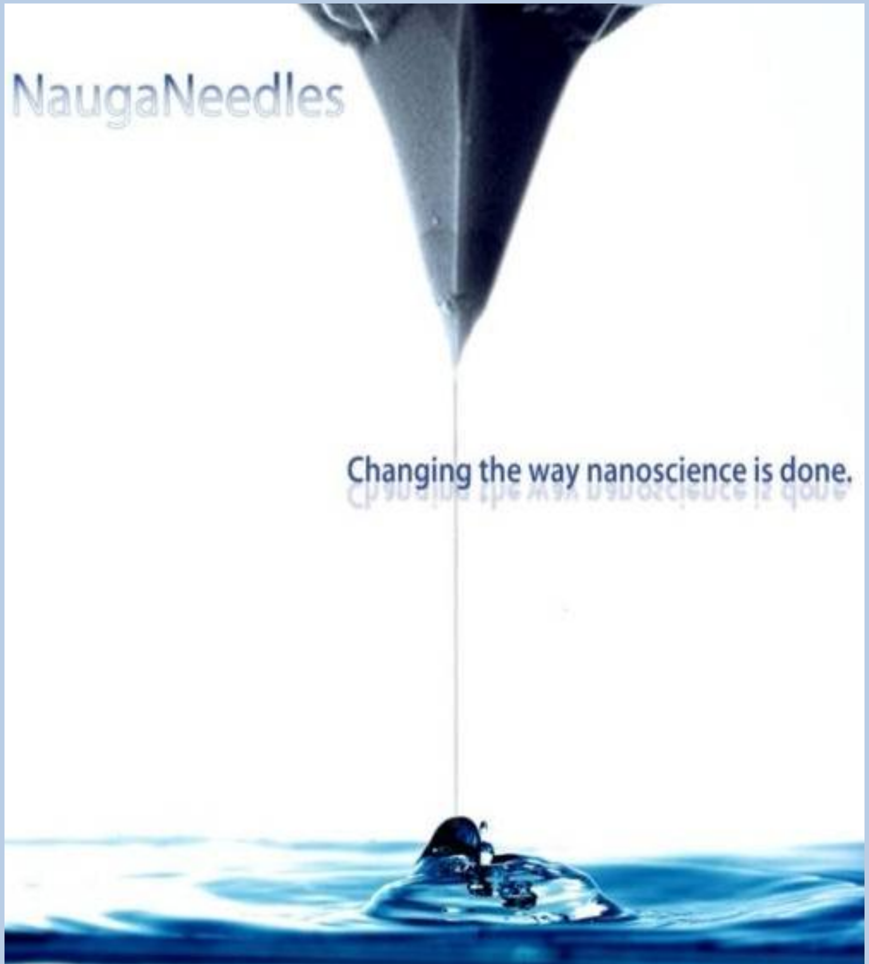

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NaugaNeedles NanoCantilever™ (NCL)

NaugaNeedles has a unique technology to selectively grow individual metallic Silver/Gallium (Ag_2Ga) nanoneedles at any selected location and orientation. Based on this technology, NaugaNeedles is proud to introduce the first commercially available NanoCantilever.™ The NanoCantilever (NCL) has spring constants as low as 10^{-5} N/m, high frequency bandwidth with resonance frequencies in the 0.02–10 MHz range, small suspended mass (femto-grams), and relatively high quality factors (Q) of 50 under ambient conditions [1]. The NanoCantilever™ (NCL) is fabricated of Ag_2Ga crystalline intermetallic compound [2] with excellent optical properties, mechanical flexibility and chemical stability in ambient condition. The NCLs can be produced in variety of lengths (5 to 200 µm long) and thicknesses (100 to 300 nm). ***Figure 1*** shows an optical image of a stationary NCL (left) and SEM images of an NCL as it is being vibrated by electrostatic force inside an SEM in 1st, 2nd and 3rd natural frequency mode. Also, as noted in ***Figure 1***, despite their nanometer size, NCLs can be seen under an optical microscope.

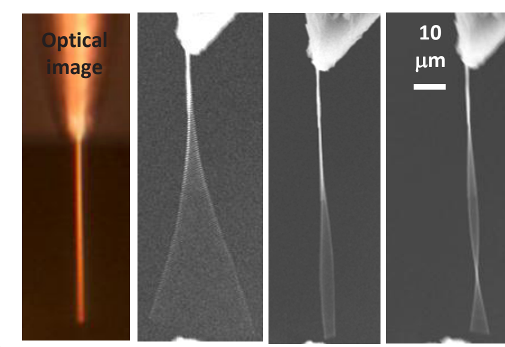

Figure 1: optical (left) and SEM images of a NanoCantilever

Due to their crystalline structures, NCL are extremely robust and do not plastically deform even when buckled beyond 50% of their original length [3]. The vibration spectra of the NCLs can be detected by standard instruments (e.g. using a MSA-500 Micro System Analyzer from Polytec Inc [1,4] (***Figure 2***), SIOS-interferometer & vibrometer from PiezoSystemJena Inc [5], or a custom made noninterferometric optical setup [6]). ***Figure 2c,d*** shows the vibration spectrum of a NanoCantilever using a Laser Doppler Vibrometer (LDV) from Polytec.

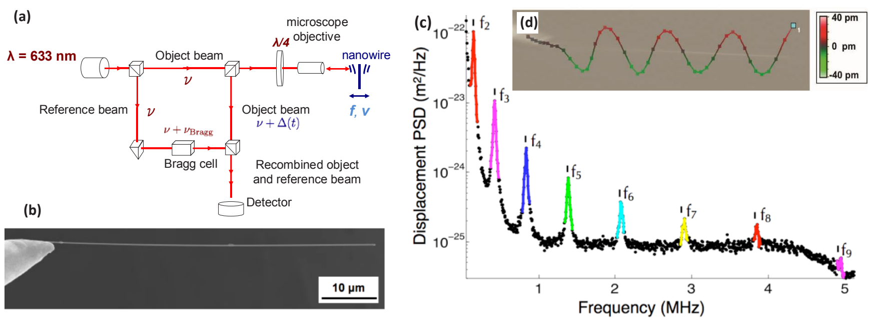

Figure 2: (a) Schematic diagram of the laser Doppler Vibrometer. (b) SEM image and (c) the measured displacement of a thermally excited Ag_2Ga NanoCantilever (NCL). (d) NCL displacement detected by scanning the laser beam along the NCL.

Vibrational Properties of NCLs in Water and Vacuum

Shorter NCLs, ranging between 5 to 10 µm in length, were submerged under water, and measurements were performed to evaluate whether immersion under a liquid might pose a problem for the LDV technique. In a recent study, the NCL resonance in air for a short NCL (7.7 µm long, 300 nm diameter) was measured (blue curve in ***Figure 3a***). This resonance frequency spectrum broadened when the same NCL was submerged under water (green curve in ***Figure 3a***). For this particular NCL, the Q of the resonance was 48 in air and ~1.2 in liquid. To determine the effect of pressure, similar experiments were performed on an NCL (length 7.8 µm, diameter 150 nm) (***Figure 3b***). For a pressure of 30 Torr, it was found that the Q had been enhanced from 24.8 under ambient conditions to a value of 135 for a pressure of 30 Torr. Obviously, the Q can be further increased by a greater decrease in the pressure.

Femtogram Mass Sensing Using NCLs in Air

In another study, a number of tests were performed to demonstrate the downward shift in resonance frequency upon added mass. These results are summarized in ***Figure 3c***. Upon re-measurement, the vibrational spectrum shows a downward shift compared to the spectrum of the pre-coated cantilever. The fractional frequency shift was measured to be 1.3 kHz. (***Figure 3c***, inset) This result, combined with the measured dimensions of the NCL, indicates a mass addition of 2.6 fg.

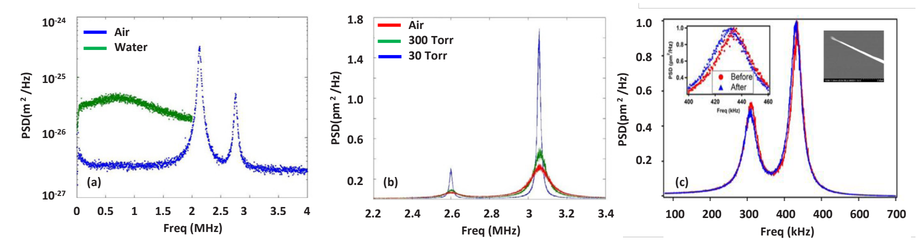

Figure 3: (a) A comparison between the power spectral density (PSD) of an NCL measured by the LDV in air (blue curve) and in wate, (green curve). (b) The PSD of an NCL as a function of air pressure. The Q of the resonance sharpens considerably (Q_{760} = 24.8; Q_{30} = 135) as the pressure is reduced to 30 Torr. (c) The PSD of an NCL measured before and after amorphous carbon deposition. The resonant frequency shifts downward by 3.1 kHz.

The Young's modulus of the material has been measured at 84GPa [1] making the utility of NanoCantilevers ideal for ultra small mass sensing and high frequency bandwidth pico-Newton force detection, and has already been demonstrated by several researchers around the world (e.g. Purdue University and Lawrence Berkeley National Laboratory [1,6]).

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