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Magnetopiezoresistance effects in an InAs/AlGaSb nanomechanical resonator with extremely small power consumption

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Nano-electromechanical systems (NEMS), realized in semiconductor beams/cantilevers, enable the coupling of electronic and mechanical properties and represent an exciting area of research [1–3]. These devices offer a range of new applications including highly sensitive charge detection [4], electron spin detection [5] and quantum measurement [6, 7].

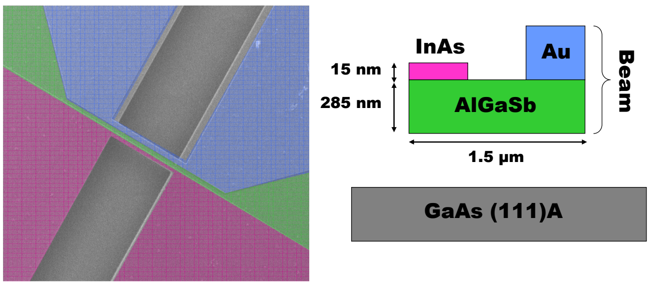

FIG. 1: An SEM image of the device measured with the Au (blue), InAs (pink) channels and the AlGaSb (green) trench incorporated into the 8 μm long and 1.5 μm wide beam where the Au channel is used to actuate the beam and the InAs channel is used to detect the beam displacement. Also shown is the cross-section of the beam suspended above the GaAs substrate and the direction of the magnetic field.

Displacement detection via the piezoresistive method has advantages in device minimization and integration. However, this is offset by the need for large bias currents ($\sim\mu$A) to enhance displacement sensitivity. Such high bias currents in nanoscale structures result in significant resistive heating thus impairing displacement sensitivity and limiting low temperature applications. In this study we demonstrate the detection of nanoscale radiofrequency mechanical oscillations with a bias current as small as 5 nA, by utilizing the strong strain effect on the electron interference in a quasi-1D electron system incorporated on to the mechanical resonator [8].

The semiconductor heterostructure used to fabricate the quasi-1D electron system and the mechanical resonator consisted of InAs(15 nm)/$Al_{0.5}Ga_{0.5}Sb$(285 nm)/GaAs(111)A(substrate) [9]. The heterostructure was processed into a free standing structure (InAs/$Al_{0.5}Ga_{0.5}Sb$) by utilizing electron beam lithography. The suspended beam, shown in fig. 1 is 8 μm long and 1.5 μm wide. It consists of Au and InAs channels that are electrically isolated by the AlGaSb trench all 0.5 μm wide.

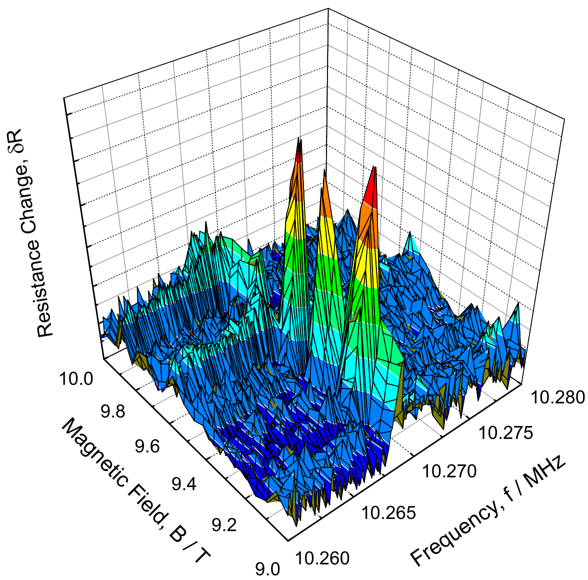

FIG. 2: The resistance change measured in the InAs channel as function of beam vibration frequency and magnetic field. A large resistance change occurs when the beam is at resonance but by changing the magnetic field this resistance change can be modified.

The beam was actuated using the magnetomotive method where an alternating current was passed in the Au channel in the presence of a magnetic field. An out of plane beam resonance frequency, f_0 = 10.268 MHz and

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quality factor, $Q = 12000$ was measured. The beam oscillation was then detected by measuring the resistance change in the InAs channel as a function of beam vibration frequency and magnetic field and is shown in fig. 2. The resistance change at the beam resonance frequency (magnetopiezoresistance) was strongly peaked. By varying the magnetic field, this resistance change at resonance could be modulated. The magnetopiezoresistance showed reproducible aperiodic oscillations. The fluctuations in the magnetopiezoresistance arose due to the strain in the vibrating beam which modified the Fermi wavelength. This modulation in the Fermi wavelength resulted in shifts of the relative electron phase between the different electron conduction paths, therefore changing the resistance. This variation in the magnetopiezoresistance enabled an InAs bias current as small as 5 nA to detect the mechanical oscillations of the beam.

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