Driving the performance of nanosystems to the limit

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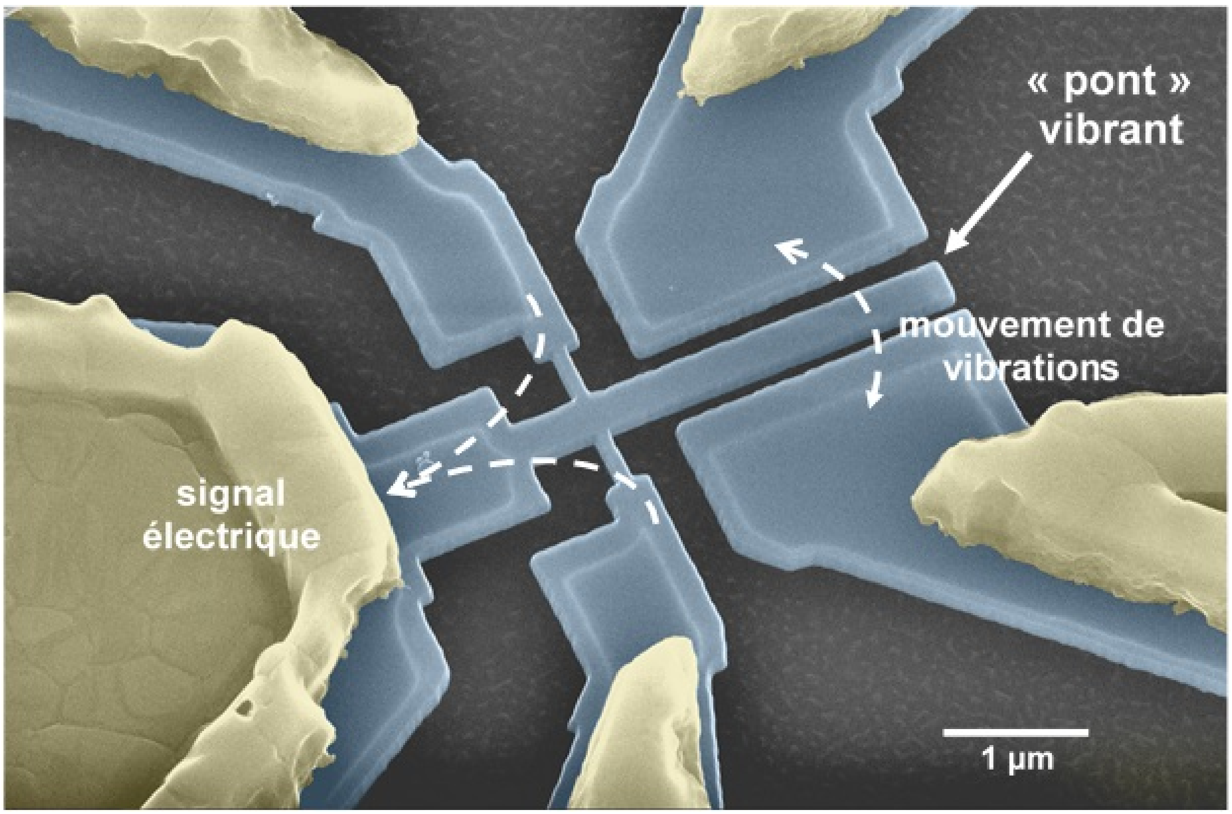

A joint CEA / University of Grenoble-Alpes research team, together with international partners, has developed a diagnostic technique capable of identifying performance problems in nanoresonators, a type of nanodetector used in research and industry. These nanoelectromechanical systems, or NEMS, have never been used to their maximum capabilities. The detection limits observed in practice have always been well below the theoretical limit and, until now, this difference has remained unexplained. Using a totally new approach, the researchers have now succeeded in evaluating and explaining this phenomenon. Their results, described in the February 29 issue of *Nature Nanotechnology*, should now make it possible to find ways of overcoming this performance shortfall.

NEMS have many applications, including the measurement of mass or force. Like a tiny violin string, a nanoresonator vibrates at a precise resonant frequency. This frequency changes if gas molecules or biological particles settle on the nanoresonator surface. This change in frequency can then be used to detect or identify the substance, enabling a medical diagnosis, for example. The extremely small dimensions of these devices (less than one millionth of a meter) make the detectors highly sensitive.

However, this resolution is constrained by a detection limit. Background noise is present in addition to the wanted measurement signal. Researchers have always considered this background noise to be an intrinsic characteristic of these systems (see Figure 2). Despite the noise levels being significantly greater than predicted by theory, the impossibility of understanding the underlying phenomena has, until now, led the research community to ignore them.

The CEA-Leti research team and their partners reviewed all the frequency stability measurements in the literature, and identified a difference of several orders of magnitude between the accepted theoretical limits and experimental measurements.

In addition to evaluating this shortfall, the researchers also developed a diagnostic technique that could be applied to each individual nanoresonator, using their own high-purity monocrystalline silicon resonators to investigate the problem.

The resonant frequency of a nanoresonator is determined by the geometry of the resonator and the type of material used in its manufacture. It is therefore theoretically fixed. By forcing the resonator to vibrate at defined frequencies close to the resonant frequency, the CEA-Leti researchers have been able to demonstrate a secondary effect that interferes with the resolution of the system and its detection limit in addition to the background noise. This effect causes slight variations in the resonant frequency. These fluctuations in the resonant frequency result from the extreme sensitivity of these systems. While capable of detecting tiny changes in mass and force, they are also very sensitive to minute variations in temperature and the movements of molecules on their surface. At the nano scale, these parameters cannot be ignored as they impose a significant limit on the performance of nanoresonators. For example, a tiny change in temperature can change the parameters of the device material, and hence its frequency. These variations can be rapid and random.

The experimental technique developed by the team makes it possible to evaluate the loss of resolution and to determine whether it is caused by the intrinsic limits of the system or by a secondary fluctuation that can therefore by corrected. A patent has been applied for covering this technique. The research team has also shown that none of the theoretical hypotheses so far advanced to explain these fluctuations in the resonant frequency can currently explain the observed level of variation.

The research team will therefore continue experimental work to explore the physical origin of these fluctuations, with the aim of achieving a significant improvement in the performance of nanoresonators.

More information: Marc Sansa et al. Frequency fluctuations in silicon nanoresonators, *Nature Nanotechnology* (2016). DOI: 10.1038/NNANO.2016.19

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