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FEM Validation of a Single Degree of Freedom Model for Piezoelectric Energy Harvesters

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Analytical calculations and finite element modeling (FEM) are important tools for efficient design and optimization of piezoelectric vibrational energy harvesters [1-3]. We have previously shown [4] that cantilever based vibrational energy harvesters with large attached proof masses, Fig. 1, can be described by an analytical impedance based single degree-of-freedom (SDOF) model using appropriate lumped parameters. In this paper we validate the analytical model using FEM by performing a design study where the thickness of the piezoelectric layer is optimized.

The FEM studies were performed in COMSOL 5.1. For power calculations, the load resistance was optimized for each geometry to achieve maximum power. The device is made in silicon and uses a thin layer of AlN as piezoelectric material with dimensions listed in Tab. 1.

Using AlN for vibrational energy harvesting has several advantages compared to other commonly used materials like PZT. However, it is difficult to deposit thick layers due to the very slow deposition rate. It is therefore essential to determine the AlN layer thickness necessary to achieve a maximum output power. The peak harvested RMS power versus the AlN layer thickness has been studied. Two regions have been found. In the first region the power harvested from the device increases as the AlN layer thickness is increased. From [4] it can be inferred that the device is behaving as in the low coupled case. In the second region a maximum power is reached when the AlN thickness is above ~ 350 nm. In this second region the maximum output power corresponds to the total available power in the device. The explanation to this output power is that the device enters a region characterized by a behavior that corresponds to the high coupled case described in [4]. Depositing thicker AlN layers than ~ 350 nm in order to harvest the maximum available power is therefore not necessary.

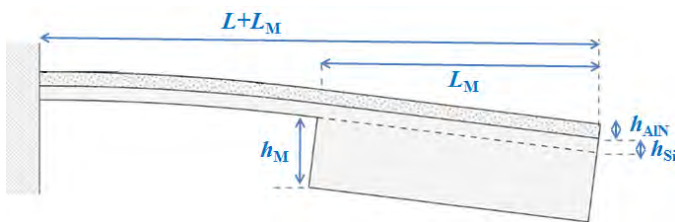


Figure 1. Schematic design of the device.

Device parameter	Value
Total beam length, $L+L_M$	6.5 mm
Mass length, L_M	3.2 mm
Beam width, W	6.0 mm
Cantilever thickness, h_{Si}	30 μm
AlN thickness, h_{AlN}	400 nm
Mass thickness, $h_M + h_{Si}$	500 μm

Table 1. Device dimensions.

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