Measurement of Repulsive Casimir Forces Using MEMS Structures

F. Torres, G. Abadal, G. Murillo, J.LL. López, A. Uranga, J. Giner and N. Barniol
Departament Enginyeria Electrònica, ETSE, Universitat Autònoma de Barcelona
Edifici Q, Campus UAB, 08193 Bellaterra, Spain
Francesc.Torres@uab.cat

In 1948, H.B.G. Casimir published a famous article with a simple but profound explanation about retarded Van der Waals interactions [1] as a manifestation of the zero-point energy of a quantized field. In its simplest form, the so-called Casimir effect is the interaction of a pair of neutral, parallel conducting planes due to the disturbance of the vacuum of the electromagnetic field. It is a pure quantum effect, there is no force between the plates (assumed to be neutral), in classical electrodynamics. Casimir was the first that was extracted a finite force between these two neutral plates, an attractive force:

$$F(d) = -\frac{\pi^2}{240}\frac{\hbar c}{d^4}A \qquad (1)$$

where *d* is the distance between plates and *A* is their area. In recent years, this effect has become highly popular both due to theoretical and experimental developments. The Casimir force was measured through different ways, with force pendulum or Atomic Force Microscopy [2, 3]. Theoretically there was an important development on calculus that involves a great spectrum of materials and geometries. The main theoretical results for micro and nanoelectromechanics field was the possibility that Casimir forces could appear as a repulsive forces, both depending on the materials [4] and the geometries [5] involved. As an example, it was proposed the geometry shown in *figure 1* as rectangular cavities made on the MEMS or substrate. The Casimir force appearing in this geometry mix both repulsive and attractive effect and, depending on the relation between dimensions, one feature could be larger than the other one. We can see in *figure 1* that for the rectangular cavity, if $a_1 \ll a_2 \ll a_3$, then [5]

$$F_2 = \hbar c\left[\frac{\pi^2 a_3}{720 a_1^3} - \frac{\xi_R(3)}{8\pi}\frac{a_3}{a_2^3} + \frac{\pi}{48 a_2^2}\right] \qquad (2)$$

where ξ_R denotes the Riemann zeta function. The repulsive Casimir forces are an interesting way to avoid the collapse of the structure into the substrate/electrode, which is the most important problem for micro and nanoelectromecanical devices (MEMS/NEMS).
The measurement of Casimir forces become very difficult, not only because of the magnitude of the forces involved (near pN) but, mainly, because of the extreme dependence of this effect on the roughness of the material and on the parallelism between planes. Both effects (an excessive roughness and a slight non-parallelism) diminishes the Casimir forces.
The work presented here is an attempt to measure the repulsive Casimir forces in real MEMS. Our first target is to try to measure the spring softening caused by Casimir forces in a silicon (heavily doped) membrane. This is based on the ACO (Anharmonic Casimir Oscillator) model [6] that predicted a shift of resonant frequencies of a resonator (based on the mass-spring model) due to the presence of Casimir Forces.
In *figure 2* we show the experimental device, with a membrane and a metallic electrode bigger than the membrane, in order to diminish as much as possible the non-parallelism between them. It is crucial that the silicon membrane will be heavily doped, because of the nature of the Casimir effect, based on the fact that the contour conditions must be metallic (or

near metallic) to ensure a good reflectivity of the electromagnetic field. And, also, it is crucial to ensure electric neutrality for the entire device to avoid the presence of electrostatic forces that could screen the Casimir interaction. The membrane, sited into high vacuum, vibrates due to thermal energy (without any other kind of external excitations) in its normal modes, and the ressonances will be measured via optical interferometry. The shift predicted by ACO model are around 2 Hz for resonators of 200 μm^2 of area and 50 nm distance between the electrode and the membrane, and increasing to 60-100 Hz for 700 μm^2 of membrane area.

The work presented here will be done in the framework of the project “fuerzas de Casimir repulsivas, medida y aplicabilidad” (TEC2007-29622-E).

References:

[1] H.B.G. Casimir, Proc. K. Ned. Akad. Wet. **51** (1948) 793.
[2] S.K. Lamoreaux, Physical Review Letters **78** (1997) 5.
[3] U. Mohideen, A. Roy, Physical Review Letters **81** (1998) 4549.
[4] O. Kenneth, I. Klich, A. Mann, M. Revzen, Physical Review Letters **89** (2002) 033001-1.
[5] A. Gusso, A.G.M. Schmidt, Brazilian Journal of Physics **36** (2006) 168.
[6] F.M. Serry, D. Walliser, G. J. Maclay, Journ. Microelectrom. syst. **4** (1995) 193.

Figures:

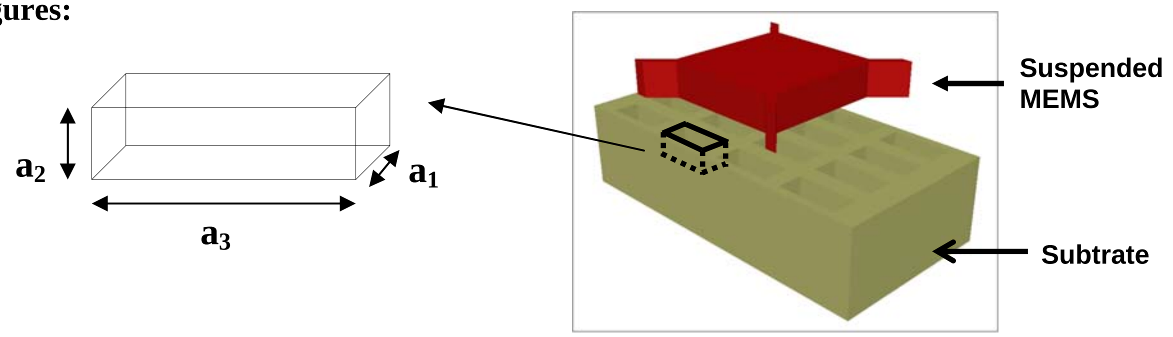

Figure 1: Possible geometry for repulsive Casimir forces

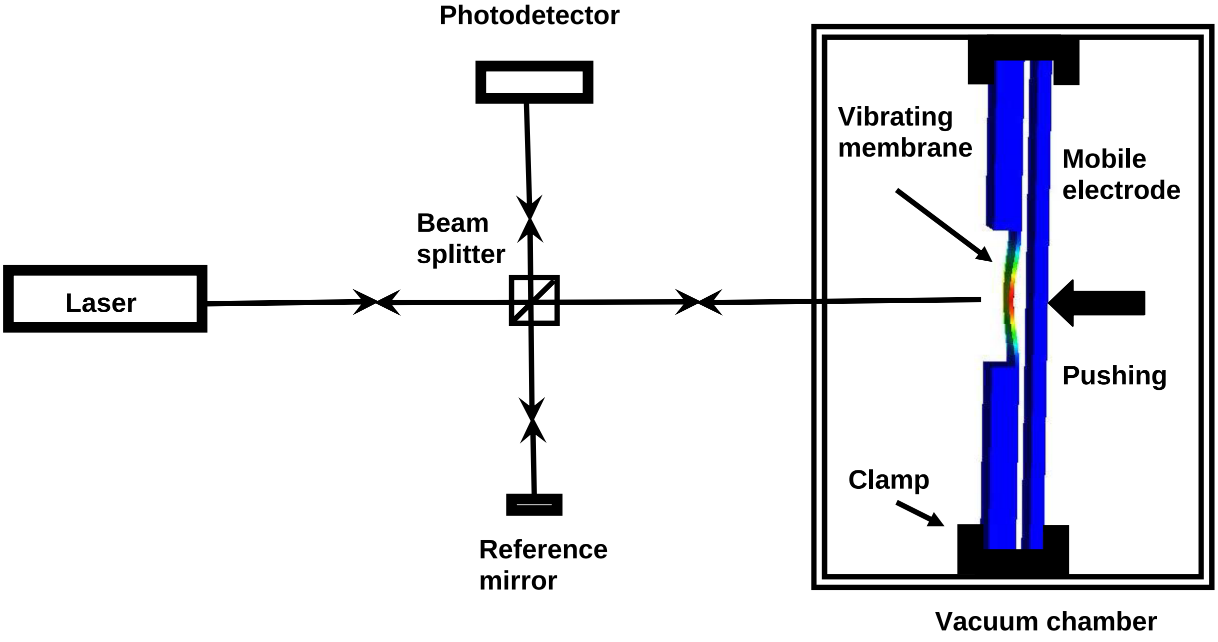

Figure 2: Set up for the measurement of the device based on a silicon membrane