Multi-cantilever array sensor system with MOEMS read-out

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ABSTRACT

Sensor systems relying on multi-cantilever deflection (as operation principle of optical detection) currently available, face general functionality constrains following the complexity of the system and its cost. Several laser sources as well as big sized detectors are needed to record the signal from each cantilever separately. This paper presents an innovative approach for integration of the MOEMS sensor system embarrassing micro-mirrors, optical elements, dedicated electronics with position sensitive detector (PSD) to allow large cantilever arrays the sensing by application of a single laser source and a compact PSD. The general system overview is presented in this paper along with exemplary representative measurement results from multi-cantilever arrays gathered for various resonant modes recorded for each cantilever.

Keywords: MOEMS, MEMS, cantilever-based sensor system, Lab4MEMS-II project

1 STATE OF THE ART

Cantilever based sensors are commonly used in a variety of research and industrial applications from the simple one ranging from basic sensing to the complex data acquisition and storage processes [1]. Several methods are available to detect a signal from such sensors and analyze the cantilever behavior. The most common ones are the piezoresistive, the optical, the capacitive and the interferometric deflection detection methods.

The former solutions profit from an application of piezoresistive elements mechanically integrated with the cantilevers. While the application flexibility of such a system is high and allows the implementation in different fields without the need of frequent adjustments, the composite structure needed for the sensor is rather inadequate: complex and expansive. Also small thickness variations and thickness-related strain deviations in the involved layers may result in artifacts eventually corrupting the measurements performed. The above measurement has moderate sensitivity due to design constraints and need of thicker structures to accommodate the piezoelectric elements

Capacitive and interferometric detection methods are not suitable for detection in liquids and electrolytes despite high sensitivity. Their application is not applicable for sensing applied to biological samples.

The optical detection is the most sensitive, even twice more sensitive method among methods discussed or mentioned in this paper. Therefore optical detection is widely used 2D arrays of cantilevers positioning measurement in biochemical sensors application. Very small changes in mass are crucial or chemical detection [2-3]. Drawback is that the method is expansive due to complex and bulky assembly. Another issue is that accurate adjustments of the optical read-out system to the cantilevers are frequent and unenviable.

Over the past several years our group has carried out works on design, manufacturing and application of micro-cantilever based micro-sensors [4-6]. These miniaturized micro-fabricated sensors (usually 50 – 600µm long/width, a few micrometers thick) are used for detection and/or measurements in many fields including gas detection, biochemical analysis, medical applications, quality and process control, and product authenticity issues. In most cases single cantilevers are functionalized for the detection of certain phenomena. Their interaction with the environment results in changes of their mechanical properties. These changes are revealed as static deflection or as a resonance frequency shift of the micro-cantilever beam. The former method is based on the determination of the deflection amplitude of the cantilever sensor. The deflection amplitude can be traced back to the force applied to the cantilever. The latter method implies a vibrating cantilever excited at its resonant frequency. The influence of the external forces, leading to effective mass change, is detected as shifts in the position of the resonant peaks.

The standard of an optical deflection measurements (Fig. 1) system for a single-cantilever system usually includes a light source (laser) directed to the surface of the cantilever and a PSD that measures the change of the position of the laser spot due to the cantilever deflection [7]. Multi-cantilever setups utilize various solutions like multiple laser sources with multiple/large sensors or laser with detectors sets movable along the array [8-9]. Due to complexity of this solution such systems are usually limited to few cantilever in array, the solution is not stable, expensive, large and requires complex, long lasting manual calibration.

The innovative system with optic's auto-adjustment feature will be presented in this paper along with a discussion on its advancements and drawbacks.

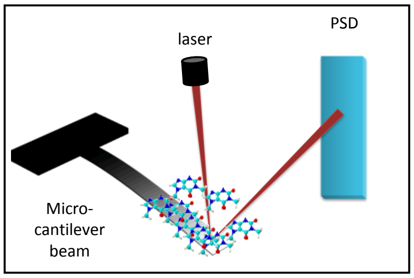

Figure 1: Schematic of standard optical deflection measurements system for a single cantilever.

2 LAB4MEMS-II PROJECT

Lab4MEMS-II project [10] is an ENIAC Joint Undertaking [11] initiative involving 19 industrial, research and academic partners under the leadership of the STMicroelectronics Italy. The final goal of the project is setup of a pilot line for innovative Micro-Opto-Electro-Mechanical-Systems (MOEMS) by development and combination of key enabling technologies (KET's). Lab4MEMS-II focuses on the development, testing and validation of such devices like micro-projectors, 3D infrared scanners and near-infrared micro-spectrometers. The success of the project will open the way to the worldwide commercialization of future applications such as contactless commanding of devices, holographic imaging and smart driving. In the frame of Lab4MEMS-II our group is developing an innovative cantilever based sensor system that features MOEMS micro-mirror, optical elements and integrated dedicated electronics for the sensing of large cantilever arrays by using a single laser source and a small sized position sensitive detector (PSD).

3 THE SENSOR SYSTEM

Lab4MEMS-II project covers research on improvement of standard optical deflection readout techniques in terms of complexity reduction, cost lowering and efficiency improvement. The novel solution [12] has been proposed and developed, where the light beam from a single laser scans across over the cantilevers directed by the 2-axis MOEMS micro-mirror. This solution implies at the creation of such a heterogeneous system integrating optical, electronic and mechanical components in a single package provides a universal, lightweight and portable sensor system. The general concept of our proof of the system concept is presented in Fig. 2.

The developed prototype (Fig. 3) profits from an application of the modified head of the atomic force microscope (AFM). The head includes a series of lenses, the MOEMS mirror forming the optical path needed to point the laser spot on the selected cantilever beam in the cantilever beams array. The laser source provides a circular, collimated, 635nm wavelength light beam. The light emitted by the laser is reflected by an actuated, two-axis 3mm diameter circular MOEMS micro-mirror.

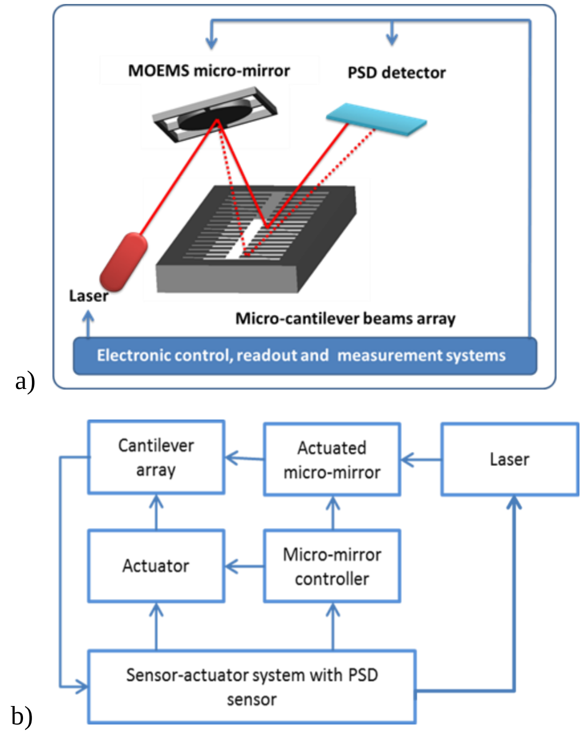

Figure 2: Schematic (a) and block diagram (b) of concept of our single laser scanning system with MOEMS readout highlighting its main components.

The X-Y rotation of this mirror is used to scan the cantilevers with laser beam and step with the beam from one measuring position to the next one. The MOEMS micro-mirror positioning is controlled via the computer through a dedicated electronic driver. The laser beam scanning over the cantilevers in array for several times in a loop performs repeated and averaged deflection measurements. The time span of a single cantilever measurement is fully customizable down to the millisecond range. The laser beam reflected by the cantilevers is collected by the optics and directed towards the custom PSD sensor. The PSD profits from the dedicated, unique, self-developed electronics transferred the collected data to the measurement computer. The laser is turned off during micro-mirror movements to reduce the noise in the recorded data. The head used in current prototype measurement unit is equipped with a top side viewport for manual calibration by means of an external CMOS camera. At the current development stage the measurement system relies on the user experience to define manually the measurement points on the cantilevers.

The dedicated holder for an array of cantilevers has been developed in frame of the project and is mounted at the bottom side of the head. The sensing beams can be excited by the air Brownian thermal noise or by external signals imposed by piezo-module or by magnetic actuation (dedicated cantilevers are required).

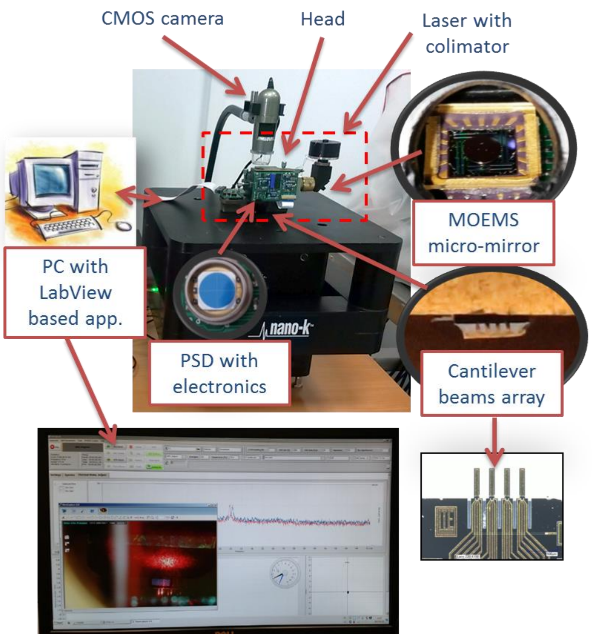

Figure 3: Proof of concept realization of multi-cantilever array sensor system with MOEMS readout.

The MOEMS system is operated by a dedicated application MTSA in newest version 9 (Fig. 4) in LabVIEW. It implements graphical programming platform with testing, programming and devices controlling, measurements and data processing features.

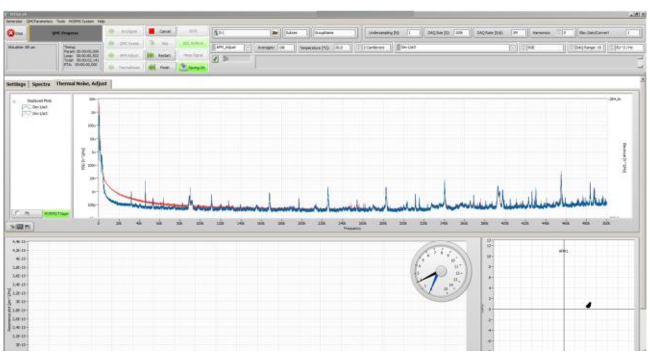
Figure 4: Screen of system control application – MTSA v9.

There are three main data processing sub-modules:

- Adjusting module – used for adjust the sensitivity of the PSD detector – graphically show the cantilever reflected signal and graphically present the position of the spot onto detector area; trough the mechanical adjustment of electronics with PSD it is possible to calibrate detector position for best sensitivity and strongest signals;
- Thermal Noise Measurement module – allow to measure and analyze single cantilevers;
- Multi-cantilever measurement module – used for automatic scan and measurements of cantilever arrays, all parameters like e.g. number of cantilevers in array, measurement speed, sample rates, temperature, averages number etc. are selectable from menu.

The application is equipped with full graphical interface and includes several additional modules like data saving in TDMS binary format compatible with the most common software platforms like Excel, Matlab and Origin.

4 SYSTEM VALIDATION

In this section we present sample measurement results of the presented system of simple 2-cantilever arrays. The CMOS camera view is presented on Fig. 5. The array consists of two identical silicon cantilevers 500µm long, 100µm wide, 5-6µm thick. The cantilever pitch is 100µm.


Figure 5: Screenshots taken during laser off state and scanning point to point of a 2-cantilever array.

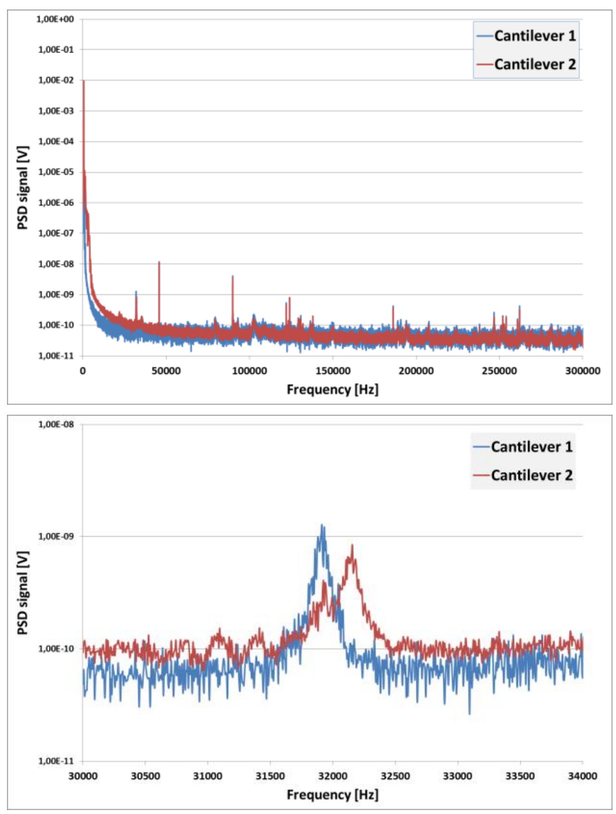

Figure 6: Frequency spectra for cantilever array obtained in scanning mode by developed system. The full spectrum (upper) and details of the first resonant mode (bottom) are presented.

Full spectral measurements present several peaks (Fig. 6). Two of the peaks reflect first resonant mode of the cantilevers. As all cantilevers in the array are intentionally identical (apart from fabrication mismatch), it was expected that peaks recorded reflect the same resonant frequencies. The deviations observed are marginal, but are explainable by various fabrication conditions that each cantilever was exposed to during the processing. Several sharp additional peaks can be observed throughout the spectrum. The measurement results have been compared with simulations and experimental data obtained on commercial equipment like e.g. Polytec vibrometer. Such investigation is presented in detail on the Fig. 7 as comparison the modeling and simulation activities. The resonant frequency and resonant mode shape for cantilever in the array under investigation are presented. The comparison shows that our system is capable of obtaining the same type of information of currently available systems on the market, however allowing for portable use and faster measurement. Presented results also proved high sensitivity of developed system – cantilever beams array was exited only by air Brownian motion.

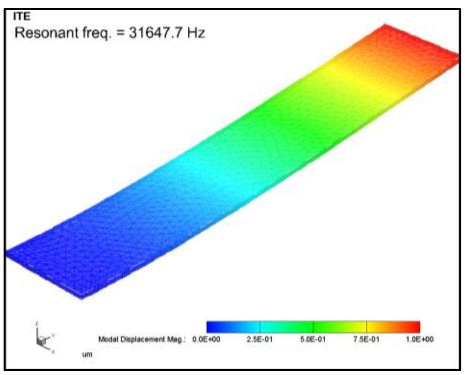

Figure 7: Modeling and simulation result – resonant frequency and resonant mode shape for cantilever from array under investigation .

5 SUMMARY

Novel approach for sensor systems for sensing arrays of cantilevers with the use of one single laser source and a single small sized position sensitive detector has been presented. Due to the integration of actuated micro-mirrors (MOEMS) and a dedicated head numerous cantilever arrays have been successfully scanned and evaluated. Several resonant modes of two cantilevers driven only by Brownian motion of the air have been detected. The system is capable of performing high resolution and sensitivity measurements of resonance frequencies and deflection in the order of picometers. The cantilevers used for the proof of concept were simple non-functionalized cantilevers, however future research and development will focus on functionalization layers and their use as sensors with outstanding sensitivity for specific sensing application.

6 ACKNOWLEDGMENTS

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