The highest amplification in tiny nanoscale devices

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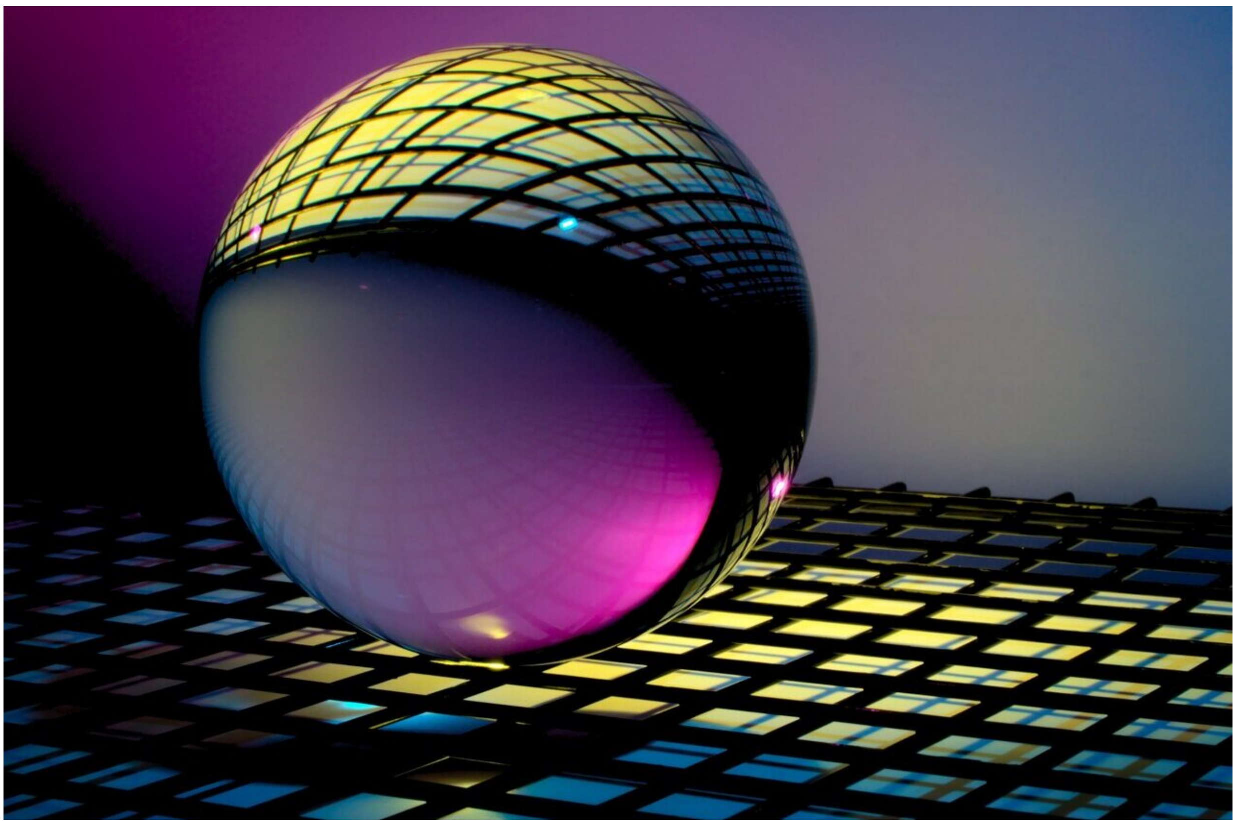

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A team of researchers from the University of Florida, led by Dr. Philip Feng, in collaboration with Prof. Steven Shaw in Florida Institute of Technology, has now demonstrated extremely high-efficient mechanical signal amplification in nanoscale mechanical resonators operating at radio frequency. The devices employed in this research might be the tiniest mechanical resonators exhibiting amplification, and the gain achieved is the highest known for all mechanical devices reported to date.

The displacement amplification is realized based on "parametric pumping or parametric amplification" of mechanical motion. Parametric amplification can be mainly achieved when a parameter of system is modulated by twice multiples of the frequency. A simple example of parametric amplification is a child playing a swing. The child can periodically stand and squat twice in a single period of the swing to increase or "amplify" the swing amplitude without anyone helping to push.

The researchers have realized the parametric amplification in the tiny nanoscale devices. The nanoscale drumhead mechanical parametric amplifiers demonstrated in this research consist of an atomically thin two-dimensional semiconducting molybdenum disulfide (MoS_2) membrane where the thickness of the drumheads is 0.7, 2.8, 7.7 nanometer with 1.8 micrometer in diameter and 0.0018–0.020 m^3 in volume. The nanodrums are fabricated by transferring nanosheet exfoliated from bulk crystal over microcavities to make suspended atomically thin nanodrums.

The researchers play the nanodrums using an amplitude modulated laser. When the laser gently "hit" the nanodrums, the light energy is converted to heat, and thermal stress can parametrically "play" or "pump" the device if the thermal actuation has twice the frequency of the resonance frequency of the device. This parametric pumping process makes the nanodrums vibrate with larger amplitude, similar to percussion instruments in much larger scale. Researchers find the photothermal effects in the semiconducting MoS_2 nanodrums are highly effective compared to other hypothetical nanoscale devices composed of mainstream semiconducting materials such as silicon thanks to intriguing thermal, optical, and mechanical properties of atomically thin MoS_2 nanosheets.

The nanoscale devices exhibit giant parametric amplification gains up to 3600, the highest measured parametric gain known for all nano/microscale mechanical resonators reported to date. The giant parametric gain is stemmed from ultimately thin nature of the device. The devices have thickness comparable to size of atom which leads to the extremely high parametric gain in tiny mechanical devices.

The highly efficient parametric amplification could be adapted to detect ultrasmall mechanical motion. In nanoscale mechanical devices, it has been challenging to have an efficient displacement signal transduction method. It has often connected to electronic circuits, but displacement signals are often superposed on the much larger electrical background and noise from readout electronics. Using parametric amplification, it is possible to first amplify the signal directly in the mechanical domain before electrical transduction, allowing us to alleviate excess amplifier noise.

The additional benefit of the parametric amplification is that the parametric amplification compensates intrinsic energy loss of the resonators, which confines mechanical vibration within a very narrow frequency bandwidth. Compared to the frequency response before the parametric amplification, linewidth or bandwidth narrowing factors up to 180,000 have been demonstrated in the nanoscale resonator, greatly improving the capability of selecting the resonance frequency. The researchers explained that the narrow linewidth is critical for some applications, including building a precise clock, and thus the parametric amplification demonstrated in this research would help to build high performance timing devices.

The researchers strongly believe this work will be of broad and great interest and will have a significant impact in the areas of emerging atomically thin materials and devices, nanoelectromechanical (NEMS) sensors and actuators, parametric operation of nanoscale resonators, and nanomechanics. The researchers can also expect that, when implemented with careful design and improved engineering control, such tiny devices will become a powerful approach and possibly a new paradigm for realizing high-performance sensing and other information processing devices, in both classical and quantum engineering, metrology, and other applications where parametric amplification will play important roles.

This work is now formally accepted in *Applied Physics Reviews*.

Provided by University of Florida

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