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X-Sense2 RTD 2013

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Towards 1000x broadband amplification: A micromechanical amplifier for acoustic emission detection

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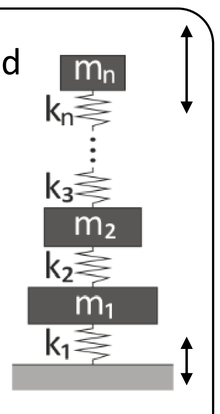
Motivation

- High-sensitivity MEMS acoustic emission sensors are in general band-limited to a single resonance line [1,2]
  → disadvantageous when detecting weak, broadband environmental vibrations
- Broadband mechanical amplifier for vibration sensing is proposed

Concept

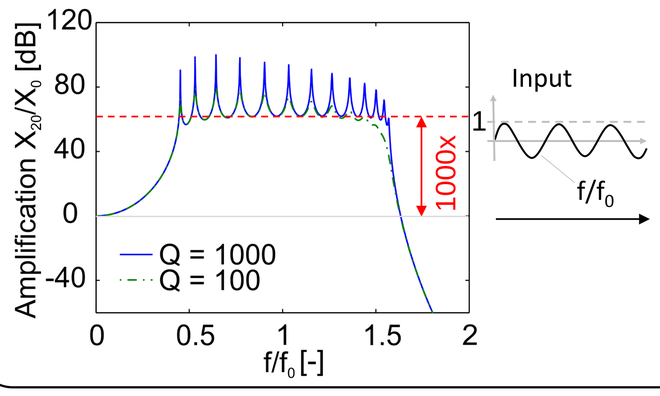
The mechanical amplifier consists of concentrically arranged masses with following design constraints (i = 1, … n):

- $\frac{m_{i-1}}{m_i} = 2$
- $\frac{k_i + k_{i+1}}{m_i} = \omega_0$

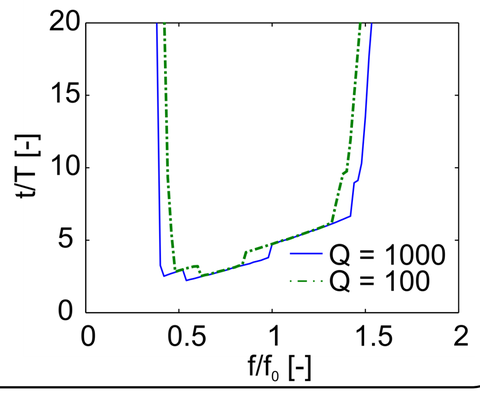


Weak vibrations exciting the outer-most mass and traveling towards the center mass are amplified, if they are within the allowed frequency band.

Definition of amplification (mainly independent of Q)



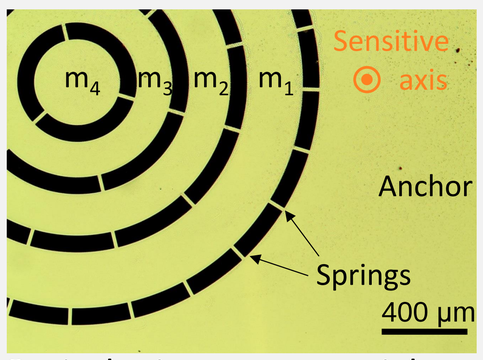
Number of oscillations to reach 1000x amplificaton



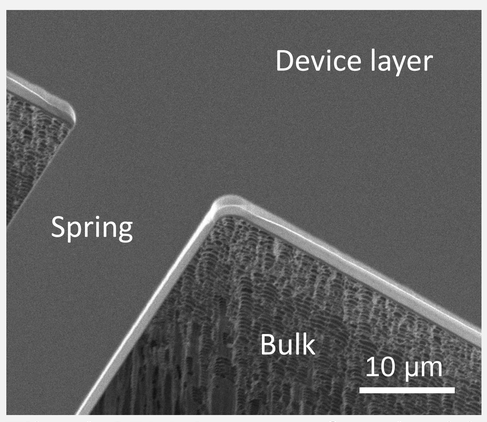
Design approaches

Out-of-plane and in-plane moving structures have been designed and fabricated. The out-of-plane structures were made in SOI with the springs in the thin device layer and the in-plane structures in Si.

Out-of-plane

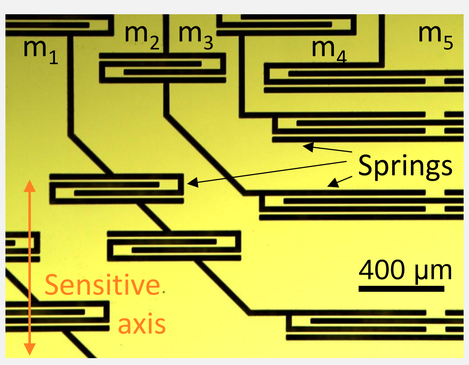


Optical microscope partial top view of out-of-plane device.

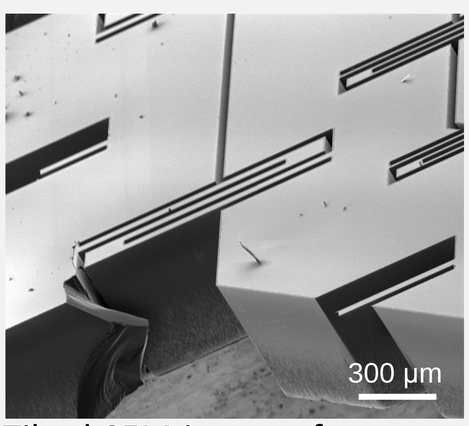


Tilted SEM image of a double clamped beam (spring).

In-plane



Optical microscope partial top view of in-plane device.

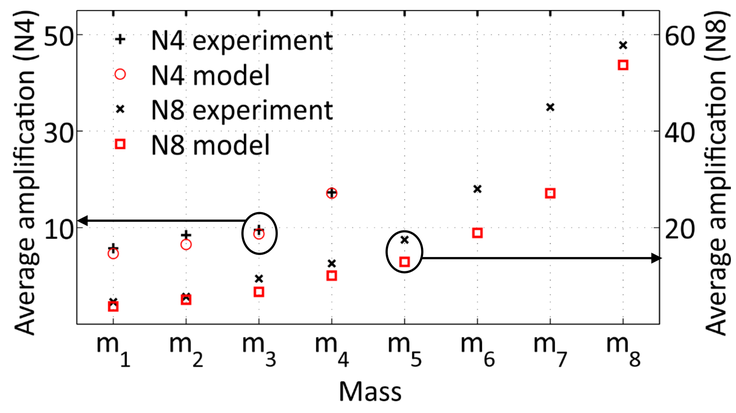


Tilted SEM image of serpentine spring.

Results

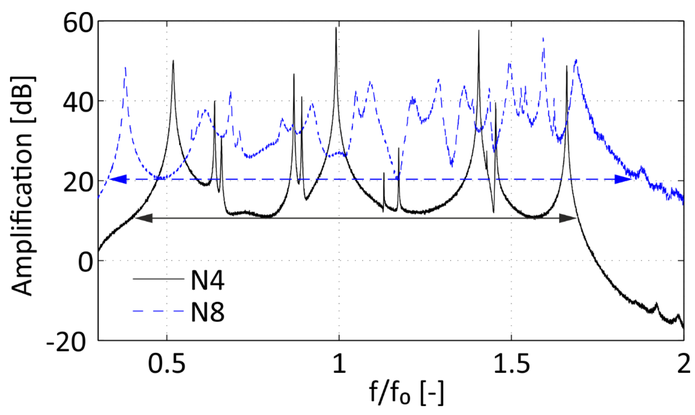
Measurements shown were performed on the out-of-plane moving structures with a Laser Doppler Vibrometer.

Average amplification



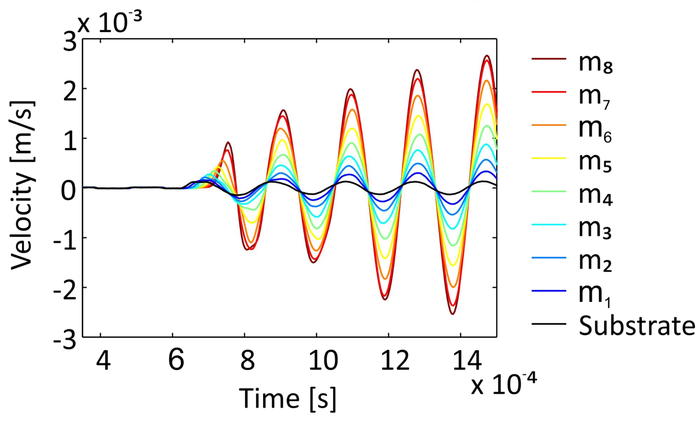
Average amplification at each mass of N4 and N8 is shown. A 3-times higher amplification can be observed at the center mass for N8.

Transfer function



Transfer functions of the central masses of N4 and N8 are given. N8 shows a higher average amplification over a broader normalized bandwidth.

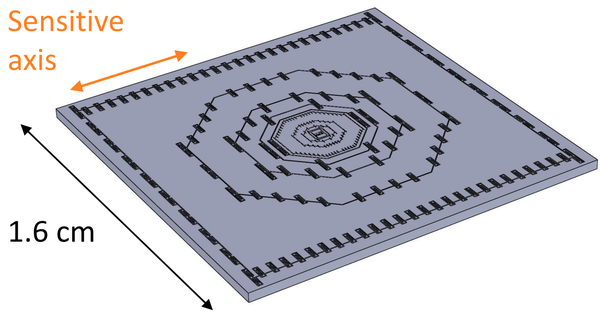
Transient response near first Eigenfrequency

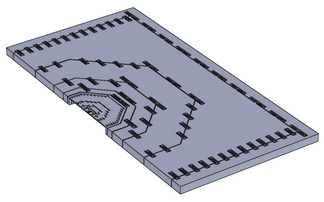


Displacements of each mass of N8 are given. Indicent mechanical vibration is shoaled in a tsunami-like fashion towards the center mass.

Outlook

Process and design studies to increase the amplification up to 1000x are ongoing: As an example, such a design based on two functional substrate layers may achieve a baseline-amplification of 500.





Cross-secton showing thinner masses in the center.

References

[1] W. Wu, D. W. Greve, and I. J. Oppenheim, "Characterization and noise analysis of capacitive MEMS acoustic emission transducers," in Proceeding of IEEE Sensors Conference, 2007, pp. 1152-1155.

[2] H. Saboonchi and D. Ozevin, "MEMS acoustic emission transducers designed with high aspect ratio geometry," Smart Mater. Struct., vol. 22, no. 9, Sep. 2013.

Acknowledgments

- Yunjia Li for helpful discussions and support in process development
- FIRST-CLA cleanroom staff of ETH Zürich as well as cleanroom staff at BRNC in Rüschlikon
- This research has been funded by Nano-Tera.ch, a program of the Swiss Confederation, evaluated by SNSF

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