# Co-simulation framework in COMSOL Multiphysics® for displacement of a MEMS cantilever using a depletion Schottky transducer

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**INTRODUCTION**: Depletion layer MEMS actuators have been demonstrated in the past in p-n junctions as well as Schottky barrier interfaces to be effective transducers for internal transduction of high Q MEMS resonators without the need for piezoelectric materials or small resonator-electrode gaps[1]. We have presented an FEM model of this transducer, wherein the electrostatic forces generated in the depletion layer and the displacement amplitude of the cantilever are co-simulated using COMSOL Multiphysics®.

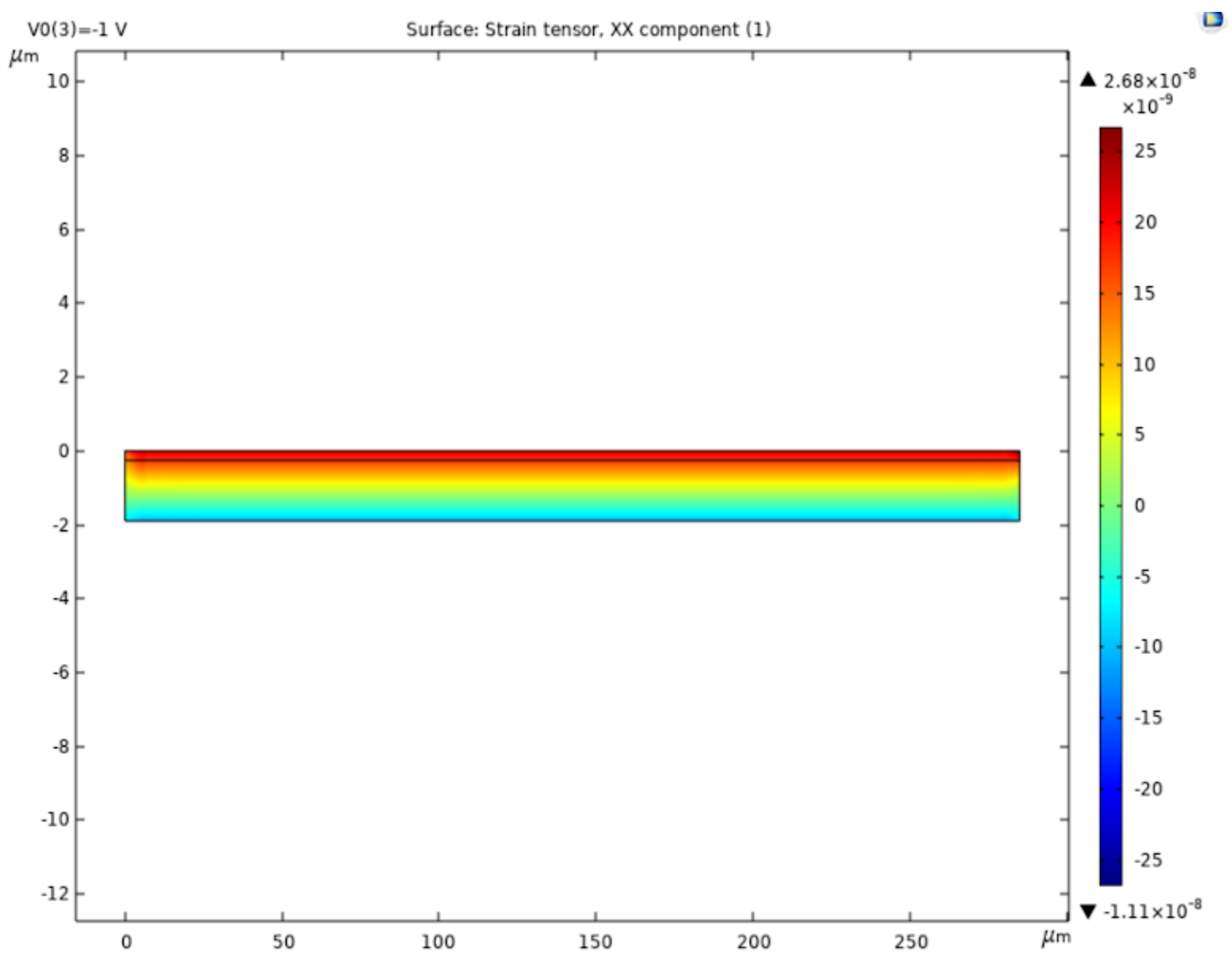
**THEORY**: We have simulated a cantilever acting as a Schottky with the Metal Semiconductor interface at the top surface of the cantilever. A depletion layer is created at this interface. This depletion layer results in electrostatic forces that actuate the cantilever.

An equivalent force applied on the free end of the cantilever, in the downward z direction (F_net) that generates the same bending moment as the internal depletion force [2],[3].

$$F_{net} = \frac{0.3535 v \omega h \sqrt{N e \epsilon V_{DC}} V_{AC}}{L}$$

Given dimensions are denoted by symbols h for thickness, L for length and ω for width. The Schottky barrier is reverse biased and the net built in voltage across the junction is $V_{DC}$. Applied AC voltage, permittivity of semiconductor, doping density of semiconductor and electronic charge are denoted by $V_{AC}$, ϵ, N and e respectively.

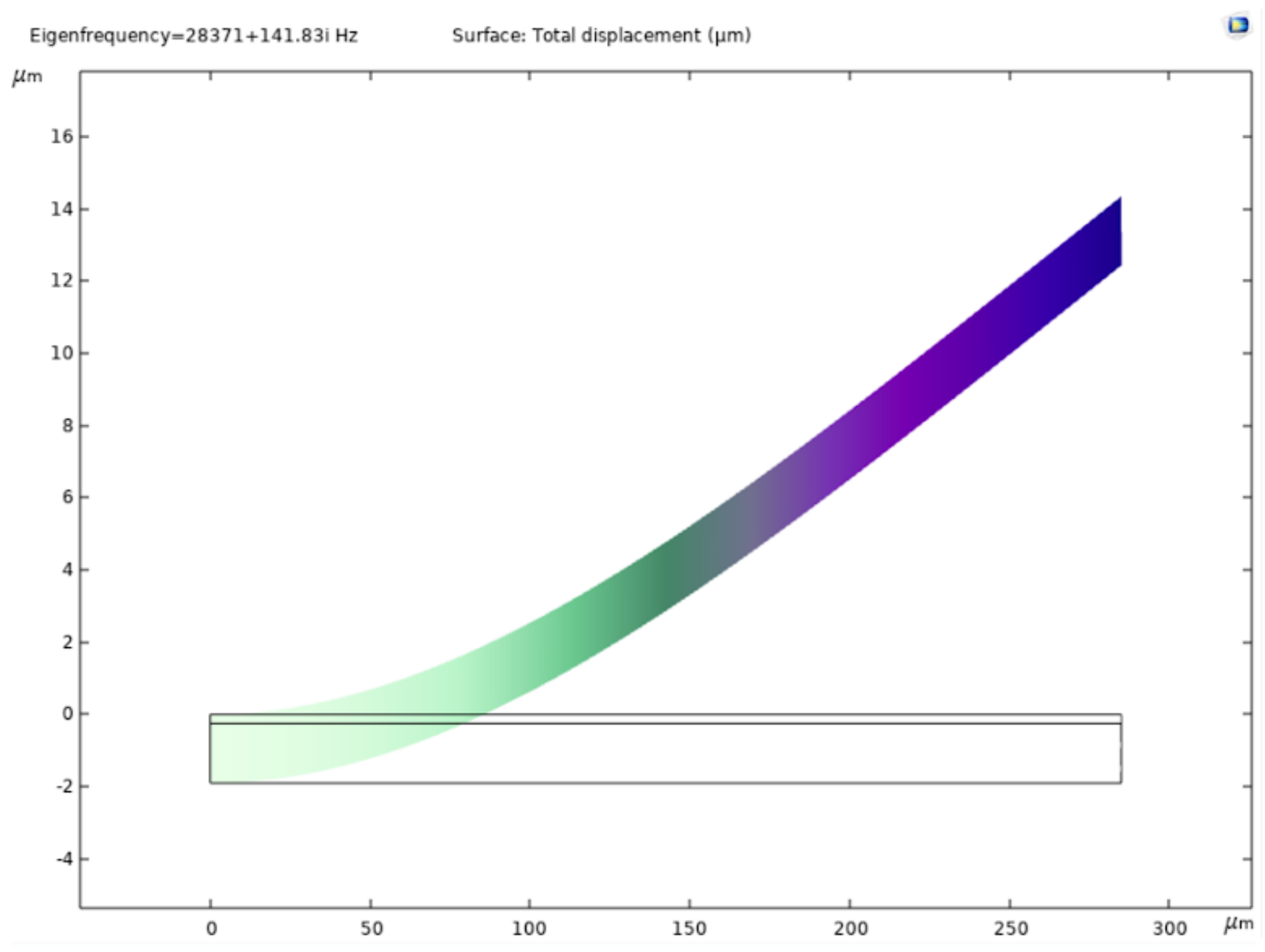
$$a_0 = \frac{QF_{net}}{K} = \frac{1.414 v Q L^2 \sqrt{N e \epsilon V_{DC}} V_{AC}}{E h^2}$$



(a) Derived Strain distribution in Semiconductor Module

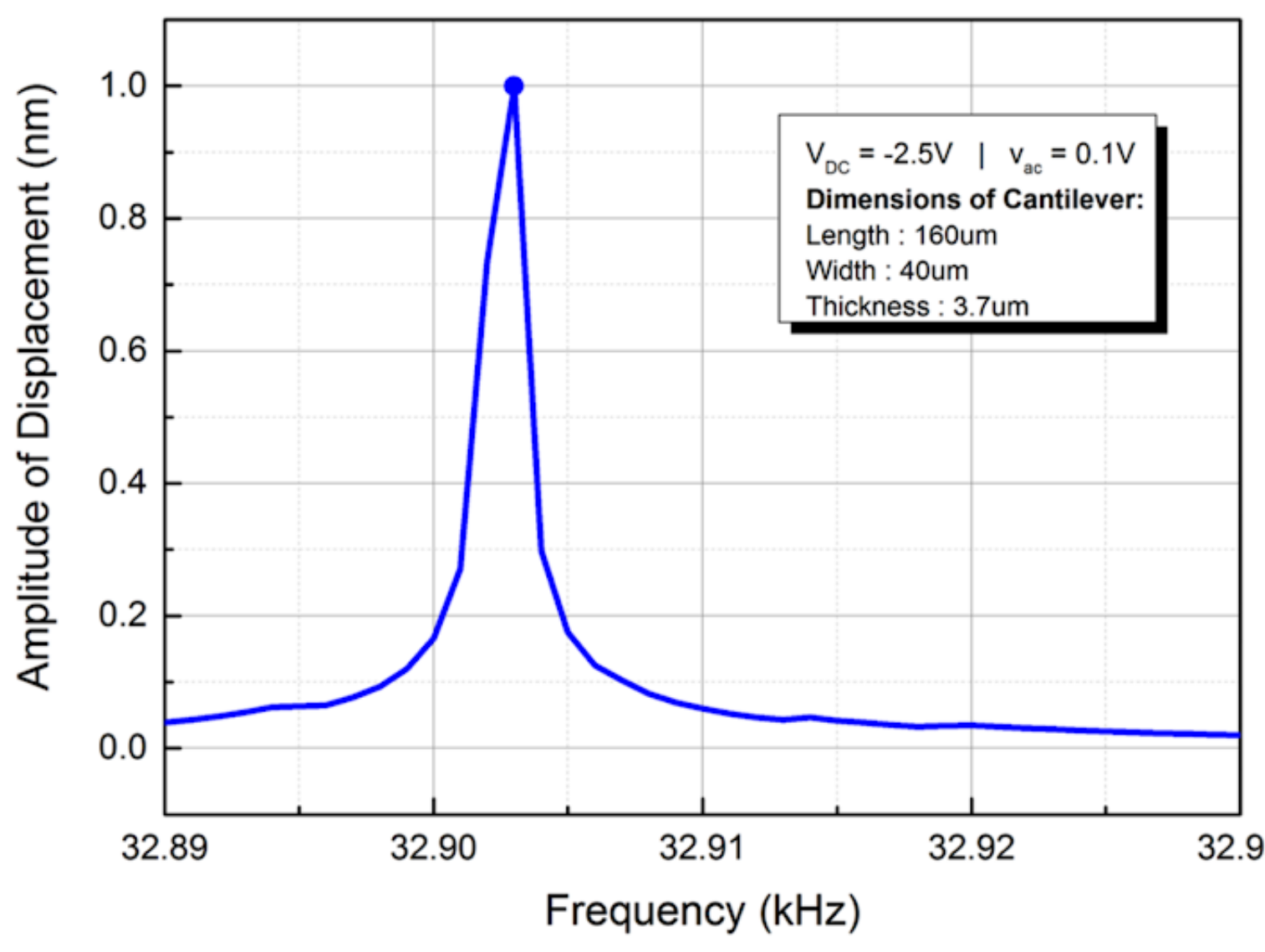
**Figure 1**. Derived Strain distribution in Semiconductor Module

The system as a discrete mass spring-damper system operating at resonance, with displacement at free end $a_0 \sin(2\pi f_0 t)$ and mechanical quality factor Q; we can now written the amplitude of oscillation $a_0$ as mentioned above.



(b) Displacement Profile of Cantilever in Solid Mechanics

**Figure 2**. Displacement profile of Cantilever



(c) Frequency Distribution of the Cantilever

**Figure 3**. Frequency distribution of Cantilever

**SIMULATION**:

1. The electric field across the cantilever is obtained using the Semiconductor Module.
2. The charge density is obtained across the cantilever using Semiconductor Module.
3. A new parameter is defined to equate it to the force density that is the product of electric field with charge density.
4. To avoid making the simulation time too large we will integrate the force density across the cantilever from the top surface to 1/10th of the thickness since the forces will only be confined to the depletion layer.
5. We use the Structural Mechanics Module to apply this obtained force to the cantilever.
6. Obtain the frequency distribution of cantilever while sweeping the value of reverse bias voltage applied.

**CONCLUSIONS**: The FEM simulation results obtained agree well with the analytical model and experimental results reported in literature. The Multiphysics simulations therefore provide a possible co-simulation use case for MEMS resonators.

## REFERENCES:

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2. J. H. T. Ransley, A. Aziz, C. Durkan, and A. A. Seshia, "Silicon depletion layer actuators," Applied Physics Letters Vol. 92, 184103, 2008.
3. Kiran Dhope and Siddharth Tallur, "Equivalent force analysis of a Schottky depletion layer MEMS actuator," Joint Conference of the IEEE International Frequency Control Symposium & European Frequency and Time Forum, 2019.

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