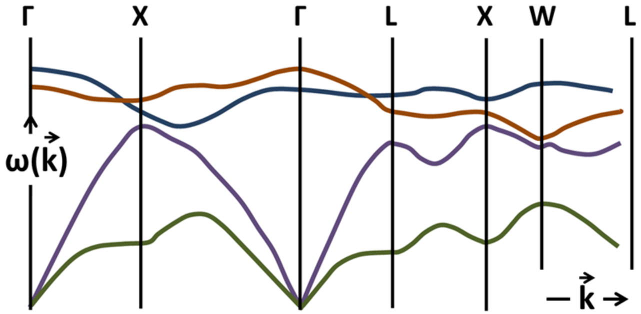
Friction

→ damping

→ heat transfer efficiency

- Phonon lifetime
- Lattice vibration mode
- Averaged mean path

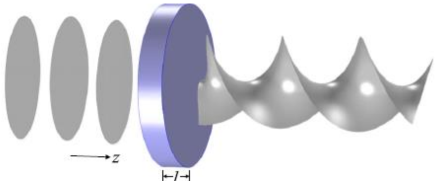


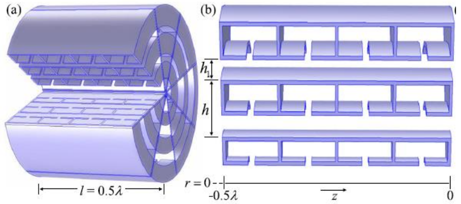


Sun Yat-sen University

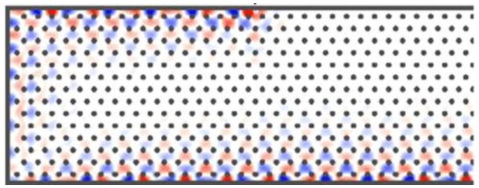
Design of acoustic metamaterials for nontrivial applications

Acoustic angular momentum





Acoustic cloak: topological insulator



Thank you for your attention!