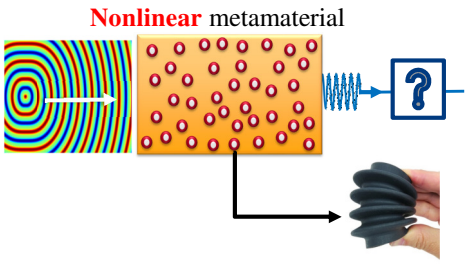
# Emergent phenomena in nonlinear metamaterials

P. B. Silva*[a], V. G. Kouznetsova[a], M. J. Leamy[b] and M. G. D. Geers[a]

* Email: p.brandao.silva@tue.nl

[a] Department of Mechanical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands

[b] George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, USA




## Introduction

**Metamaterials** are engineered structures in which the design of a meta-atom with specific dynamics gives rise to on-demand and unusual behavior of the artificial structure, making it possible to **manipulate waves**.

## Research Objective

Reveal physical phenomena induced by **material nonlinearities** in **locally resonant metamaterials** and develop appropriated techniques for their analysis.

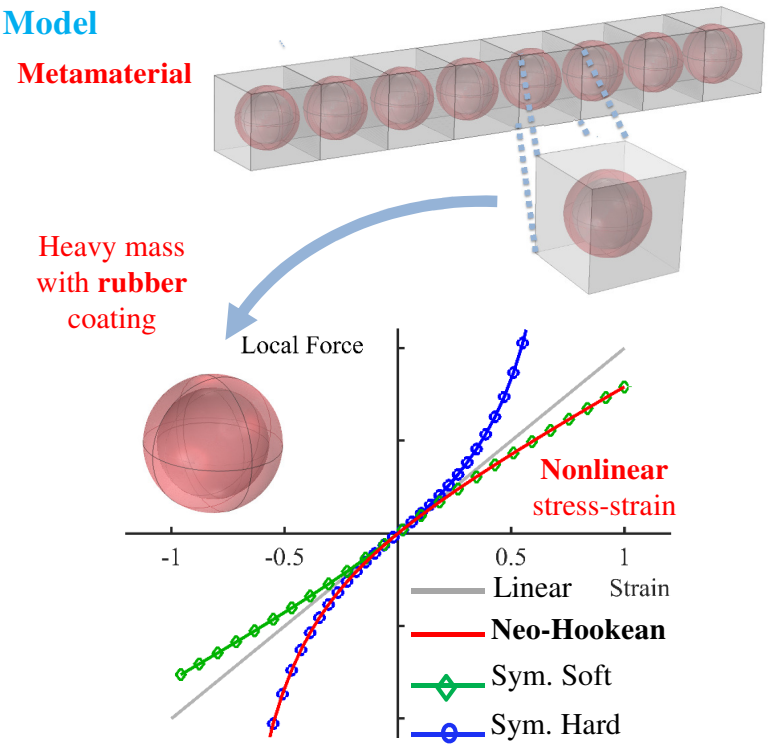
## Methodology

Approximating techniques are used to describe the oscillatory motion of the nonlinear periodic system:

- ❑ **Harmonic Balance** method
- ❑ Method of **Multiple Scales**

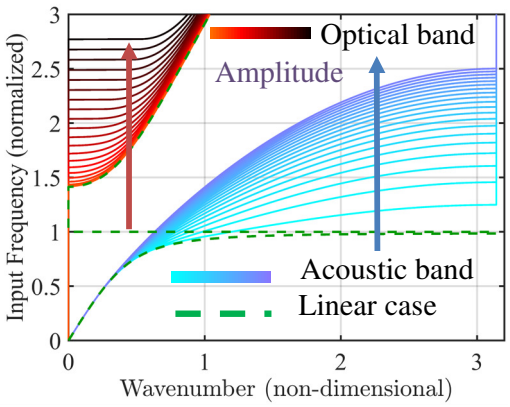
**Direct Numerical Simulations** are performed in order to verify the approximating solutions.

## Model

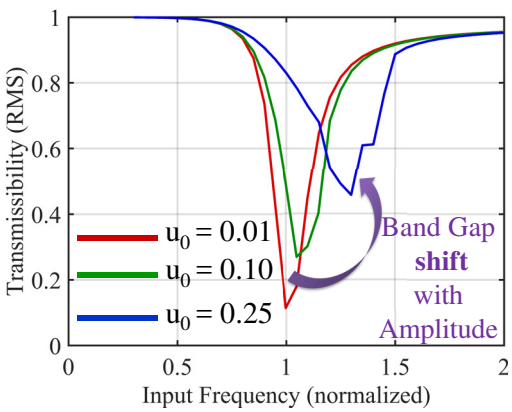



## Results

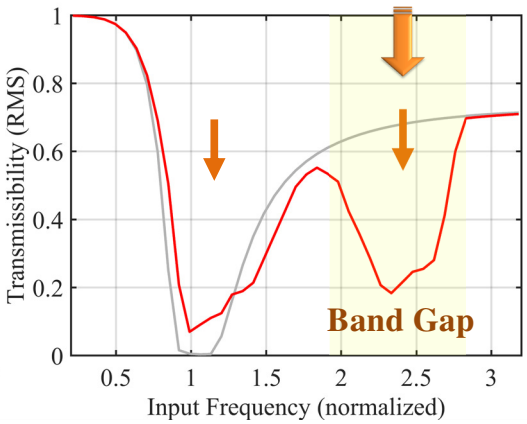
### Dispersion Diagram




### Tunability




### ½ Harmonic Band Gap [1]




## Discussions

Results provide understanding of the effect of material nonlinearity in local resonant metamaterials.

- ✓**Amplitude dependent** band gap position.
- ✓**Shifting** band gap due to hardening/softening.
- ✓**Co-existence** of acoustic and optical modes
- ✓Possibility of generating **½ harmonic band gap** in case of asymmetric stress-strain relation.

## Outlook

❑ The features of nonlinear metamaterials make them promising for applications in: **sensor technology, imaging**, among others.

❑ Develop a numerical scheme involving both time and space to be incorporated into the classical **Computational Homogenization**.

**Reference:** [1]Silva P. B., Kouznetsova V. G., Leamy M. J., Geers M. G. D. 2018. *Emergence of a subharmonic band gap in non-linear locally resonant metamaterials.* In preparation.