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Piezoresistive Nanomechanical Cantilever based on InAs/AlGaSb Heterostructure

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1. Introduction

Since a decade efforts are focused on decreasing the sizes of cantilever in order to improve the performance of their properties like the resonant frequency. High resonant frequency mechanical oscillator may be coupled to a single electron transistor [1]. Such coupling is expected to allow the detection of mechanical quanta and will open the way to the mechanical quantum computer. Within that context we have fabricated an electro-mechanical device composed of an InAs/AlGaSb nanomechanical cantilever (3x1.5x0.3 μm^3 for length, width and thickness respectively, see Fig. 1) and we propose a novel method of characterization using Atomic Force Microscope (AFM). In the first section, the realization of the device is described following in the second section by the characterization. In the last section, the results of measurements are given with a discussion on the length dependence of the properties of realized structures.

2. Realization of the device

The sample used is an InAs(15 nm)/AlGaSb(285 nm) heterostructure grown by Molecular Beam Epitaxy on a undoped (111)A GaAs substrate. As the Fermi level is pinned in the conduction band at the surface of the InAs layer, a 2D electron gas is confined naturally in the near-surface region. This phenomenon preserves the electric conductivity even for the nanometer-size structures [2].This is an alternative to the conventional GaAs/AlGaAs heterostructures which have the problem of carrier depletion for device size reduction [3]. The device is composed of a cantilever free standing above the substrate (Fig. 1) and two Ti/Au pads for electrical connections.

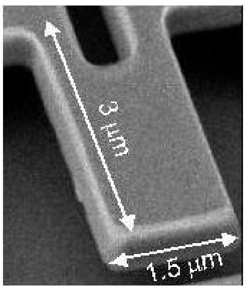

Fig. 1 SEM picture of the realized cantilever.

The electrical current flows from one pad to the other pad through the cantilever legs and plate. First the pads are patterned using the lift off technique on the top of InAs layer. The cantilever is shaped between the two pads using successively e-beam lithography and BCL_3 dry etching. In order to ensure electrical insulation, a mesa pattern is also defined around the device by BCL_3 dry etching. The cantilever is then released with an ammonia solution.

3. Characterization using AFM

AFM is commonly used for profiling sample with a sub-angstrom height detection. However AFM is also used today like a tool to build nano-size devices [4] or to characterize tiny structures mechanically [5]. In order to characterize our sample, piezoresistance measurements were performed. The piezoresistive effect comes from change in electrical resistance due to modification in the carrier concentration and/or mobility of the InAs layer after applying a mechanical deflection to the cantilever. The sample is mounted on the z-piezo translator of a commercially available AFM and the tip of the AFM cantilever is brought to the apex of our cantilever. Modulating the sample height by the z-piezo transalator creates a vertical displacement of our cantilever. This is an alternative way for actuation of tiny structures in contrast with more sophisticated methods [6]. The change in resistance due to the displacement of the cantilever is converted into a voltage change by a Wheatstone bridge circuit. The voltage change is then amplified and recorded by a spectrum analyzer.

4. Results of characterization

The method described previously allows characterizing the realized cantilevers through piezoresistance measurements. The sensitivity and the resolution of the cantilevers were obtained. In the case of a displacement sensor, the sensitivity is given as the fractional change in resistance per vertical displacement of the sensor. Fig. 2 shows the voltage change with respect the cantilever displacement and the biased voltage. Very small displacement (~0.4 nm) can be detected with reasonable biased voltage.

The slope of the curves divided by the biased voltage is proportional to the sensitivity. At a biased voltage of 0.4 Volts, a high cantilever sensitivity of 2.64 x 10^{-4} nm^{-1} is obtained. The resolution of the cantilever determines the minimum displacement that can be measured and is calculated as the measured total noise from the cantilever divided by the sensitivity. Fig. 3 shows the resolution of the cantilever for three decades of frequency. At lower frequency than 1kHz, the measured total noise is limited by

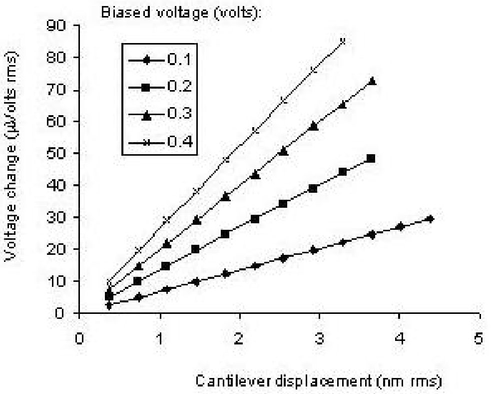

Fig. 2 Voltage change versus cantilever displacement.

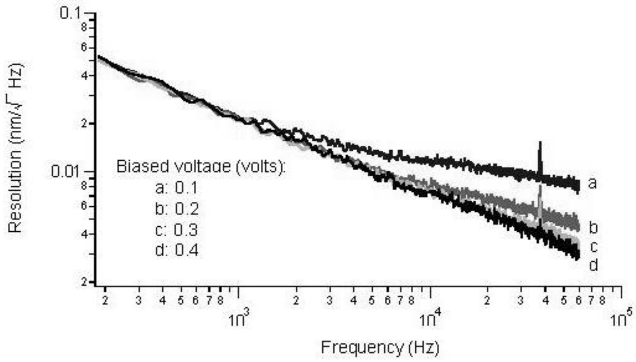

Fig. 3 Resolution of the cantilever.

the 1/f noise, which is proportional to the bias voltage, so that the resolution doesn't depend on the biased voltage (at a frequency of 714 Hz, the resolution is worth 2.6 x 10^{-2} nm/$Hz^{0.5}$). At higher frequency, the resolution is lower as the biased voltage is increased because the noise is limited not only by 1/f noise but also by Johnson thermal noise, which is independent of the voltage [7].

In Fig. 4 the length dependence of the sensitivity and the resolution is represented. The sensitivity increases as the length of the cantilever decreases. The measurement points follow a L^{-2} law where L is the length of the cantilever. This behavior is explained by the proportionality relation between the fractional change in resistance and the strain of the piezoresistive material under mechanical stress (the strain is inverse proportional to L^2). The resolution tends to saturate down to a low value while the length of the cantilever decreases.

5. Conclusions

Nanoelectromechanical devices composed of an InAs/AlGaSb nano-size cantilever have been realized and characterized. The tip of an AFM cantilever was found to be a convenient way to actuate such tiny structures and to create strain change in the piezoresistive material for piezoresistance measurement. A high sensitivity was measured. A study of the resistivity and the resolution was done with respect to the length of the cantilever. The resolution saturates down to a low value though the sensitivity is inverse proportional to the square length of the cantilever.

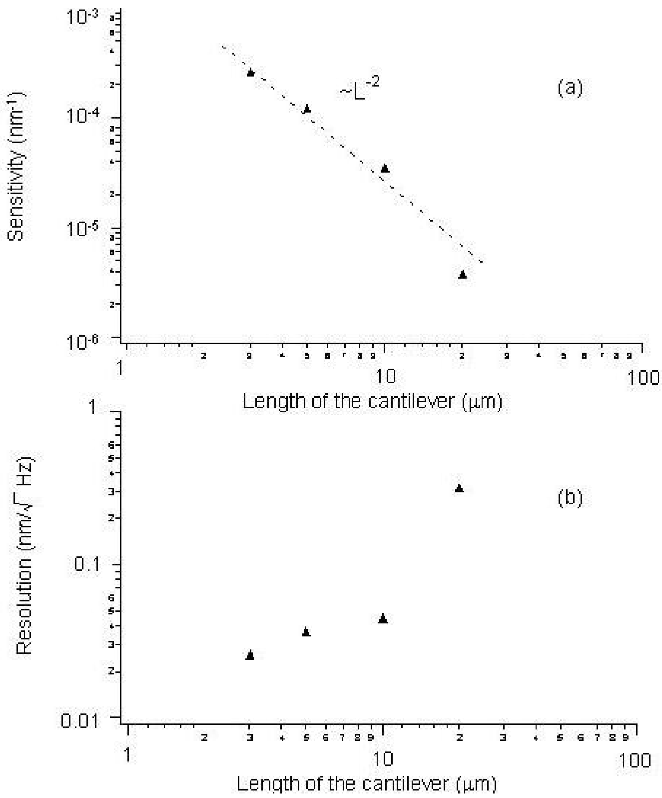

Fig. 4 Length dependence of the sensitivity (a, Vbias=0.4 Volts) and the resolution (b, Vbias=0.4 Volts, frequency=714 Hz).

Acknowledgements

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