S. Hu[1,2], B. Manansala[1], U. Fitzer[1,2], D.Hohlfeld[2], T. Bechtold[1,2]

Topology Optimization of Multi-Resonant MEMS

INTRODUCTION AND MOTIVATION

The methodology of topology optimization (TO) has been introduced in the late 1980s. Yet, it was only in the recent years and with the widespread introduction of 3D printing in industrial applications, TO started getting more and more attention. TO uses a simple isotropic material model with penalization (SIMP model), which parameterizes the material distribution on a fixed domain, mostly a finite element mesh, instead of classic geometric properties such as length or thickness. A typical workflow is shown in Figure 2. This allows for more freedom in terms of geometrical and topological variation during the optimization process.

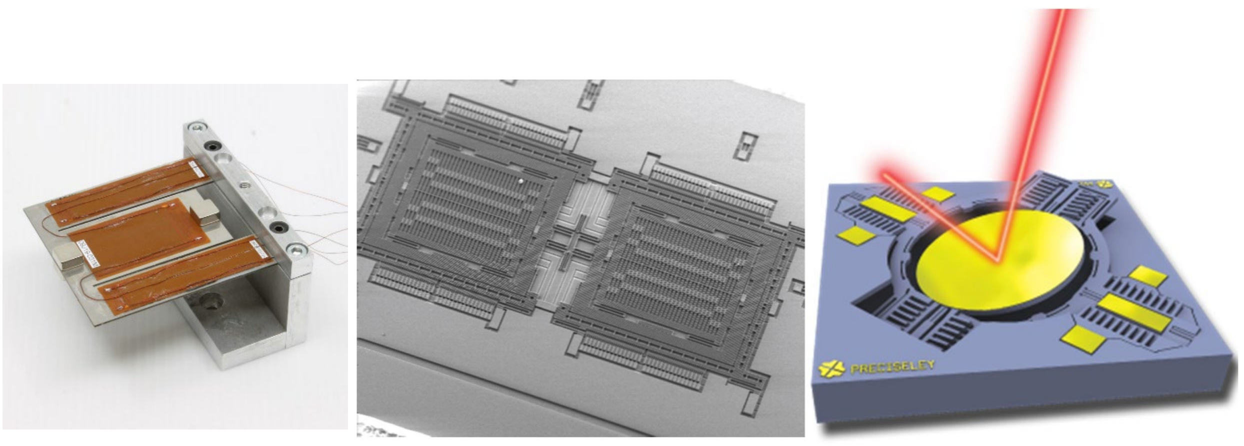

Fig. 1: Photos of a multi-resonant piezoelectric energy harvester (left), a MEMS gyroscope [1] (mid) and a micromirror [2] (right).

On this poster, we demonstrate that TO is a promising automatic design approach for microelectro-mechanical systems (MEMS). With our focus set on multi-resonant devices, we successfully applied TO on a gyroscope; a micromirror as used in projectors; and on a piezoelectric energy harvester (Figure 1). The optimization resulted in geometries unlike any classical designs.

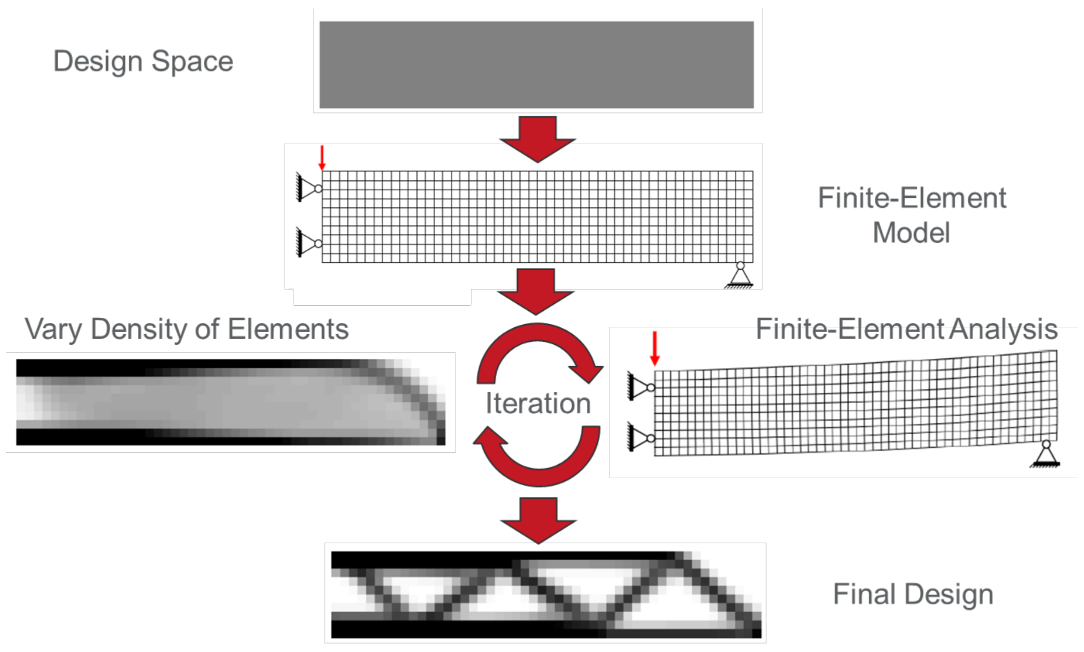

Fig. 2. Schematic diagram of SIMP based TO.

PIEZOELECTRIC ENERGY HARVESTER

A piezoelectric energy harvester transforms mechanical vibration into electrical energy via the piezoelectric effect. These devices are popular due to their high power density, scalability and geometrical simplicity. The design goal of these devices is to have the structures resonance frequency matching with the excitation frequency of the vibration source. Piezoelectric energy harvesters can be build multi resonant, such that they can operate on a broader frequencies range. In this optimization, our goal is to have the its first resonance frequencies at 73 and 77 Hz, respectively. At same time, we minimize the relative difference in the (di-) electrical energy of the structure at these two resonance frequencies. These goal would allow the optimized structure to have a frequency range of constant high level of power output around 75 Hz. The design space with which we initialized the optimization and the optimal structure are presented in Figure 3.

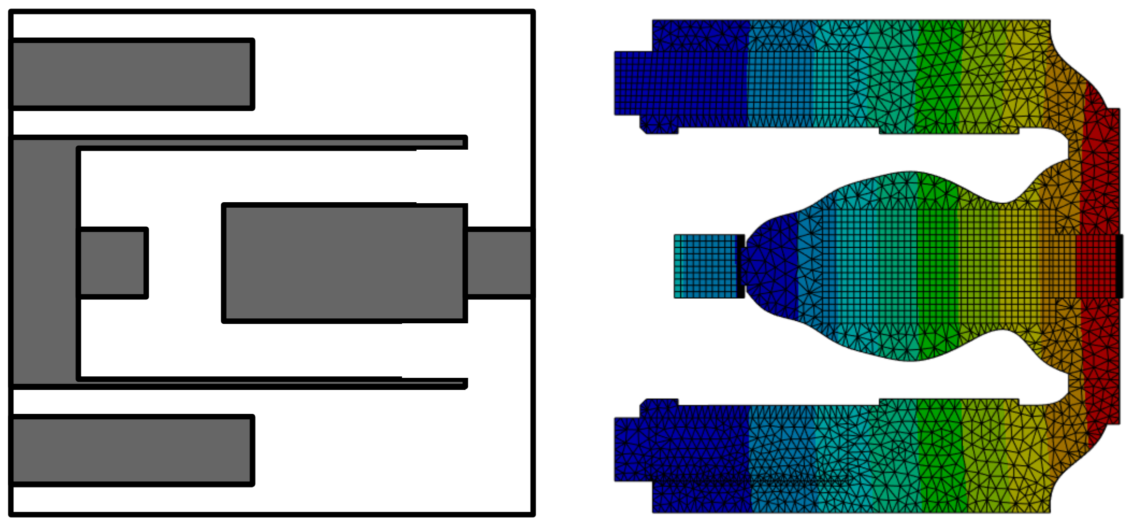

Figure 3: Design space of for the optimization of the piezoelectric energy harvester (left) and the corresponding optimal design (right). The gray areas are excluded from the optimization as they are reserved for the piezoelectric patches, tip masses and air gaps for avoiding collision during operation.

MICROMIRROR

Micromirrors are micromechanical light modulators. This is achieved by a tilting motion around one or two orthogonal axes driven at their respective resonance frequencies. They can be found in lots of every-day applications, such as in barcode scanners or projectors / head-up displays, which was the application we considered, here, for our optimization. We optimized the resonance frequencies to be suitable for the projection of an image with a resolution of 1920x1080 at 60 Hz. Because of the size of the device, we set the resonance frequencies of the structure to be multiples of its required value at 250 kHz and 300 kHz, respectively. The design space and the optimized geometry is depict in Figure 4.

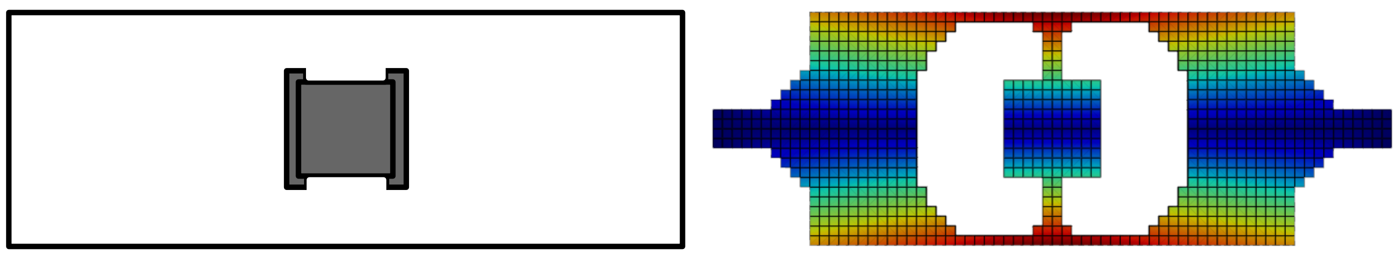

Figure 4: Design space of for the optimization of the micromirror (top) and the corresponding optimal design (bottom). The gray areas are excluded from the optimization with the central square being the mirror, and air gaps are introduced for collision avoidance during operation.

MEMS GYROSCOPE

Gyroscopes are devices used for measuring angular acceleration. Their MEMS version are popular in some consumer electronics, such as smartphones or smartwatches. A MEMS gyroscopes typically consist of a proof mass suspended by a compliant structure that allows the mass to oscillate in two orthogonal directions. These two movement corresponds to the first two resonance modes of the structure, where the first mode is called the drive mode and the second mode is called the sense mode. The design goal of a vibrational gyroscope is to have the sense mode at 2-10% higher frequency than the drive mode, while the frequencies of higher (spurious) modes are significantly higher than the sense mode. For our optimization we set the goal frequencies to be 3.8 Hz (drive), 4 Hz (sensing) and >5 Hz (spurious), respectively. The design space and optimized geometry is shown in Figure 5.

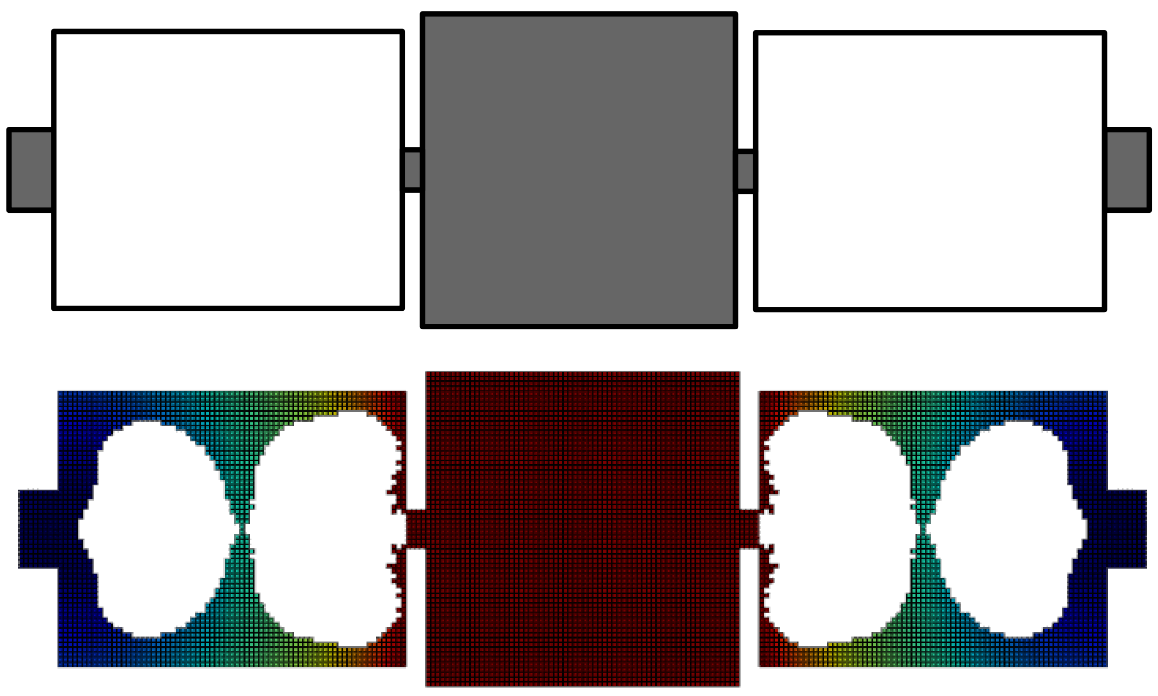

Figure 5: Design space of for the optimization of the MEMS gyroscope (top) and the corresponding optimal design (bottom). The gray areas are excluded from the optimization, as the design space only covers the compliance structure.

LITERATURE

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JADE UNIVERSITY OF APPLIED SCIENCES
Wilhelmshaven Oldenburg Elsfleth

[1] Department of Engineering | Jade University of Applied Sciences | Wilhelmshaven, Germany
Contact: tamara.bechtold@jade-hs.de

Universität Rostock Traditio et Innovatio

[2] Institute of Electronic Appliances and Circuits | University of Rostock | Rostock, Germany

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