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NONLOCAL THERMOELASTIC DISSIPATION IN MICRON- AND SUBMICRON- RESONATORS

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ABSTRACT

Microelectromechanical systems (MEMS), such as miniaturized sensors and actuators, are currently adopted in a wide variety of situations. Their diffusion is growing in many fields, e.g. aerospace industry, telecommunications, civil engineering. In many applications, the micro-device includes a high frequency mechanical resonator. Such systems must be designed by considering the prediction of the dynamic response; in particular, one important issue is represented by the accurate evaluation of dissipation, induced by various factors. The damping level, strictly connected to dissipation, is measured by means of the so-called quality factor Q; the inverse of Q can be physically interpreted as the fraction of energy lost per radian. Operatively, the quality factor can be computed after performing the eigenvalue analysis for the considered structure. Due to the presence of damping, the eigenvalues are generally complex numbers; the quality factor for a specific vibrating mode is proportional to the ratio between the imaginary and the real part of the corresponding eigenvalue.

The total amount of dissipation for a micromechanical system is determined by many causes, which can be roughly divided into two categories. The first one ("fluid damping") embraces phenomena related to the interaction of the solid parts with the surrounding gases, and has been investigated in [1]. This communication is focussed on the second class of dissipative phenomena, that are connected to loss mechanisms in the solid material ("solid damping"). It is worth noting that fluid damping has been recognized as a major source of dissipation in case of moderately high gas pressure. The effects of fluid damping are overwhelmed by solid damping when the micromechanical devices are packed in a near-vacuum environment, as frequently happens in real-life problems.

Solid damping is induced by a lot of physical and chemical processes and many of them are still needing further investigation.

Thermoelastic loss is traditionally considered as a fundamental dissipation mechanism for small-scale mechanical devices [2]. Nevertheless, some recent experimental results show that the classical local thermoelastic analysis can not be applied in resonators whose dimensions are small, below some microns [3].

The discrepancy between theory predictions and experimental results, when the scale of the problem decreases, suggests that some internal characteristic length is not sufficiently small with respect to structural dimensions to justify the use of continuum local theory. The domain of applicability of continuum theories can be extended to small scale problems by nonlocal models [4]. In [5] a nonlocal thermoelastic model has been developed and applied to micro and nano resonator. The proposed model has been introduced in analytical simplified formulae, valid only for vibrating beams of simple geometry.

The present communication deals with the implementation of the nonlocal model in a finite element code, suitably developed by the Authors in order to solve multiphysics problems. In this way, it is possible to introduce some additional nonlocal effects which are disregarded by the simplified formulae and to analyze vibrating structures of different geometries.

Parametric studies show that nonlocality can increase the thermoelastic damping, resulting in a lower quality factor which can better interpret the observed behavior, at least in a certain range of resonators dimensions.

For nanometric thickness of the vibrating device, however, the nonlocal thermoelastic dissipation alone can not qualitatively predict the experimentally observed energy loss since at the nanoscale the solid dissipation is strongly influenced by surface effects. The physical causes of surface damping are currently investigated by many researchers in physics and chemistry. Among the various possible sources of surface loss one cite the presence of thin oxide films, crystal defects and Rayleigh waves.

In this communication, an attempt is made for the phenomenological modelling of surface damping. The mechanical behaviour of dissipative surface layers is first investigated analytically for simple cases (vibrating beams). The outcomes of such studies are then exploited in order to construct a proper model of surface damping, which can be eventually introduced into a finite element code. The numerical results are compared to experimental data on cantilever beam resonators, with the purpose of identifying some uncertain parameters of the proposed model. The identified model can be effectively used in simulations of devices with different geometries.

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