Casimir forces between micromechanical components on a silicon chip

H. B. Chan[1], L. Tang[1], C. Y. Ng[1], M. Nikolic[2], C. T. Chan[1], A. W. Rodriguez[2]
[1]The Hong Kong University of Science and Technology, Hong Kong, China
[2]Princeton University, USA

Quantum fluctuations give rise to van der Waals and Casimir forces between electrically neutral conducting objects. For free space, the electromagnetic field can be identically zero in the classical picture. In quantum electrodynamics, on the other hand, electromagnetic fields can never be exactly zero in free space because they are continuously fluctuating. The energy of a photon mode is given by $(n+1/2)\hbar\omega$, where $\hbar$ is the Planck's constant/2π, ω is the frequency of the mode and n is the number of photons. In other words, there is a finite zero-point energy $(1/2)\hbar\omega$ even when no real photons are present. For a cavity formed by two perfectly conducting plates, the electromagnetic field must satisfy the boundary conditions. The zero-point energy density for the electromagnetic fluctuations between the plates is smaller than that in free space. As a result, there is a net attractive force between the plates:

$$F_c=-\pi^2\hbar cA/240z^4, \qquad (1)$$

where c is the speed of light, A is the area of the plates and z is the distance between them.

At the micrometer scale Casimir forces are typically negligible. Nevertheless, according to Eq. (1), they increase rapidly with decreasing distance. For perfectly conducting plates, the pressure reaches one atmosphere at separations of ~ 10 nm. As miniaturization continues to take place, micromachined components become more closely-packed and such quantum effects could start to become important. For example, it has been pointed out that the Casimir force can initiate the pull-in of components, leading to stiction. As a result, there have been a number of suggestions to reverse the sign of the Casimir force to make it repulsive by, for instance, making use of meta-materials.

Even though micromechanical force transducers are widely used in experiments that investigate the Casimir force, demonstration of the Casimir force on the chip level remains a challenge. So far, in all experiments one of the interacting surfaces is an bulky, external object that must be carefully positioned close to the force sensing element.

Here, we demonstrate that the Casimir force can become the dominant interaction between components within the same silicon chip, without the need of external objects [1]. Our device consists of a doubly-clamped silicon beam (100 μm long and ~ 1.42 μm wide) and a movable electrode attached to a comb actuator, fabricated from the 2.65μm-thick device layer of a silicon-on-insulator wafer. The beam (red) serves as the force sensing element and the comb actuator controls the distance between the beam and the movable electrode (blue) along the y direction.

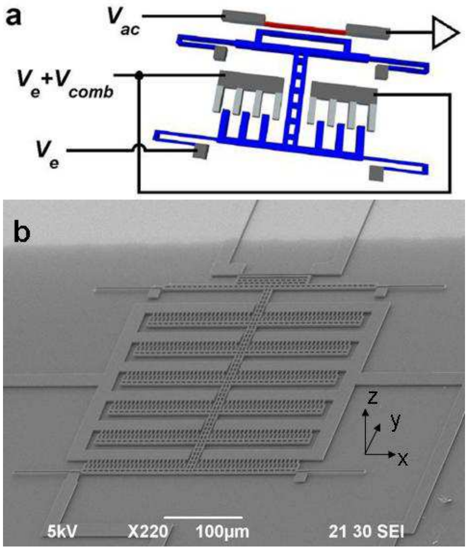

Figure 1. (a) A simplified schematic of the beam, movable electrode and comb actuator. (b) Scanning electron micrograph of the device.

After compensating for the residual voltage to minimize the electrostatic forces, we measure the force gradient exerted by the movable electrode on the beam as a function of distance [1]. The measured Casimir force gradient agrees well with theoretical predictions.

The main advantage of this platform is that the two interacting surfaces are defined by lithography and etching, ensuring that they are automatically aligned after fabrication. In the talk, we will present results from an ongoing experiment that uses this platform to create surfaces with complex shapes. The Casimir force in this structure exhibits a non-monotonic dependence on distance.

This work is supported by HKUST 600511 and 16300414 from the Research Grants Council of Hong Kong SAR.

[1] J. Zou, Z. Marcet, A. W. Rodriguez, M. T. H. Reid, A. P. McCauley, I. I. Krachenko, T. Lu, Y. Bao, S. G. Johson and H. B. Chan, "Casimir forces on a silicon micromechanial chip,' Nature Communications, vol. 4, 1845, 2013.