Measurement of Repulsive Casimir Forces Using Silicon Membranes.

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In this work we present an attempt to measure repulsive Casimir force. The Casimir force is a direct manifestation of boundary dependence of quantum vacuum due to the alteration by the boundaries of the zero-point electromagnetic energy. This phenomena was first described by H.B.G. Casimir in 1948 [1] with an explanation of retarded Van-der-Waals interactions. Casimir found an expression of a finite and attractive force between two infinite and neutral planes. This positive Casimir force has been measured several times, between a sphere and a plane, using different methodologies [2, 3].

Few years ago the existence of a repulsive Casimir force was also predicted [4]. The Casimir effect is strong dependent on boundary. Size, geometry, topology and materials that compose the boundary can switch the force from attractive to repulsive. Kenneth and co-workers [4] predicted the repulsive Casimir force between element 1 and 2 immersed in a medium 3, with the relation between their permitivities as $\varepsilon_1>\varepsilon_3>\varepsilon_2$. Gold, bromobenzene and silica fulfill this relation, and have been used by Capasso and co-workers [5] to measure, for the first time, the repulsive Casimir force.

On the other hand, repulsive Casimir force due to the geometry of the boundary was predicted by many authors, as Gusso and co-workers [6]. This work predicts the existence of a repulsive component of the Casimir force between two plates if one of them has a set of rectangular cavities.

One of the main problems of MEMS (MicroElectromechanical Systems) is the sticktion, the collapse of the resonant structures on the electrodes or substrate. The existence of the repulsive Casimir forces could solve, or diminish, this problem, extending the life of MEMS. The aim of our work is focused on measuring the repulsive Casimir forces on MEMS, particularly between a silicon membrane and an electrode.

We have calculated the Casimir forces between a silicon membrane and an electrode which is engraved with a set of rectangular cavities. Our attempt of measurement is based on the ACO model (Anharmonic Casimir Oslillator) [7] which predicts a shift of the resonance frequency of MEMS due to the presence of the Casimir force. We have calculated this shift on the resonance frequency of a silicon membrane (thermal excited) with the distance between membrane and electrode (engraved with rectangular cavities). For an attractive force, the shift is negative (spring softening) and for a pure repulsive force the shift is positive (spring hardening).

To measure the frequency shift we have fabricated a demonstrator: on a SOI wafer, with 300 nm thick crystal silicon, we have opened a window at the back side of the wafer and we have performed a wet etching (KOH etching) of the silicon (around 500 μm thick) until the oxide layer. Then we have etched the oxide, obtaining a crystal silicon membrane of 300 nm of thickness. We have fabricated a set of these membranes with different areas (different resonant frequencies): 500 μm^2, 700 μm^2 and 1000 μm^2. On the other hand, in a silicon wafer, we have fabricated the electrode, making a hollow 1 μm deep and circular shape at the center of the wafer. Finally, using electron beam lithography, we have engraved the set of rectangular cavities of sides 100 nm wide, 1 μm deep and 100 μm long. A gold layer, 20 nm thick, was deposited both on the wafer with the membranes and the wafer with electrode (in order to enlarge the Casimir effect). Finally, the two wafers were sealed (between them) forming a cavity 1 μm deep between membranes and electrodes.

In order to measure the frequency response of the membrane we have design a measurement system based on Fabry-Perot interference method. The demonstrator will be mounted in a vacuum chamber (in order to reduce the damping effect of the air) forming a Fabry-Perot cavity with a red-light filter. Outside the vacuum chamber there are a 632.8 nm He-Ne laser and an optical system designed for detecting the membrane vibration on a photodetector (1 GHz bandwidth) connected to a spectrum analyzer (see figure 3). The measurement system is now in the test stage.

References:

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Figures:

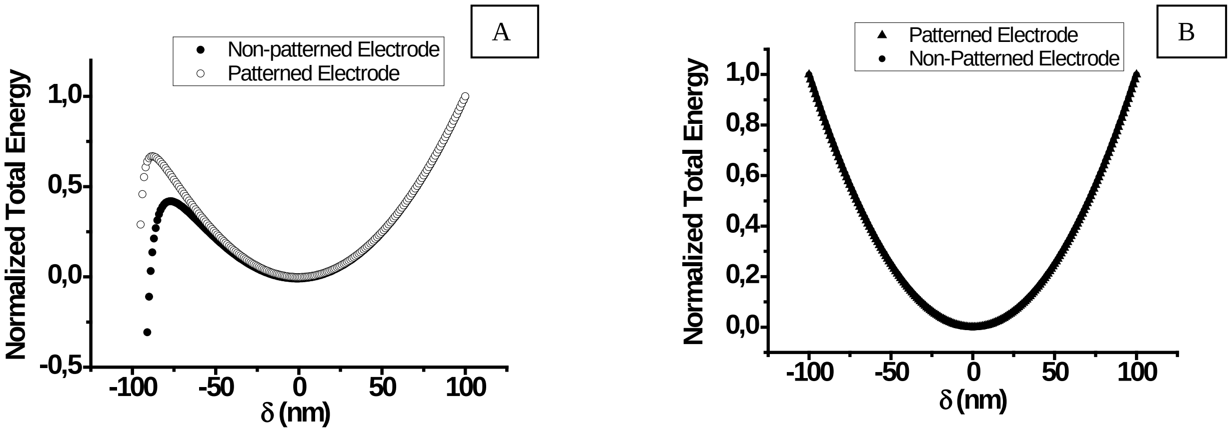

Figure 1: Normalized total membrane energy (Total Energy/Maximum Elastic Energy) versus membrane displacement. **A:** The membrane in his equilibrium position is at L=100 nm from the fixed electrode. **B:** Membrane is at L=800 nm from the fixed electrode. At that distance the total membrane energy is barely modified by the Casimir effect and the membrane vibrates harmonically.

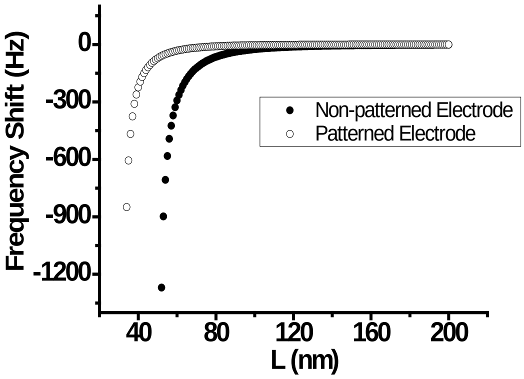

Figure 2: Frequency shift of the membrane resonator frequency due the presence of the electrode at distance L. With the patterned electrode the frequency shift is reduced respect the non-patterned electrode.

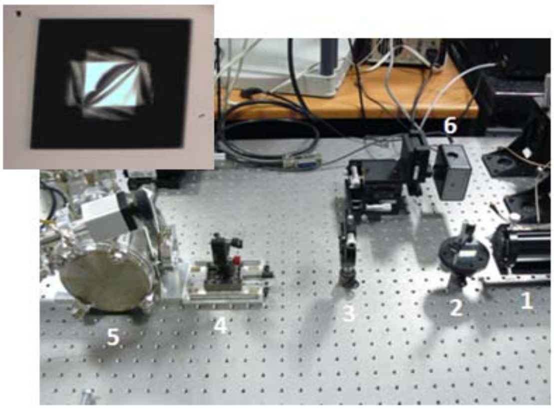

Figure 3: Experimental Set-up and membrane (inset). Laser (1), beamsplitter (2), retarder (3), focusing lens (4), vacuum chamber where the bonded wafers and the filter forming the Fabry-Perot cavity are introduced (5) and photodetector (6).