Fabrication, metrology and application of electromagnetically actuated cantilever arrays

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In various scanning probe microscopy (SPM) based technologies it is necessary to drive and control resonance cantilever oscillation. Various methods of vibration excitation were proposed including thermal and electromagnetic schemes. In the electromagnetic technique the magnetic field of the permanent magnet interacts with the current flowing through conductive loop producing the Lorentz force [1,2]. The described technology suffers however from nonuniformity of the magnetic field which additionally is extremely difficult to describe. In our experiments we fabricated, measured and applied 1x4 arrays of electromagnetic cantilevers. The silicon cantilever beams integrated with gold metal paths were manufactured using a double-side micromachining technique, including of front-side plasma etching of the cantilever shape combined with backside chemical and plasma etching of a silicon membrane. The first step consisted of wet oxidation and coating of the wafer with the low pressure chemical vapor deposition (LPCVD) of Si_3N_4 film, followed by photolithography and KOH etching to form a 50um thick membrane. The next step consisted of photolithography and etching of cantilever shape in deep reactive ion etching (DRIE) process to obtain "relief" defining desired thickness of the cantilever (3-5um). The developed relief technique may be applied down to 3-4 um range with satisfactory yield of the microprobes. In our system permanent magnet is replaced with Helmholtz coil pair. Such a system provides homogenous magnetic field which can be precisely tuned.[3] Interaction between homogenous magnetic field and current produces force only when current vector has component perpendicular to the magnetic field vector (Fig. 1). In the described system every single cantilever have its own current loop giving possibility to control the vibration independently . The cantilever deflection is linearly proportional to both current and magnetic field. By driving cantilever close to its eigenmode frequency with different current amplitudes and magnetic field values we were able to calibrate deflection sensitivity (Fig. 3). Experimental data is in good agreement with the theoretical values. We were also able to characterize mechanical crosstalk between each cantilever (Fig. 2). We also propose changes to cantilever array structure where mechanical crosstalk between cantilevers will be reduced (Fig. 4). Presented results confirm that electromagnetic actuation is possible with single nanometer resolution and nanonewton force regime. In future cantilever arrays with electromagnetic actuation will be used in parallel SPM and force spectroscopy measurements.

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[2] B. Lee, C. B. Prater, and W. P. King, Nanotechnology **23,** 055709 (2012)
[3] E.L. Bronaugh, in *IEEE Intern. Symp. on Electromagnetic Compatibility*, Atlanta, 1995, pp. 72–76.

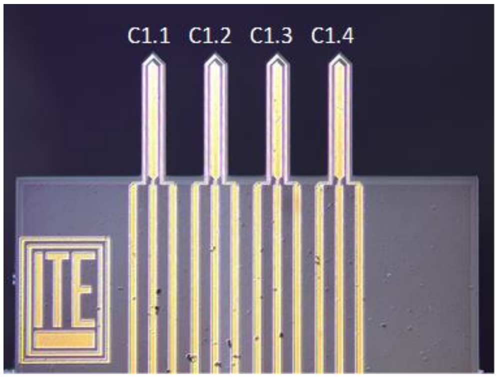

Fig. 1: Cantilever array microscope image: Each cantilever is 100 µm wide and 500 µm long. Resistance of current loops in in range 300-500 Ω.

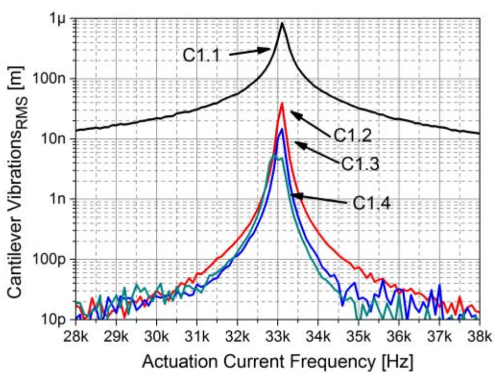

Fig. 2: Mechanical crosstalk in electromagnetically actuated cantilever array: Mechanical vibrations of C1.1 induce vibrations in other cantilevers which vibration amplitudes are only one decade lower.

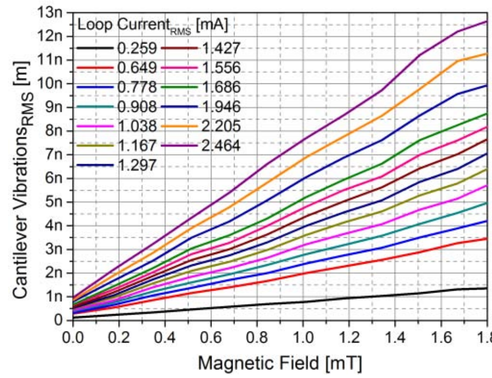

Fig. 3: Actuation sensitivity for C1.1 in various operating conditions: Vibration of cantilever is scaled down according to both external magnetic field and ac current in loop. Sensitivity of this particular cantilever is equal to 2.71 nm*mA^{-1}mT^{-1}

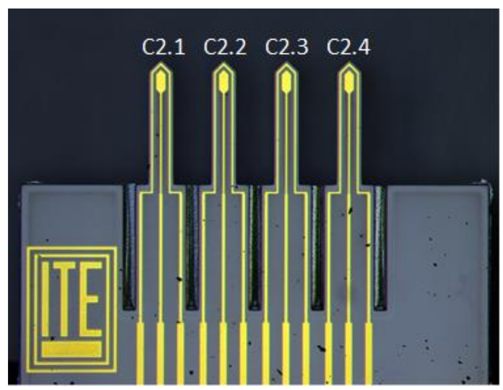

Fig. 4: Cantilever array 2 microscope image: Each cantilever is 100 µm wide and 500 µm long. Resistance of current loops in in range 90-150 Ω. This array has additional cut in holder between cantilevers. The cut is made in order to reduce mechanical crosstalk between the cantilevers.