Controlling the effective bending stiffness via out-of-plane rotational resonances in elastic metamaterial thin plates

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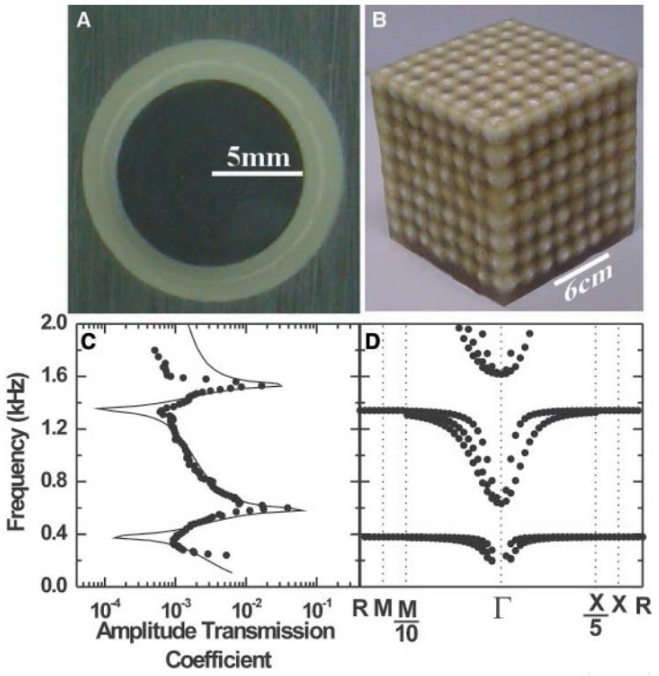
Soochow University

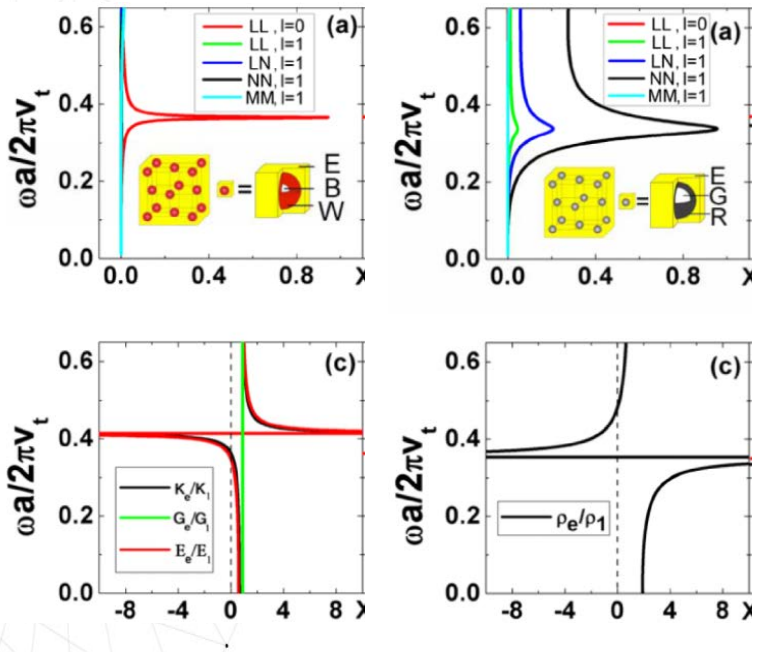
Beginning and development of elastic metamaterial

ρ<0



Liu Z Y, *Science* **289** 1734-6(2000)

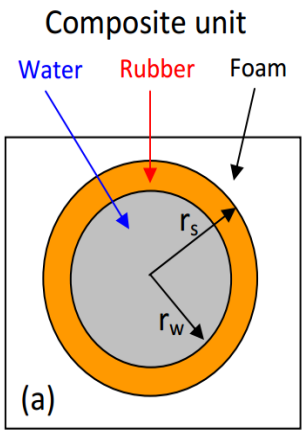
ρ<0, K<0

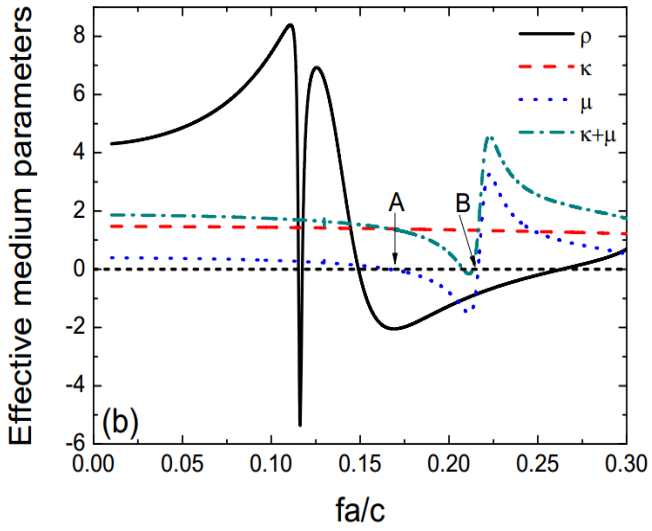


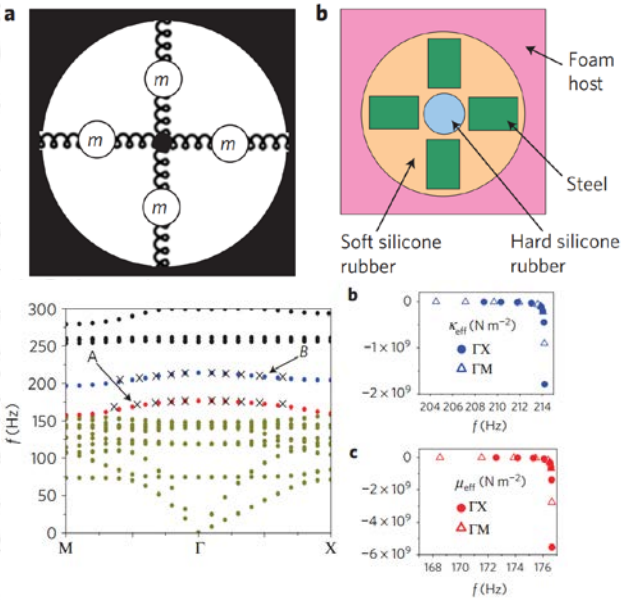
Ding Y Q, *Phys. Rev. Lett* **99** 093904(2007)

ρ<0, μ<0

Super anisotropy





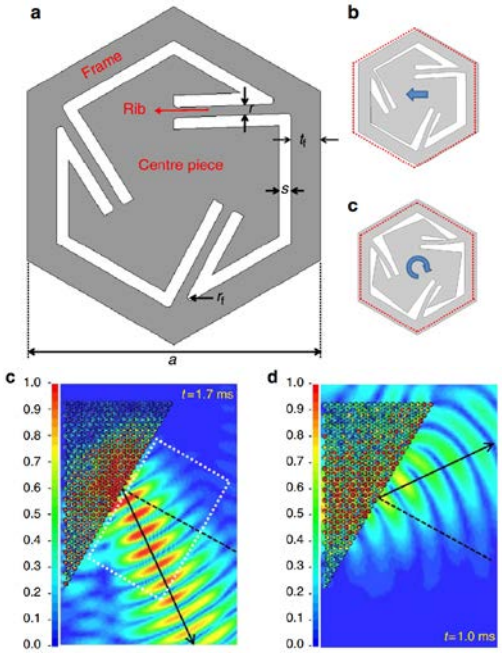


Wu Y, *Phys. Rev. Lett* **107** 105506(2011)

Lai Y, *Nat. Mater.* **10** 620-4(2011)

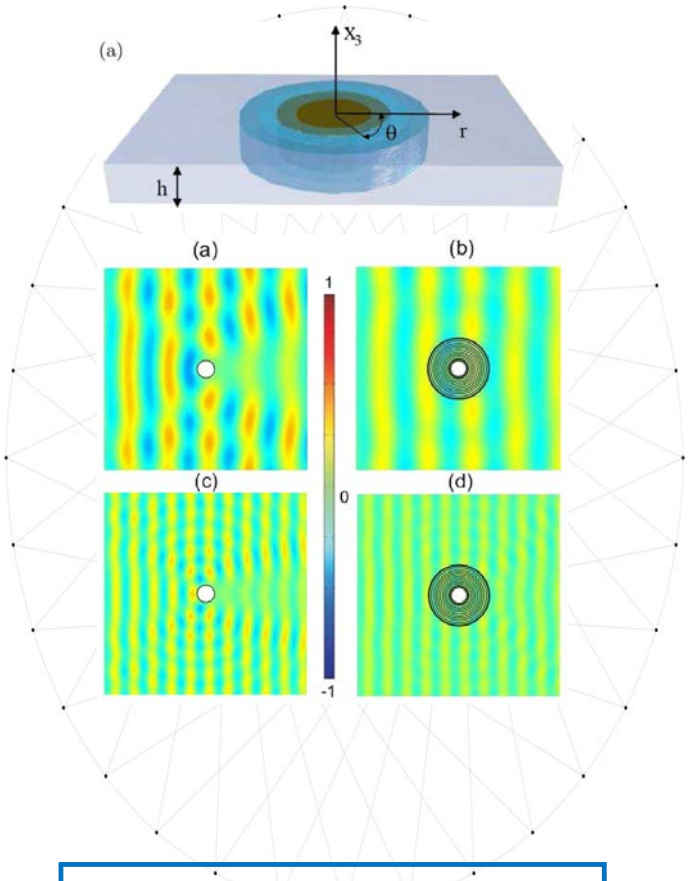
Some novel phenomena and applications

Negative refraction



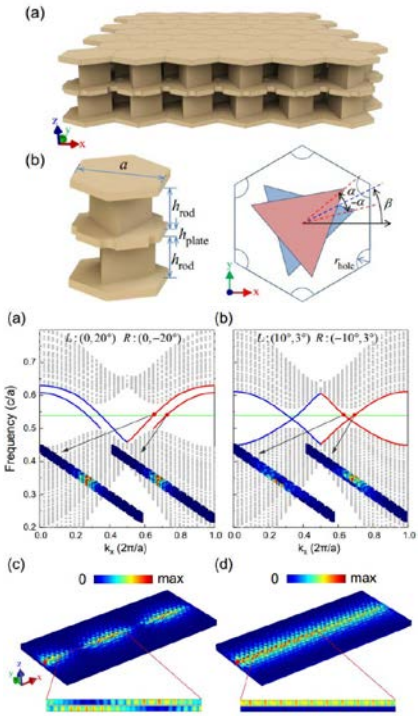
Zhu R. *Nat. Commun.* **5** 5510(2014)

Cloaking



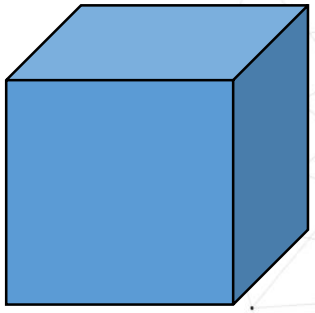
Farhat M. *Phys. Rev. Lętt.* **103** 024301(2009)

Topological effect

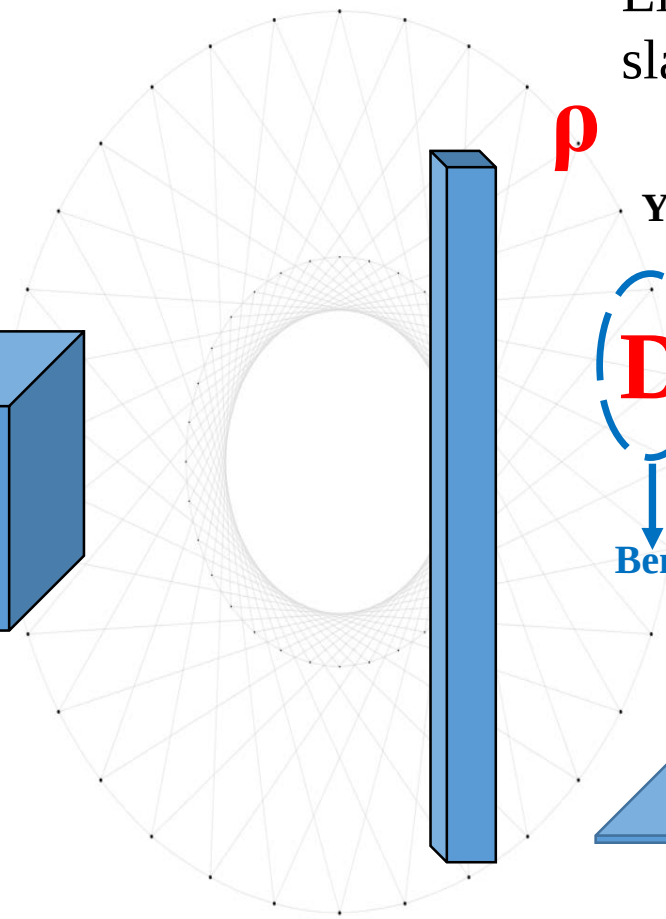


Lu J Y. *Phys. Rev. Lett.* **120** 116802(2018)

Elastic medium:



Elastic rod or slab:



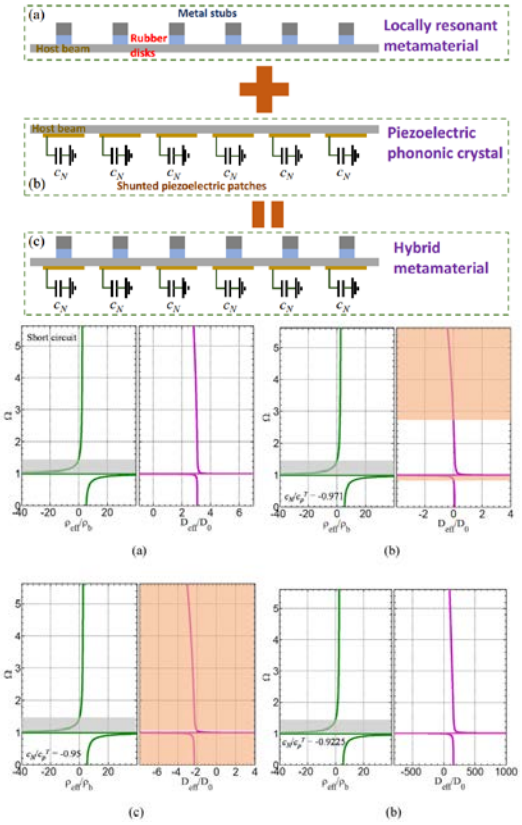
Young's modulus for flexural wave

$$D = E\,I$$

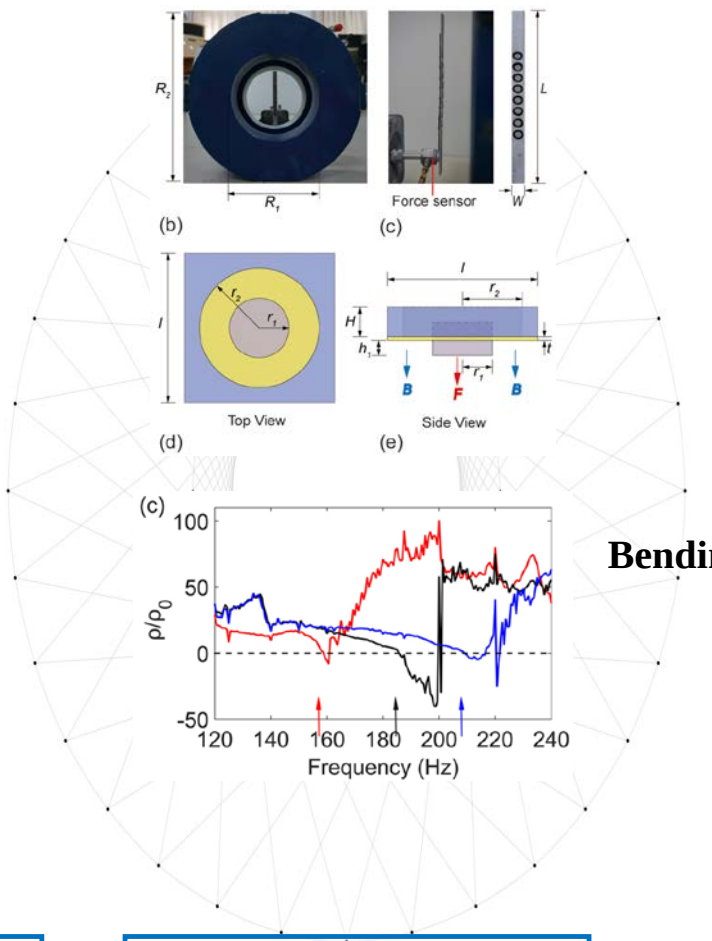
Bending stiffness

Moment of inertia

Controlling D by tuning E in elastic metamaterial beams



Chen Y Y. *J. Mech. Phys. Solids* **105** 179-98(2017)



Qian W. *J. Appl. Phys.* **119** 1734(2016)

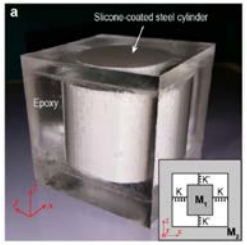
Young's modulus

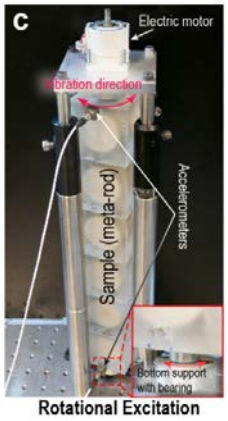
$D = EI$

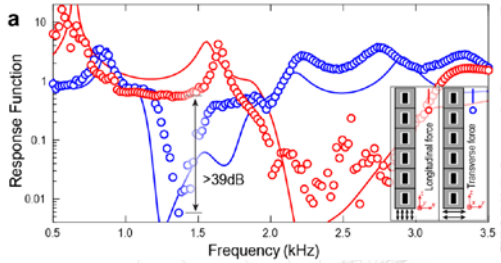
Bending stiffness

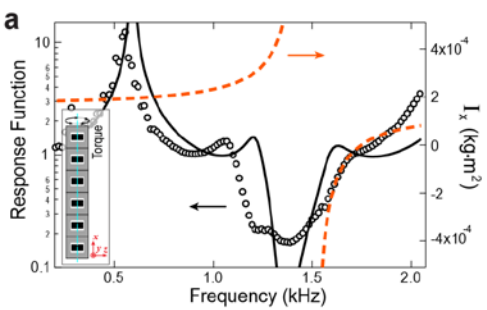
Moment of inertia

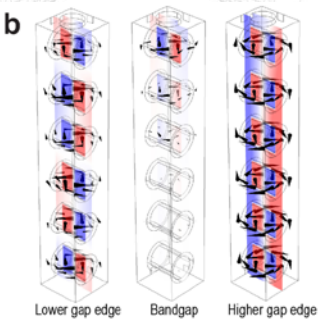
If the D can be controlled by I in elastic metamaterial thin plates







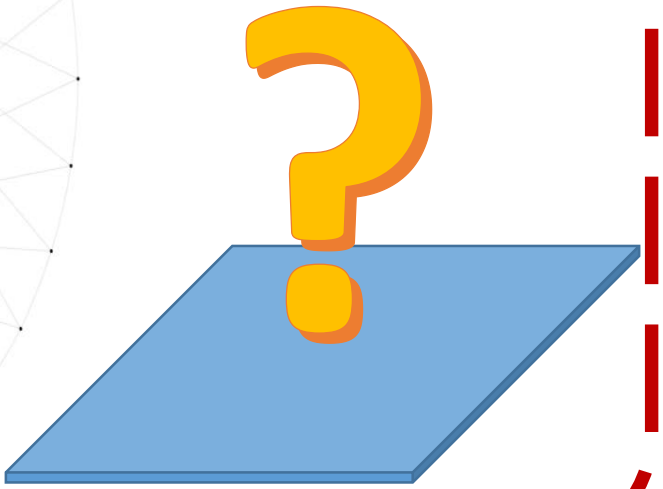


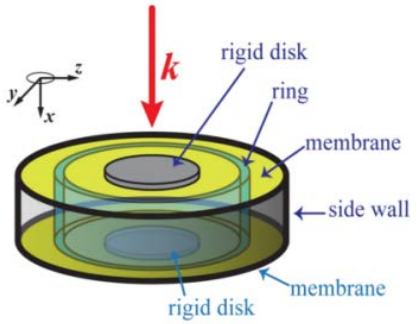


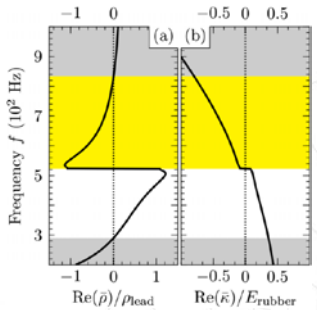
Ma G C. *Nat. Commun.* **7** 13536(2016)

1D ✓

2D ?





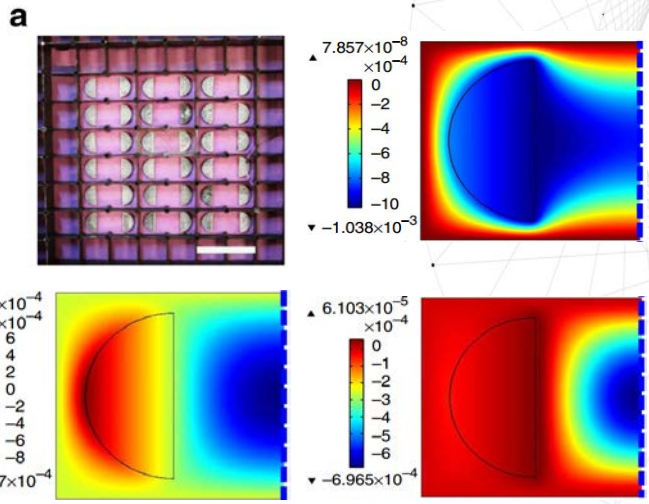


Doubly Negative Mass Density and Bulk Modulus

a=5cm
r_1=1cm
r_2=1.5cm
h=0.5cm

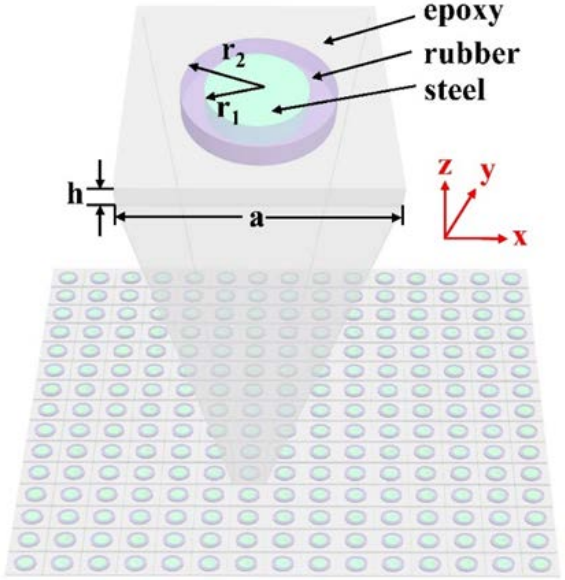
Dipolar resonances

Yang M, *Phys. Rev. Lett* **107** 134301(2013)



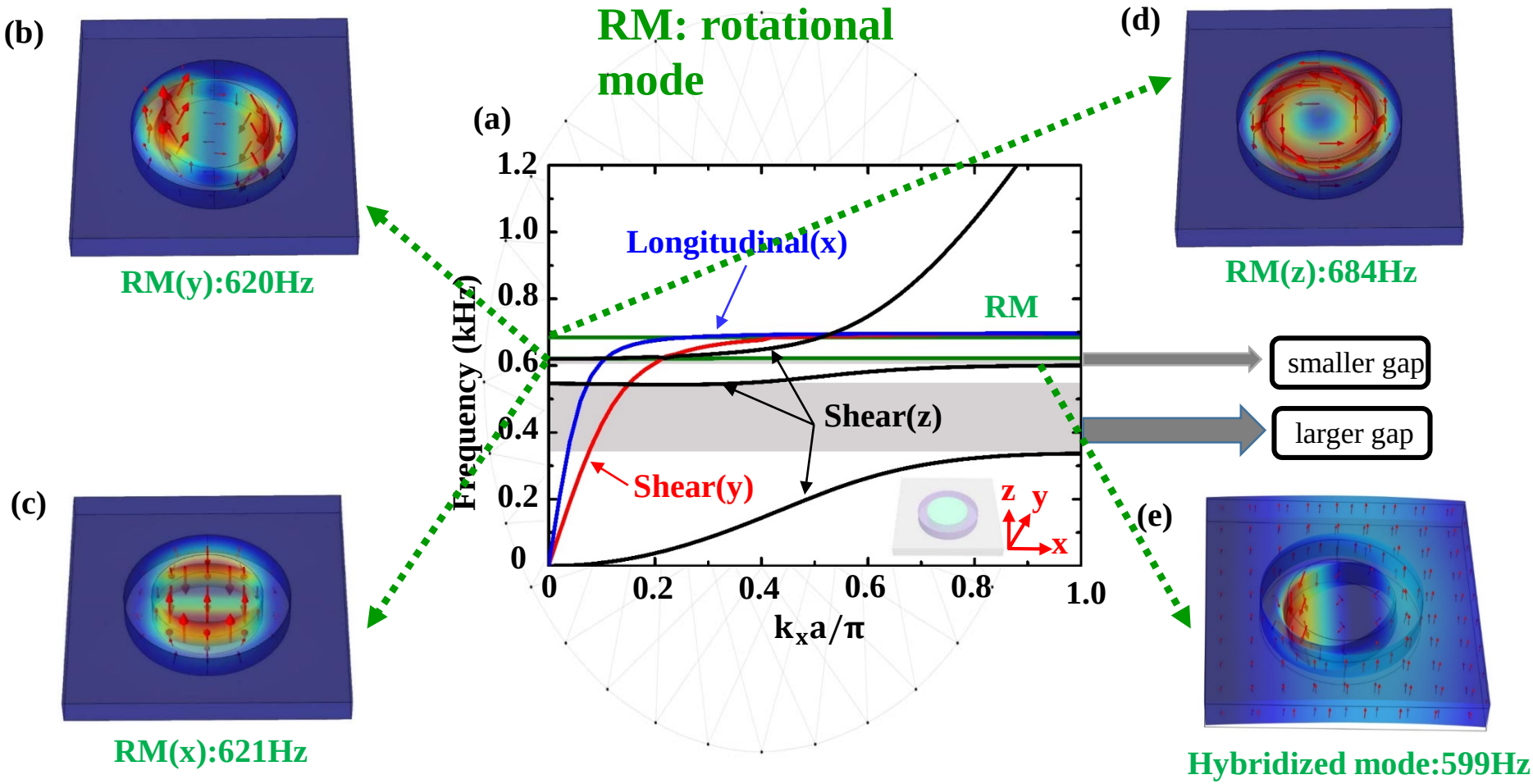
What about D?

Our work

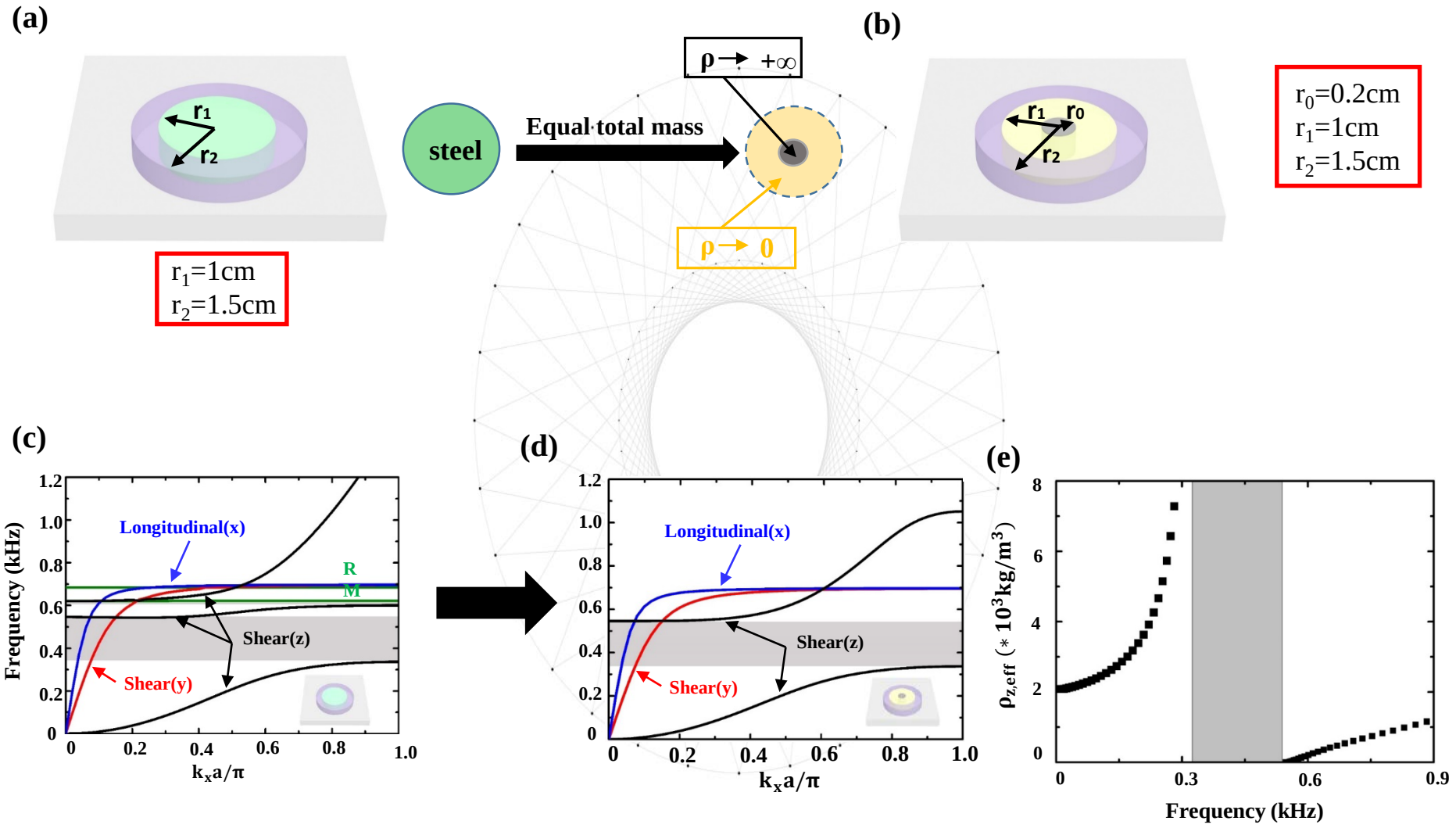


super absorber

Mei J. *Nat. Commun.* **3** 756 (2012)


RM: rotational mode
(a)
(b)
RM(y):620Hz
(c)
RM(x):621Hz
(d)
RM(z):684Hz
(e)
Hybridized mode:599Hz
Longitudinal(x)
RM
Shear(z)
Shear(y)
Frequency (kHz)
$k_x a/\pi$
0
0.2
0.4
0.6
0.8
1.0
1.2
z y x
smaller gap
larger gap

Reducing I while keeping other physical parameters to be the same



Calculating the effective bending stiffness by the resonant

resonant frequency

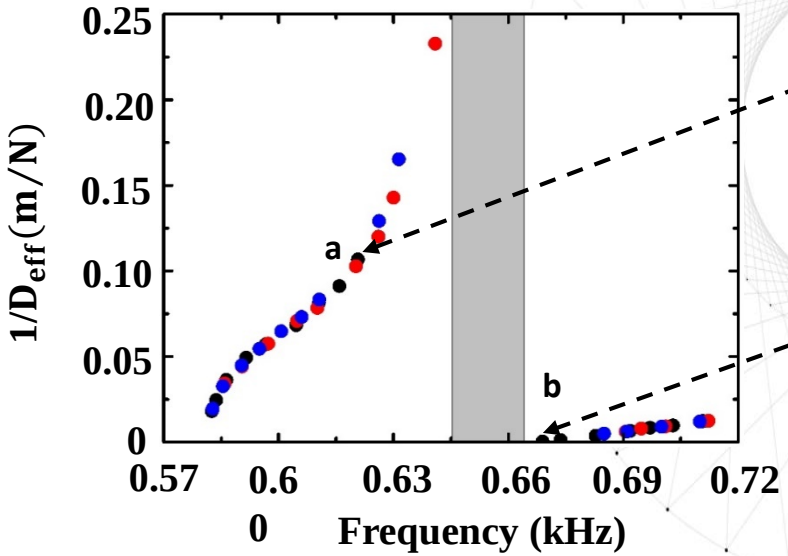
order along the x and y directions

$$\omega_{mn} = \pi^2 \frac{m^2+n^2}{b^2}\sqrt{\frac{D_{eff}}{\bar{m}}}$$

side length

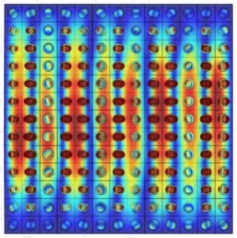
$$\bar{m} = \rho_z^{eff} * h$$

Boundary condition: $(W)_{x=0}=0$; $(W)_{y=0}=0$.

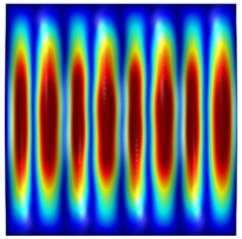


D_{eff}=9.38N/m

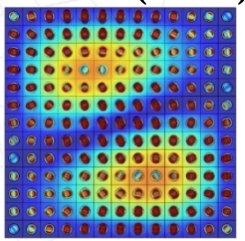
F=621Hz(a state)



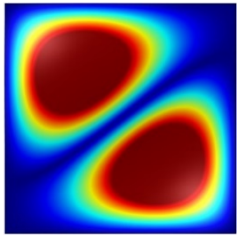
F=619Hz



F=669Hz(b state)



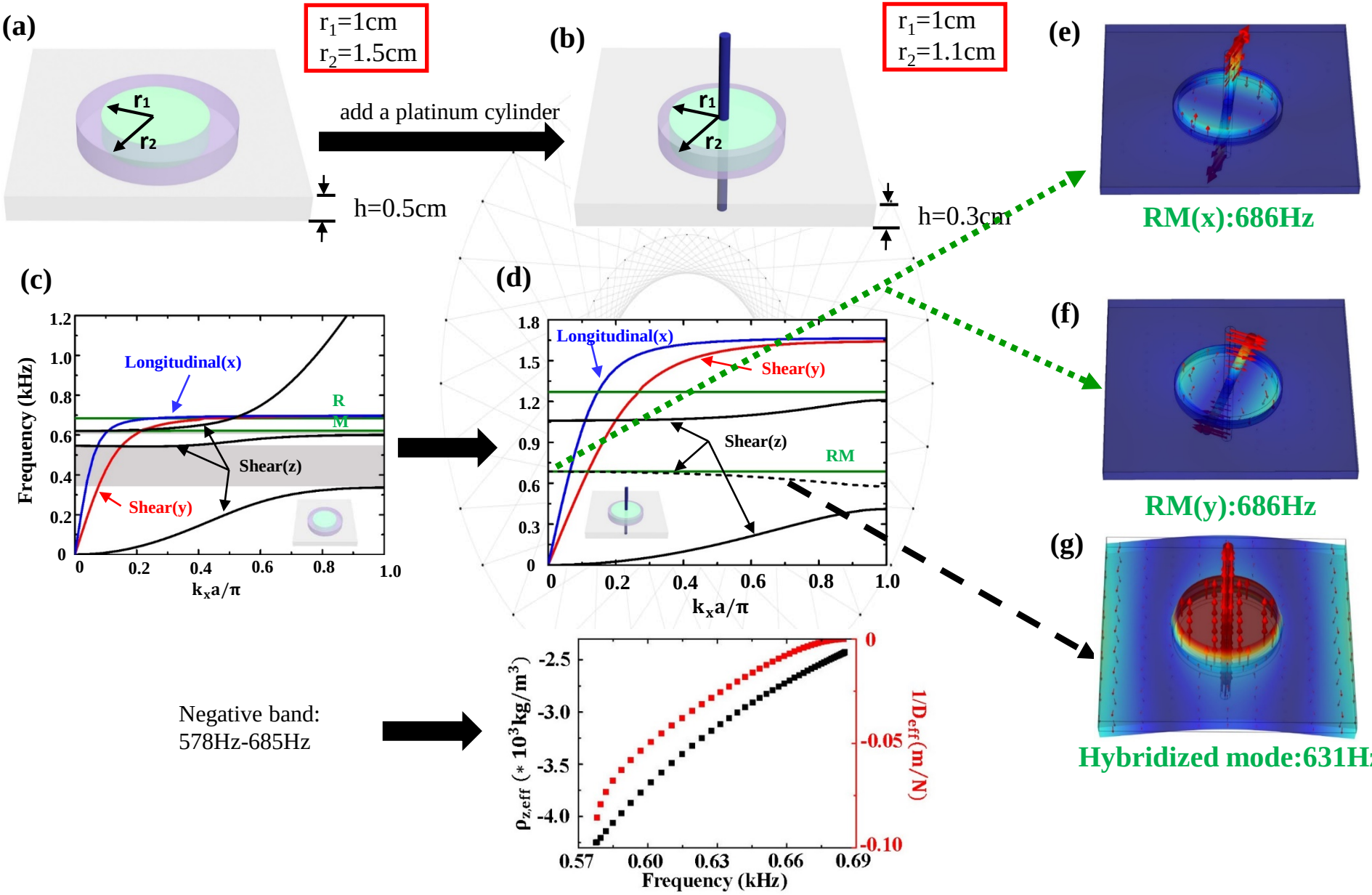
F=668Hz



D_{eff}=3042.7N/m

Black /red /blue dots represent the effective bending stiffness of plate with 13×13 / 15×15 / 18×18 unit cell, respectively.

Double negativity in bending stiffness and mass density



Conclusions

- We have systematically investigated the resonant behaviors of an elastic metamaterial thin plate.
- By engineering the out-of-plane rotational resonances, we can control the effective bending stiffness in the elastic metamaterial thin plates.
- We realize negative band induced by double negativity in bending stiffness and mass density.
- Our work demonstrates a design principle in controlling flexural waves in elastic thin plates.

Thank you ！