Novel Simulation of a Voltage-Driven Electro-Thermo-Mechanical MEMS Self-Oscillator

S. Ouenzerfi[1], H.A.C. Tilmans [2], S. El-Borgi[3], X. Rottenberg[2]

[1]KACST-Intel Consortium Center of Excellence in Nano-manufacturing Applications (CENA), Riyadh, KSA; IMEC, Leuven, Belgium; Applied Mechanics and Systems Research Laboratory, Tunisia Polytechnic School, University of Carthage, La Marsa, Tunesia

[2]IMEC, Leuven, Belgium

[3]Applied Mechanics and Systems Research Laboratory, Tunisia Polytechnic School, University of Carthage, La Marsa, Tunesia; Texas A&M University at Qatar, Mechanical Engineering Program, Engineering Building, Doha, Qatar

Abstract

Introduction
This paper presents the modeling and simulation of electro-thermo-mechanical self-oscillators, an emerging type of M/NEMS-enabled timing devices in which sustaining electronic amplifiers are not required for their operation. Indeed, they realize amplification in the mechanical domain and feedback by crossing three physical domains: electrical, thermal and mechanical. We derive theoretical self-oscillation conditions for electro-thermo-mechanical self-oscillators based on a direct application of the Barkhausen criterion. We further extend the results from previously reported self-oscillators pumped with direct current [1][2] to demonstrate the possible self-oscillation in case of the more attractive and practical direct voltage pumping for devices with a positive piezoresistive coefficient. Using COMSOL Multiphysics®, we present finite element model simulations that support our theoretical developments.

Use of COMSOL Multiphysics®
COMSOL Multiphysics® has been used to simulate the device, check the capability of DC voltage driven oscillator and validate the threshold oscillation limit condition. The material properties of the structure were taken from literature [1][3]. First, we use the Joule Heating and Thermal Expansion Interface to set up a thermo-mechanical resonator simulation (see details presented in Fig. 1). Excitations and boundaries conditions are adjusted to describe a purely thermo-mechanical resonator. Then, we include piezoresisivity effects by describing the electrical conductivity of the constitutive material as a function of the local stress values [4], thus providing the mechanico-electrical feedback our device relies on. To finally efficiently study the self-oscillation aspect our device targets, we combine "Stationary" and "Time-Dependent" studies so that we decouple the thermo-mechanical settling of the self-oscillator at its working point and the self-oscillation in itself.

Results

In Fig. 2, we present the simulation result generated with COMSOL Multiphysics® demonstrating thermally induced ringing (thermo-mechanical resonator). Figure 3 shows the key simulation results describing the initiation and stabilization of self-oscillations. The self-oscillation confirmed through COMSOL Multiphysics® simulations (oscillation growth) confirms the validity of our analytical model suggesting that voltage-drive is a valid pumping mean for self-oscillators in case of positive piezoresistive coefficient. Further, we check the analytical conditions we derived for the self-oscillation threshold by performing COMSOL Multiphysics® simulations driven at various bias voltages. The results of these are shown in Fig. 4. Sustained oscillations are obtained when the loop gain is larger than one while a stable, non-oscillating, state is obtained if this condition is not fulfilled. These results support the analytical model built around the threshold voltage condition.

Conclusion

This work focuses on the simulation of self-amplification mechanisms in an emerging type of MEMS oscillator. This phenomenon results from intrinsic material properties and geometry of the resonator. We used COMSOL Multiphysics® to couple thermal, mechanical and electrical domains in order to assess and predict the self-oscillation conditions in this MEMS oscillator. The COMSOL Multiphysics® results are in good agreement with analytical developments and confirm the possibility we theorized of driving the structure with bias voltage in case it is constituted of a material with positive coefficient of piezoresistivity.

Reference

[1] K. L. Phan, P. G. Steeneken, M. J. Goossens, G. E.J. Koops, G. J.A.M. Verheijden and J.T.M.v. Beek, "Spontaneous mechanical oscillation of a DC driven single crystal" ,Apr. 2009 http://arxiv.org/abs/0904.3748

[2] A. Rahafrooz and S. Pourkamali, “Fully Micromechanical Piezo-Thermal Oscillators,” in Int. Electron Devices Meeting (IEDM), 2010, pp. 158-161.

[3] Smith, C. S., Piezoresistance effect in germanium and silicon. (1954).Phys. Rev. 94, 42-49.

[4] H.Saboonchi and D. Ozevin, ” Optimization of Design Parameters of a Novel MEMS Strain Sensor used for Structural Health Monitoring of Highway Bridges “in Proc. 8th COMSOL Conference, BOSTON, 2011.

Figures used in the abstract

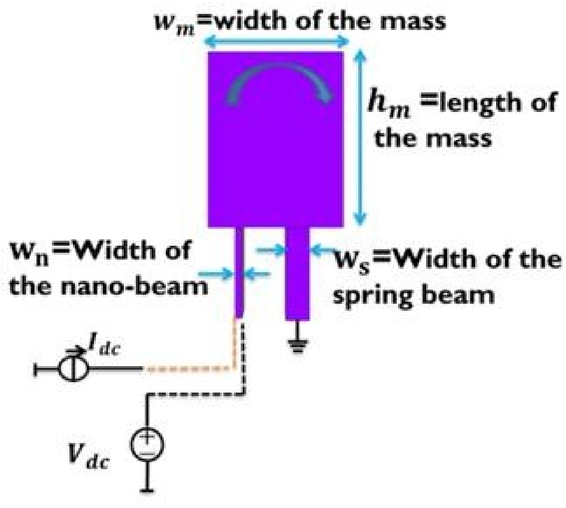

Figure 1: Schematic representation of a typical design of the mechanical oscillator . Either direct current or direct voltage can be used to pump the oscillator

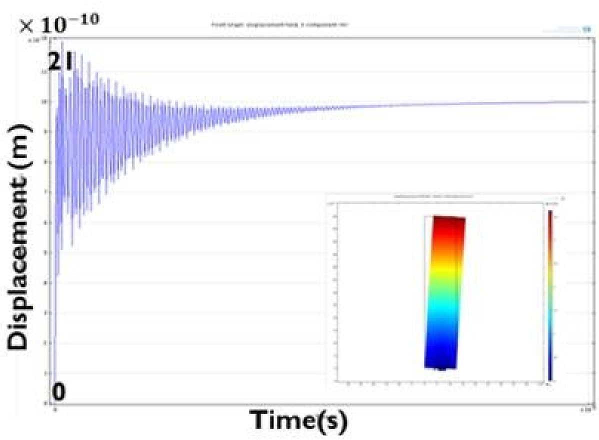

Figure 2: COMSOL simulation without piezoresistivity presenting thermo-mechanical resonator and damped ringing resulting from a step-voltage excitation

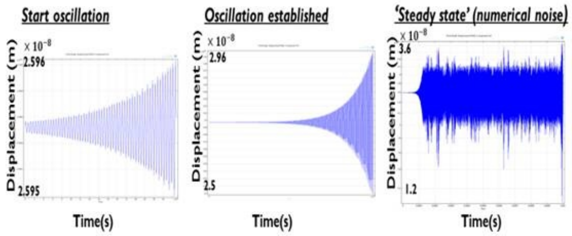

Figure 3: COMSOL simulations including piezoresistivity and presenting self-oscillationkick-in with growing amplitude

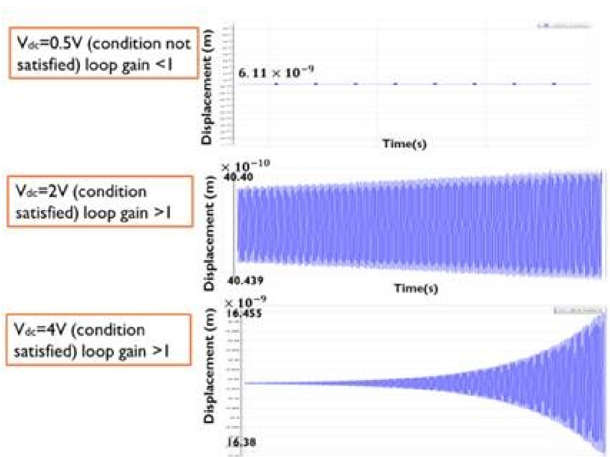

Figure 4: Three cases simulations with COMSOL to verify the analytical threshold for self-oscillation.