Nano – optomechanic: from Light Pressure to the Casimir Force

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To our knowledge, we report for the first time the optical detection of periodical mechanical deformations of a macroscopic object induced by an oscillating Casimir force. A direct comparison of the periodical mechanical deformation caused by the light pressure and the Casimir force has been performed.

The Casimir force is a concequence of the zero-order vacuum electromagnetic fluctuations [1] leading to attraction between two metallic plates separated by distance Z. Due to a strong dependence on Z ($F \sim 1/Z^4$), the Casimir force manifests itself in a pronounced way at distances less than 1 μm. This means that the vacuum fluctuation modes with the characteristic periods of the order of optical wavelengths give a significant contribution into the Casimir force. For this reason the term “virtual light” can be used for these fluctuations. They result in the attraction between the metallic plates described by the real pressure [1] is:

$$P_c = -\frac{\pi^2 \hbar c}{240 Z^4} \qquad (1)$$

where c is the speed of light, and ħ is the Planck constant. It is interesting to compare (1) with the pressure of the real light given by:

$$P = \frac{I}{c}(1+R) \qquad (2)$$

where R is the reflectivity of the illuminated surface of the object. This means that the Casimir force is equivalent to the light pressure with the intensity:

$$I = -\frac{\pi^2 \hbar c^2}{240 Z^4 (1+R)} \qquad (3)$$

Direct experimental comparison of the pressures induced by the Casimir force and the real light was the main goal of the present work.

The Casimir force was investigated for the case of interaction between a high-conductive plate and a conductive sphere. The “plate” was a thin pellicle with a diameter of 7.62 cm and a thickness of 5 μm, covered by a thin (120 nm) aluminium film, and the “sphere” was a spherical glass lens also coated with a thin alluminium film. They were placed into a vacuum chamber. The lens position was controlled by a piezoelectric driver, so the distance between the lens and pellicle varied as $Z = Z_0 + \delta\cos\Omega t$, where Ω is the lens oscillation frequency. It can be shown that the amplitudes of the first and second harmonics of the Casimir pressure in this case are:

$$P_{\Omega} = \frac{3Bb}{Z_0^3\left(1-b^2\right)^{5/2}};$$

$$P_{2\Omega} = \frac{3Bb^2}{Z_0^3\left(1-b^2\right)^{5/2}} \qquad (4)$$

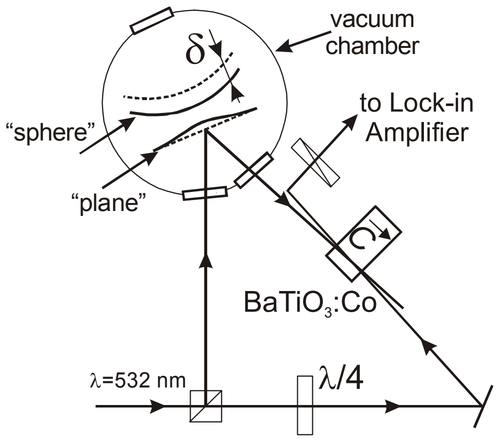
where $B = -\pi^3 \hbar cr/(360\times S_{eff})$, $b = \delta/Z_0$, S_{eff} is the effective surface of interaction, and it is assumed that b<1.

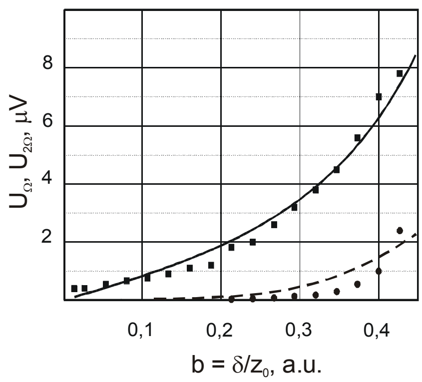
The mechanical pellicle deformations caused by the Casimir force were detected by an adaptive holographic interferometer based on a photorefractive $BaTiO_3$:Co crystal [2]. The experiments were performed in the range Z_0 = 300 ÷ 600 nm and $\Omega/2\pi$ = 3.0 Hz.

The output signals versus the lens vibration amplitude (in relative units) are shown below.

To compare the Casimir force and the light pressure, the lens was removed and the pellicle was illuminated (from the side where the lens had been located) by a periodically modulated laser beam. This beam caused the pellicle deformation similar to some extent to the deformation by the Casimir force. To have the same output signal P_{Ω} see (3)), we used the illuminating light intensity of the order of 4…8 W/cm^2.

To summarize, we have detected the Casimir force and compared it with the pressure of the real light. A reasonable agreement between the theory and experiment has been obtained.





Experimental setup (left); the example of the experimental measurements and theoretical calculations of the Casimir force at Z_0 = 370 nm (right). The squares show the first harmonic, the circles show the second harmonic; the solid lines are theoretical calculations in accordance with Eq. 4 (in relative units).

References

[1] H.B.G. Casimir, On the Attraction Between Two Perfectly Conductive Plates, Proc. K.Ned. Akad.Wet., **51**, (1948) 793

[2] V.M. Petrov, J. Hahn, J. Petter, M.P. Petrov, T. Tschudi, Precise subnanometer control of the position of a macro object by light pressure, Opt. Lett. **30**, 3138-3140 (2005)