Mechanical modulation of tunnel junction as an ultra sensitive NEMS

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Abstract

In this contribution we present a series of results, obtained by Finite Element Analysis (FEA), concerning a novel type of NEMS: tunnel junctions mounted on thin membranes. The current is modulated via a mechanical stress applied on the barrier material (SiO_2) instead of a modulation of the electrical field. The tunnel junction can be obtained by vertically oxidizing a thin bar of silicon or aluminum, the choice for silicon being made due to the IC compatibility of the technology employed.

A mechanical stress applied to the junction induces changes in the height and length of the barrier, related to the modifications induced by the structure deformation into the semiconductor band structure and to the oxide thickness. A particular way of applying the stress is to mount the structure on a thin silicon membrane, micromachined in a SOI (Silicon On Insulator) wafer [1]. In this case it is not the piezoresistivity that one seeks to implement but the dilation thickness of oxide tunnel because of the exponential dependence of the tunnel current on the oxide thickness. Another important advantage is that one can achieve an applied stress on the structure in the order of GPa without special equipment. Moreover, the tunneling current can be dynamically modulated using the resonance frequencies of the membrane. Maintained in resonance by an external forced oscillation (e.g. by a piezoelectric stack), frequencies in the order of hundreds of MHz can be achieved with a fine tune related to the geometrical dimensions of the membrane. The available technology allows us to micromachine in silicon different types of membrane, from large ones of $3x3mm^2$, 30µm thick, down to thin membranes of $150x150\mu m^2$, 1µm thick, micromachined on SOI wafers, therefore offering a wide range of membrane deformation (for a specific domain of applied pressure) and of resonance frequencies. For an in-plane stress sufficiently small for that the variation of the band gap in the semiconductor remains small [2], one can investigate the tunnel current modulation related to the oxide thickness variation.

The studied structure geometry (Figure 1a) is sufficiently large in order to avoid, in a first approach, other effects related to the geometry. The thickness considered for the oxide is 3nm (which is achievable by local AFM oxidation) and is sufficiently small for direct tunneling through the barrier. The structure is mounted on a thin membrane (Figure 1b), 1µm thick, which is micro machined in a SOI wafer. The membrane deformation and the corresponding stress distribution (Figure 2a) are simulated as a function of the applied pressure, allowing to determine optimal positioning and dimensions for a maximal response as a function of the membrane type and size [3]. The SiO_2 thickness variation resulting from the membrane deformation (Figure 2b) is used for tunneling current calculations. The relative variation of the tunneling current calculated as a function of the applied pressure is in the order of 5% for 100kPa of applied pressure (Figure 3a), and increases up to 30% for 1MPa of applied pressure. A comparison to existing experimental results have been performed in order to validate the models utilized. The tunneling current modulation through a 2.1nm thick oxide barrier was simulated as a function of the applied field. Figure 3b shows a good agreement with the experimental values.

The results concerning the tunnel current and the equivalent sensitivity to the applied pressure for the simulated structure are very promising and open a novel approach for new NEMS devices with a broad field of application. A first prototype is currently under development.

References

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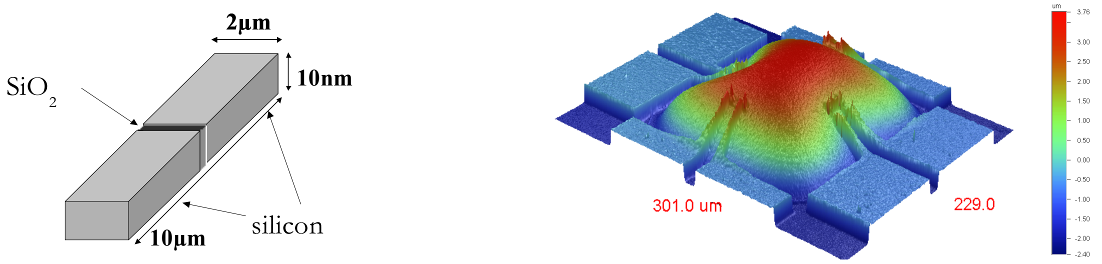
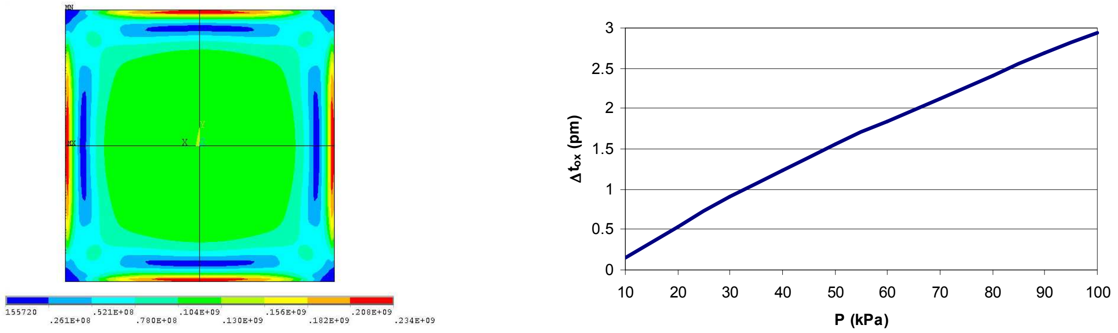
Figures



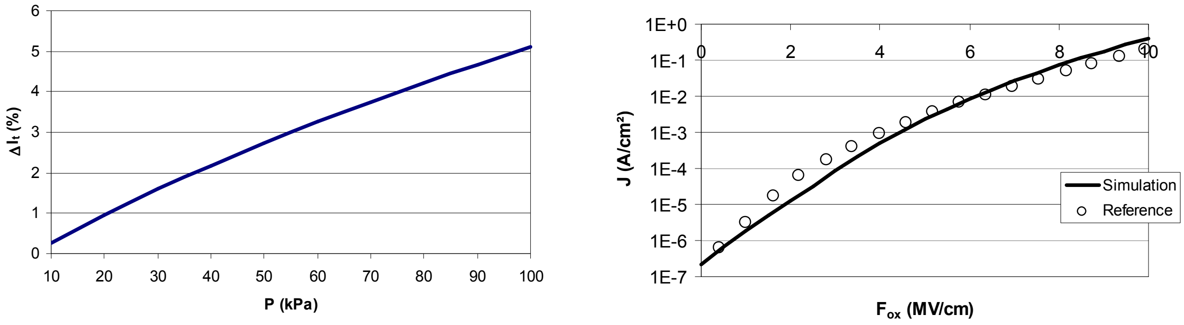
(a) ***(b)***

Figure 1(a) *Schematic view of the structure (Si/SiO$_2$/Si) used for simulation;* ***(b)*** *Measurement of a thin silicon membrane deformation (optical profilometer).*



(a) ***(b)***

Figure 2 (a) *Stress distribution, calculated for a 1µm thick stressed membrane (P=50kPa);* ***(b)*** *Thickness variation of the oxide as a function of the applied pressure.*



(a) ***(b)***

Figure 3 (a) *Tunnel current relative variation as a function of the applied pressure;* ***(b)*** *Simulation results for application on existing experimental data (t_{ox}=2.1nm) [4].*