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Compact MEMS/NEMS Characterization Platform Using a DVD Optical Pick-up Unit with Optical Imaging Function

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ABSTRACT

In this work, we present a compact, simple and efficient platform for Micro-electromechanical systems (MEMS) / Nano-electromechanical systems (NEMS) characterization. In this platform, a CCD camera is combined with a DVD optical pick-up unit (OPU). The CCD camera captures optical image of MEMS/NEMS samples and detection laser spot, which makes laser alignment on measurement target easier. The DVD OPU is used for detection of resonant frequency measurements of the samples. Working bandwidth and noise level of the OPU are 100 MHz and $1.3 \text{ pmHz}^{-1/2}$, respectively. Furthermore, the OPU has a laser spot size of 560 nm (full width at half maximum, FWHM), which is capable of measuring cantilevers and strings with sub-micron width. A homemade nano-scale resolution X-Y-Z positioner with working distances of 12, 12, 5 mm is responsible for laser-sample alignment. Both thermal and excited resonant frequencies of MEMS/NEMS cantilevers and strings are characterized.

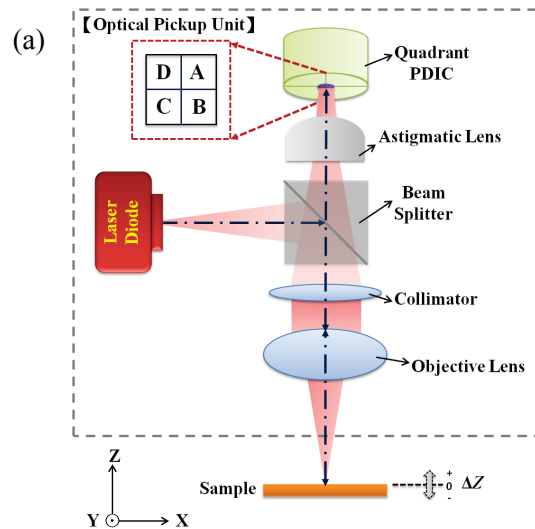
Keywords: mems, nems, string, resonant frequency, optical pick-up unit

1 INTRODUCTION

Micro-electromechanical systems (MEMS) / Nano-electromechanical systems (NEMS) sensors have been studied and developed for several decades, such as temperature sensors[1], pressure sensors[2], force sensors[3], fluid sensors[4] and biosensors[5]. Strings are relatively stiff MEMS structure compared with cantilevers, which have high resonant frequency that are used for high resolution measurements[6]. Oscillation amplitude and frequency of the strings are measured by several methods such as piezoresistive[7], capacitive[8], optical[9-12] sensing techniques. Optical interferometers are expensive but commonly used for characterizing MEMS/NEMS structures. Another technique is optical lever which is much simpler and cheaper than the interferometry. However, the optical lever detection usually accompanies bulky size and

complex operation procedures. In addition, laser spot size of commercial optical lever systems is several micrometers which is difficult to measure nano-scale structures.

Instead of bulky and expensive commercial vibrometers, we apply a DVD optical pick-up unit (OPU) with sub-nano scale detection resolution for measuring resonant frequencies of strings in air at room temperature [13-14]. Figure 1.(a) illustrates an optical path inside the DVD OPU. A laser beam emitted from a semiconductor laser diode is focused on the sample surface through a collimator and an objective lens. Through an astigmatic lens, the reflected beam impinges onto a photo detector integrated chip (PDIC), which includes four quadrant photosensors (A~D). When the laser beam is exactly focused on the sample surface, the shape of the laser spot on the PDIC is circular. Otherwise, the shape of laser spot becomes ellipse as shown in figure 1.(b). A focus error signal (FES) is defined as $(S_A + S_C) - (S_B + S_D)$ where $S_A \sim S_D$ are voltage signals from the quadrant photosensors. The DVD OPU has a voice coil motor (VCM) which provides two axes movements of the objective lens for focusing and tracking when reading data tracks on a DVD disk. In our application, the VCM can be used for compensating environmental fluctuations.



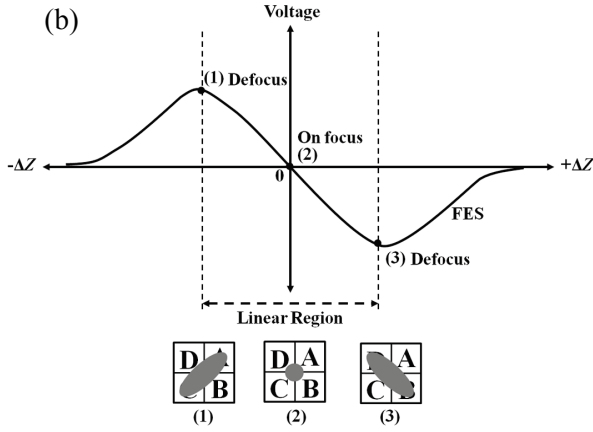


Figure 1: (a) Scheme of an optical path inside the OPU. (b) Shape of laser spot and S-curve of FES. (1) Defocus, FES > 0. (2) On focus, FES = 0. (3) Defocus, FES < 0.

The MEMS/NEMS samples can be mechanically excited by a piezo stack with a sinusoidal waveform generated by a lock-in amplifier. Resonant frequencies and phases of the sample are measured and calculated by the OPU and a lock-in amplifier, respectively. A CCD optical imaging module is integrated into the platform to monitor the laser-sample alignment. A homemade nano-scale resolution X-Y-Z positioner actuates the sample during laser spot alignment process.

2 EXPERIMENTAL SETUP

The core optical measurement component of this platform is a standard slim type DVD OPU (TOP1100S, Topray Technologies). This OPU has a two wavelength laser diode of 655 and 790 nm for DVD and CD read out, respectively. The visible 655nm wavelength laser is used in our setup, which has higher detection sensitivity. The DVD OPU is used for detecting resonant frequencies of MEMS/NEMS samples. Working bandwidth and noise level of the OPU are 100 MHz and $1.3 \text{ pmHz}^{-1/2}$, respectively. Furthermore, the OPU has a laser spot size of 560 nm (FWHM).

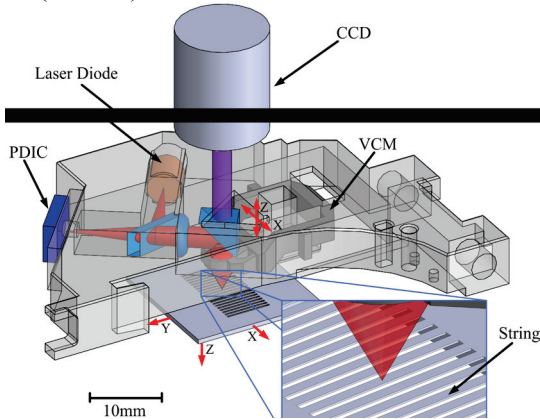


Figure 2: Schematic concept of the MEMS/NEMS characterization platform for strings measurement.

Figure 2 shows a schematic concept of the OPU based MEMS/NEMS characterization technique for strings measurement. The CCD module captures optical image of the laser spot and the sample through a beam splitter and a objective lens. The VCM of the OPU has two degrees of freedom (X and Z axes) with a working distance of $\pm 500 \mu\text{m}$ in each axis. The VCM moves the objective lens in Z axis direction for compensating mechanical thermal drift caused by environmental temperature deviations [15].

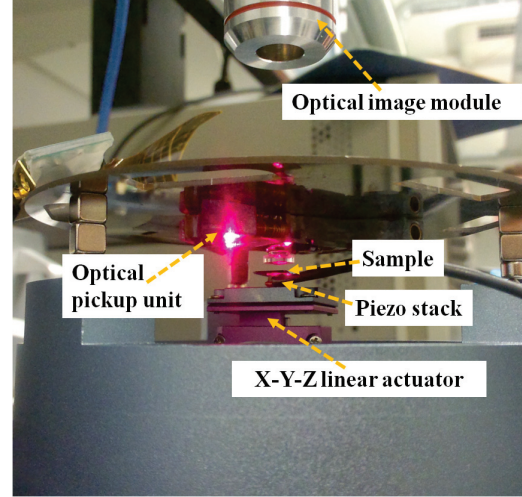


Figure 3: Photo image of string characterization platform.

Mechanical parts of the characterization platform is shown in Figure 3, a piezo stack underneath the sample is fixed on a linear actuator. The home made X-Y-Z linear actuator with 12, 12, 5 mm working distant has a resolution of 30 nm per step, which is used for laser-sample alignment. The piezo stack which fixed on top of the linear actuator can be used to oscillate the sample. A lock-in amplifier (AMU 2.4, PCI lock-in amplifier, Anfatec) generates excitation waveform and receives FES from the OPU, which has a working bandwidth up to 1 MHz.

3 RESULTS

Figure 4(a) shows suspended silicon nitride strings on a silicon chip observed by an optical microscope (OM). Each string has a micro scale dimension, width: $30 \mu\text{m}$, length: $900 \mu\text{m}$, thickness: 177 nm , that is easy to measure. The optical image captured by the CCD module of the characterization platform is shown in Figure 4 (b). The laser spot is focused on the center of the string. Size of the laser spot in Figure 4 (b) could be much smaller when a polarizer is applied in optical path of the CCD imaging module. The optical imaging function is beneficial for aligning the laser spot on the target structure much more efficient than previous study [16]. The strings are mechanically excited by the piezo stack with sine wave signal. First resonance mode of the string can be found in 610.1 kHz.

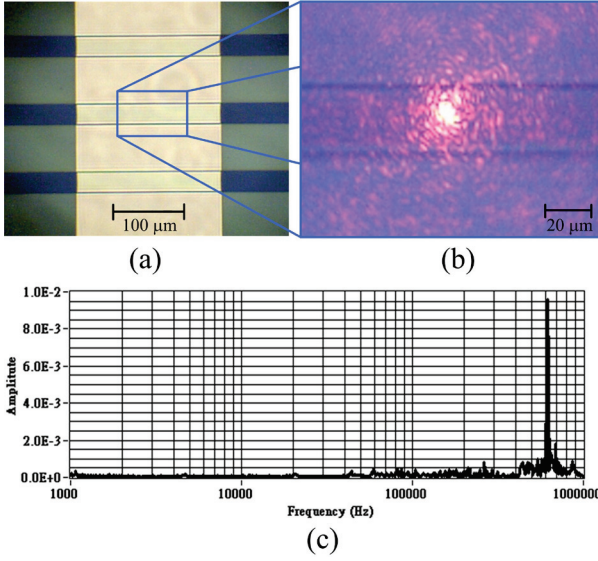


Figure 4: Silicon strings measurement. (a) OM image of fabricated suspended strings. (b) optical image of string and laser spot captured by our platform. (c) measured resonant peak is around 610.1 kHz.

The laser spot of commercial vibrometers is typically in micro-scale range, which limits measurement capability of MEMS/NEMS structures. Figure 5 shows a MEMS cantilever with a width of 1.5 μm , which is not easy to be measured by optical lever or interferometer system. Thermal noise of this cantilever can be easily measured by our MEMS characterization platform. Thermal noise spectrum shows that the cantilever has a resonant frequency of 700.3 kHz.

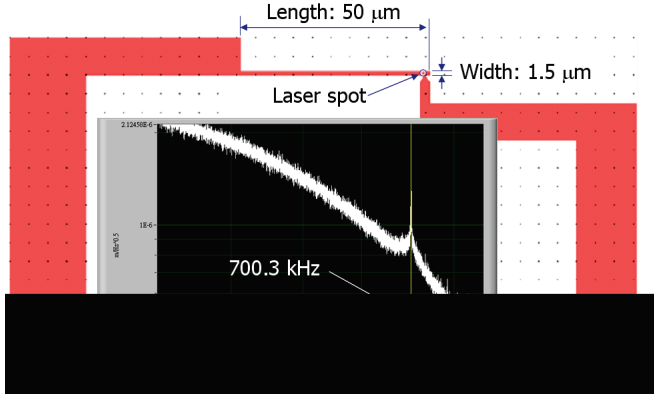


Figure 5: Dimension and thermal noise spectrum of the MEMS cantilever.

For evaluating sample size limitation of this platform, four cantilevers with width from micrometer to nanometer scale are used. The MEMS/NEMS cantilevers (1)~(4) are manufactured by focused ion beam (FIB) on a gold coated base cantilever (width: 50 μm , thickness: 2 μm), as shown in Figure 6 (a). When the laser is focused on micro-scale cantilevers (1) and (2), the reflected intensity of signals are as good as that on the base cantilever. We can still get

reflected intensities more than 50% from cantilevers (3) and (4), though the laser spot size is larger than nano-scale cantilevers. The resonant frequency of cantilevers (1)~(4) are estimated more than 6 MHz, but the working bandwidth of the commercial lock-in amplifier in our platform is 1 MHz only. Therefore we are not able to measure the resonant frequency of these cantilevers in present electronics. However, we can easily measure the resonant frequency of the base cantilever (~7 kHz) through focusing laser spot on both cantilevers (1)~(4). The measurement results suggest that we may be able to measure resonant frequencies of those cantilevers if a higher bandwidth lock-in amplifier is used.

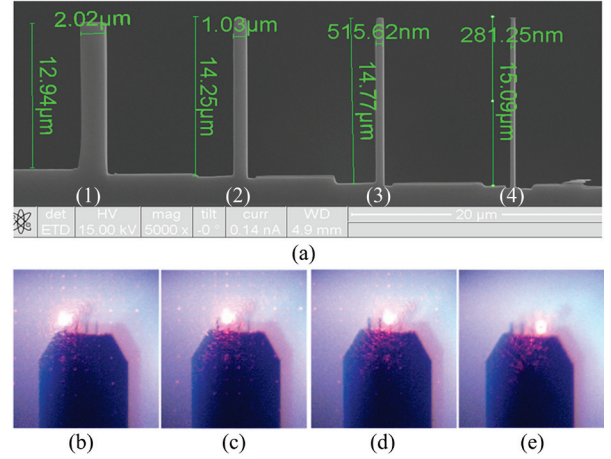


Figure 6: Dimensions of cantilevers and optical images of laser focusing. (a) SEM image of the cantilevers. (b)~(e) laser focused on micro and nano-scale cantilevers (1)~(4).

4 CONCLUSIONS

We have demonstrated the DVD OPU based MEMS/NEMS characterization platform that can measure mechanical resonances of not only micro-scale strings but also nano-scale cantilevers. The integrated optical imaging function simplifies the laser-sample alignment process which increases measurement efficiency. The home made X-Y-Z linear actuator provides long range and nano-scale movement of sample, which is crucial for NEMS features alignment. This OPU based characterization platform has several advantages, such as compact size, simple structure, nano-scale laser spot and high working bandwidth. In future work, the frequency range can be further extended by using high speed lock-in amplifiers for MHz scale frequency characterization of MEMS/NEMS structures.

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