STEP-HEIGHT MEASUREMENT OF SURFACE FUNCTIONALIZED MICROMACHINED MICROCANTILEVER USING SCANNING WHITE LIGHT INTERFEROMETRY

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ABSTRACT

Micro-cantilever arrays with different dimensions are fabricated by micromachining technique onto silicon <1 0 0> substrate. These sputtered Gold-Coated micro-cantilevers were later surface functionalized. Scanning Electron Microscopy, Atomic Force Microscopy and Optical SWLI using LASER probe are employed to characterize the morphology and image measurement of the micro-cantilever arrays, respectively. Compared with conventional AFM and SPM measurement technique, the proposed method has demonstrated sufficient flexibility and reliability. The experimental results have been analyzed and presented in this paper for MEMS Micro-cantilevers. The scanning White Light Interferometry based two point high resolution optical method is presented for characterizing Micro-cantilevers and other MEMS micro-structures. The repeatable error and the repeatable precision produced in the proposed image measurement method is nanometre confirmable. In this piece of work, we investigate the micro-structure fabrication and image measurement of Length, Width and Step-Height of micro-cantilever arrays fabricated using bulk micromachining technique onto Silicon <100> substrate.

KEYWORDS: *Scanning Electron Microscopy; Atomic Force Microscopy; Micro-cantilever; Optics; Image Measurement; Silicon (100), Scanning White Light Interferometry.*

I. INTRODUCTION

Step height measurement is required in many fields including semiconductors, micro-circuitry and printing. Small steps are often measured using a profilometer, calculating the least-squares straight line through the data, and then identifying the areas above and below this as being step and substrate. The step height is calculated using a least-square fit to the equation: Z = aX + b + h Î´ where a, b, h are unknowns and Î´ takes the value of +1 in the higher regions and -1 in the lower regions. The unknowns a and b represent the slope and intercept of the line. The step height is calculated as twice the value of the third unknown, h. This approach is fine for samples where the flatness of the step and substrate both are good.

Accurate measurement of dimensions of microstructures using optical method has received much attention because of their potential advantages over conventional AFM/SPM techniques. [1] A common method to fabricate the micro-cantilevers is to pattern the deposited continuous film using bulk or surface micromachining technique. [1-2] However, these methods are demonstrated perfect only for sub-micron micro-cantilever arrays. As the micro-cantilever size decreases to nanometres, interesting behaviour may be expected. In particular, reduced micro-cantilever size results in change of domain structure [2] and will affect the characterization of the micro-cantilever. One of the other methods to fabricate the nanometres micro-cantilever array is laser micromachining the deposited material onto a silicon substrate.[2,3] Until now, the conventional image measurement technique for planar micro-structural properties of micro-cantilever on silicon <100> substrates have been studied. [6] However, the applicability of optical methods for microstructure arrays is established. In this piece of work, we investigate the micro-structure fabrication and image measurement of Length, Width and

Step-Height of micro-cantilever arrays fabricated using bulk micromachining technique onto Silicon <100> substrate.

II. THE METHOD

Small steps are often measured using a profilometer, calculating the least-squares straight line through the data, and then identifying the areas above and below this as being step and substrate. The step height as depicted in figure 1 is calculated using a least-square fit to the equation: Z = aX + b + h Î´ where a, b, h are unknowns and Î´ takes the value of +1 in the higher regions and -1 in the lower regions.

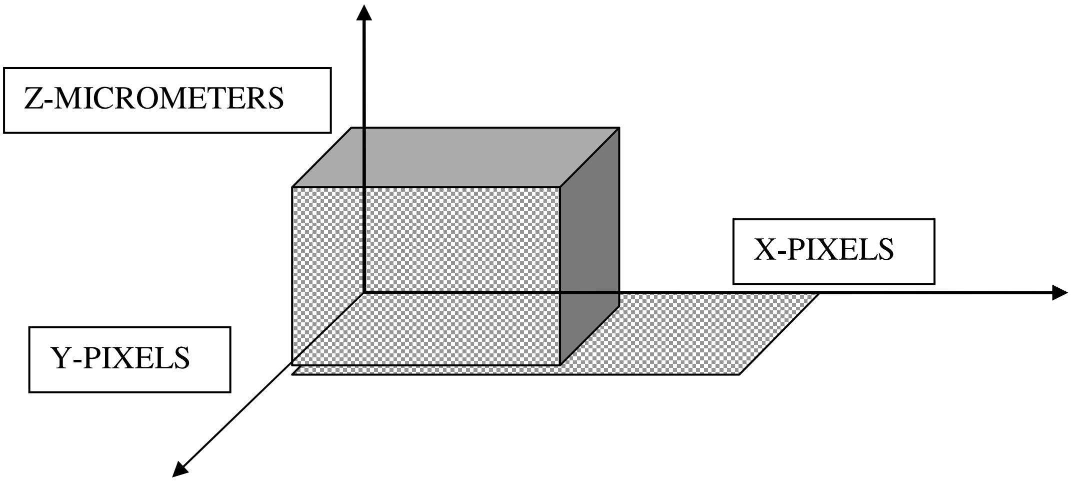

Figure 1. Three-dimensional profile of a 500-mirometer standard step height obtained from scanning white-light interferogram. The repeatability of the measurement is 10 nm.

The unknowns a and b represent the slope and intercept of the line. The step height is calculated as twice the value of the third unknown, h. This approach is fine for samples where the flatness of the step and substrate both are good.
We use optical method for precision measurements using interferometry. The ideal way to analyze complex interference data electronically is to acquire a high density of data points per interference fringe to capture all the detail of the interference signal. There are, however, practical limits to the amount of data that can be stored, processed, and displayed. This is particularly true of scanning white-light interferometry (SWLI) for surface topography measurement. These instruments use broadband sources together with mechanical translation of the object or reference surface to measure large discontinuous surface features. Typically, a SWLI instrument acquires three to five intensity values per interference fringe per pixel and process millions of data values to generate a single three-dimensional image. The volume of data involved means that 500 micrometers of depth range can require several minutes just for data acquisition. A piezoelectric actuator (PZT) is used to translate the object in a direction parallel to the optical axis of the interferometer over an interval of several tens of micrometers. The resulting interference pattern for a single pixel resembles the data simulation. The traditional way of measuring surface topography with such a system is to calculate the fringe contrast as a function of scan position and then relate the point of maximum contrast to a surface height for each pixel in the image. There are several ways to calculate the fringe contrast for this purpose, including measuring the maximum and minimum intensity values, by standard phase-shift interferometry formulas or digital filtering. These fringe-contrast techniques have in common a high density of image frames over the range of PZT translation.
The proposed method uses the fundamental physical concept of frequency domain processing of interferograms is that a complex interference pattern may be considered the incoherent superposition of several simple single-frequency interference patterns. Each of these single-frequency patterns may be represented by the simple formula,

$$I = 1 + \cos(\phi) \quad (1)$$

Where,

$$\phi = k \cdot Z \qquad (2)$$

Here k is the angular wave number and the distance Z is the phase-velocity optical path difference in the interferometer. For simplicity we assume a perfectly compensated and intensity-balanced interferometer. From Eq. (2) it is clear that

$$Z = {d\phi}/{dk} \qquad (3)$$

Hence one way to measure distances is to calculate the rate of change of phase with spatial frequency. To calculate this rate of change, we need phase values ϕ over a range Δk of frequencies centered around a mean frequency ko.

A simple linear fit to the phase data provides the rate of change $d\phi/dk$ and the mean phase ϕ_0'. This information can be used to calculate the distance in either one of two ways. The rate of change of phase can be used alone to calculate distance with Eq. (3). Alternatively, this preliminary calculation can be used to remove the 2π ambiguity in the mean phase ϕ_0', which may then be used in an inverted form of Eq. (2) for high-precision measurements.

The Laser probe is used to select the points of interest on the device structure. The Measurement of Length and Width is relatively simple because the two-points placed shall be in-plane. However, for the measurement of Step-Height, the two-points shall not be in-plane. So, we fix one point (Maximum Z) using the marker and the other point can be placed where the height need to be measured (Minimum Z) as shown in Figure 2.

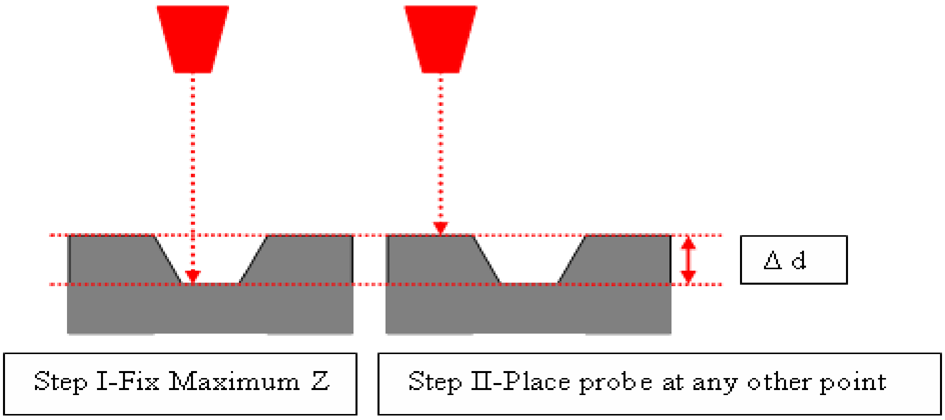

Figure 2. Proposed Two-point optical Method for Etch-Depth Measurement

The difference between Maximum Z and Minimum Z of the markers (Δd) shall give the Step-Height. The film Step-Height (Δd) is directly proportional to Wavelength of the Laser Light and is inversely proportional to twice the refractive index of the film being etched. Thus, the change in film Step-Height, using this proposed method, is measured with the relation (4),

$$Z = \Delta d = \lambda / 2 \cdot \eta \qquad (4)$$

Where, λ is the wavelength of the laser light and η is refractive index of the etched layer.

III. EXPERIMENTAL

Two procedures were used to fabricate micro-cantilever arrays. Firstly, Silicon<100> substrates were deposited by silicon-di-oxide using a thermal oxidization procedure as described previously. [4] The oxide deposition rate was about 1.5 nm/min and the gas flow rate of 18 sccm. After the oxidization and Patterning, the residual Silicon was removed by an anisotropic etchant. [5] Secondly, micro-cantilever arrays were deposited by RF magnetron sputtering from a gold target at room temperature. The sputtering chamber was firstly pumped down to 180 milli Torr. Then, the deposition of Chrome was carried out under Ar atmosphere with about 180 milli Torr and the gas flow rate of 18 sccm. During the deposition process, the continuous film of gold was also deposited onto a silicon substrate under the same condition for the convenience of measuring the film thickness.

The sputtered chrome-gold layer has affinity with thiophenol molecules. [7]Considering this fact, we have dip-coated the piezo-resistive micro cantilevers with 1 micromole thio-phenol in ethanol solution for 3 Hrs. and then, rinsed with ethanol, for 2 minutes. The surface becomes functionalized.

The surface morphology of the micro-cantilever arrays was investigated by the scanning electron microscopy (SEM, JEOL 2000). The grazing incidence LASER diffraction (GILD), which avoids the effect of substrate to the pattern, was used to study the image measurement of the microstructure. The mechanical properties at the temperature 300 K were measured by Atomic Force Microscopy.

Image measurement of significant parameters of surface functionalized micro machined micro cantilevers such as Length Width and Step- Height were obtained using SEEBREZ® optical multi-sensing system with laser probe and Taylor-Hobson's Form Talysurf® 3-D surface profiler machine with 3-D Telemap Gold 3-D profile software. The Coni-spherical Stylus with the base radius of 2 micrometers was used for the contact-mode measurements.

The co-ordinate measurements were done with SEEBREZ® optical multi-sensing system with laser probe. This system has an auto focus facility. After the sample was prepared for measurements, the origin of the wafer co-ordinates was put relatively. Then Maximum z-coordinate was fixed with a laser-beam marker. The Measurement of Length and Width is relatively simple because the two-points placed shall be in-plane. However, for the measurement of Step-Height, the two-points shall not be in-plane. So, we fix one point (Maximum Z) using the marker and the other point can be placed where the height need to be measured (Minimum Z). The difference between Maximum Z and Minimum Z of the markers (Δd) shall give the Step-Height. The change in the film Step-Height (Δd) is directly proportional to Wavelength of the Laser Light and is inversely proportional to twice the refractive index of the film being etched. Thus, the change in film Step- Height, using this proposed method, is measured with the relation (5),

$$Z = \Delta d = \lambda / 2 \cdot \eta \qquad (5)$$

Where, λ is the wavelength of the laser light and η is refractive index of the etched layer. We have measured Length, Width and Step- Height using the proposed method, which is relatively easy and accurate. The x, y and z co-ordinates of any part of the structure is measured accurately.

IV. RESULTS AND DISCUSSION

Figure 2 shows the proposed two-point-high-resolution and accurate optical method for image measurement of the micro-cantilever array. Figure 3 shows the SEM picture of the micro-cantilever array with a thickness of 500 nm.

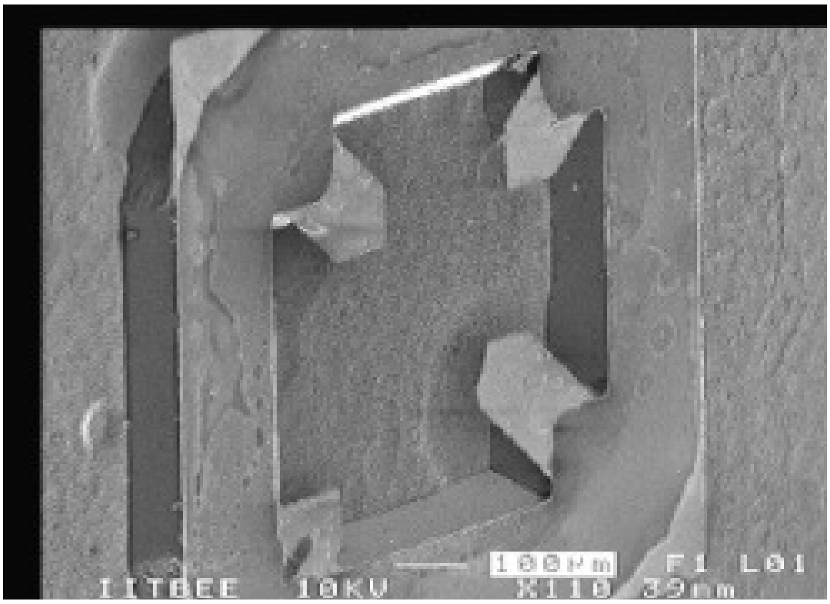

Figure 3. Scanning Electron Microscopy Micrograph of Micro cantilever on silicon<1 0 0 > surface.

The micro-cantilever has a wider parameter distribution, which the mean parameters deviation is approximately 10 nm. Further analysis of SEM shows that there is some etch-product reminiscent at the bottom of the trapezoidal etch-pit. However the side-walls of the etch-pit are smooth. Figure 4 shows the Atomic Force Microscopy of the sample. It shows that the film with micro-cantilevers is free standing in a trapezoidal micro-cavity. Further analysis shows that the crystallite size distributes in the range of 5-10 nm, calculated with the Scherrer formula.

Figure 4. Atomic Force Microscopy Micrograph of Surface Functionalized Micro-cantilever on silicon<1 0 0 > surface

To get the etch-depth information, the micro machined sample was kept on the base of a Taylor-Hobson's- Form Talysurf® 3-D surface profiler machine. The Coni-spherical Stylus was reset to original position after deciding the frame of x-y travel. The machine starts building etch-profile slowly as the coni-spherical stylus moves over the sample. Three-Dimensional Profile generated using Taylor Hobson's Talysurf Profiler machine of the sample are shown in Fig. 5, with the contact mode using coni-spherical stylus moving parallel to the film plane.

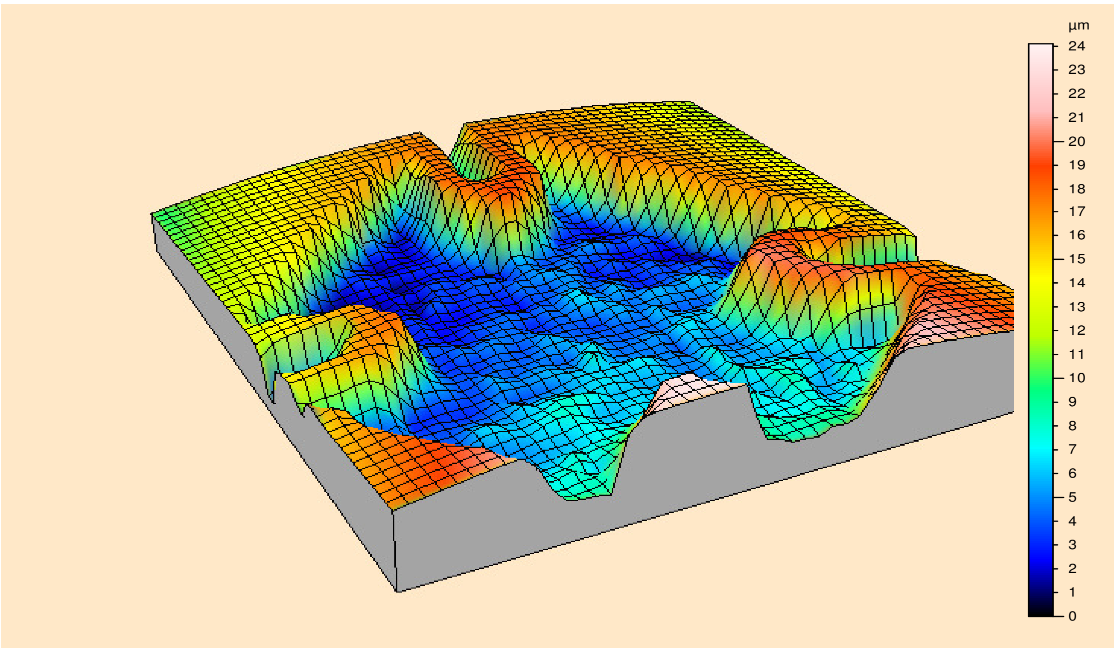

Figure 5. 3-D Surface Profiles (Silhouettes) of Micro cantilever.

The image generated using the stylus based profilometry is in conformity with the Scanning Electron Microscopy. Figure 6 and Figure 7 depicts the width and length measurement with SEEBREZ machine with high accuracy and repeatable precision.

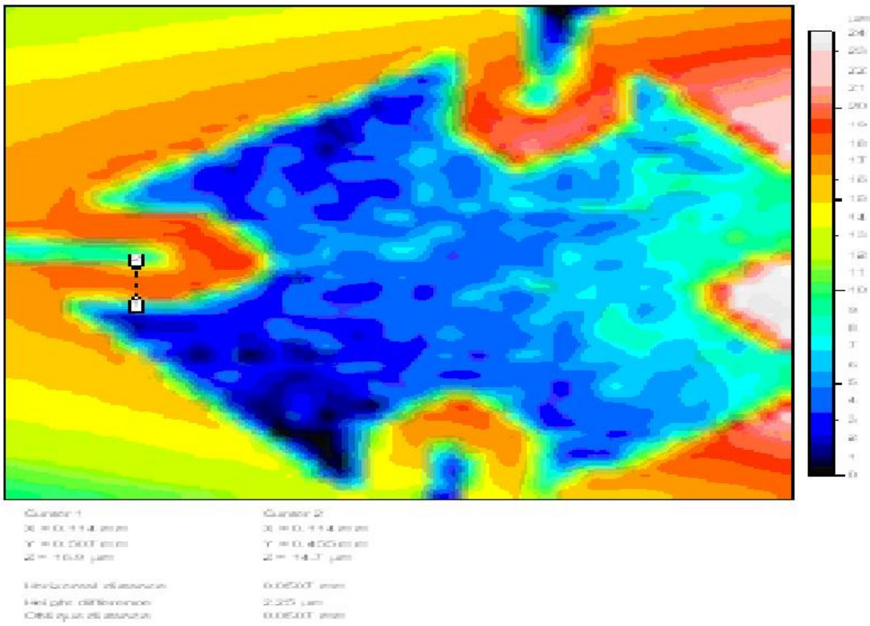

Figure 6. Width measurement of Micro cantilever.

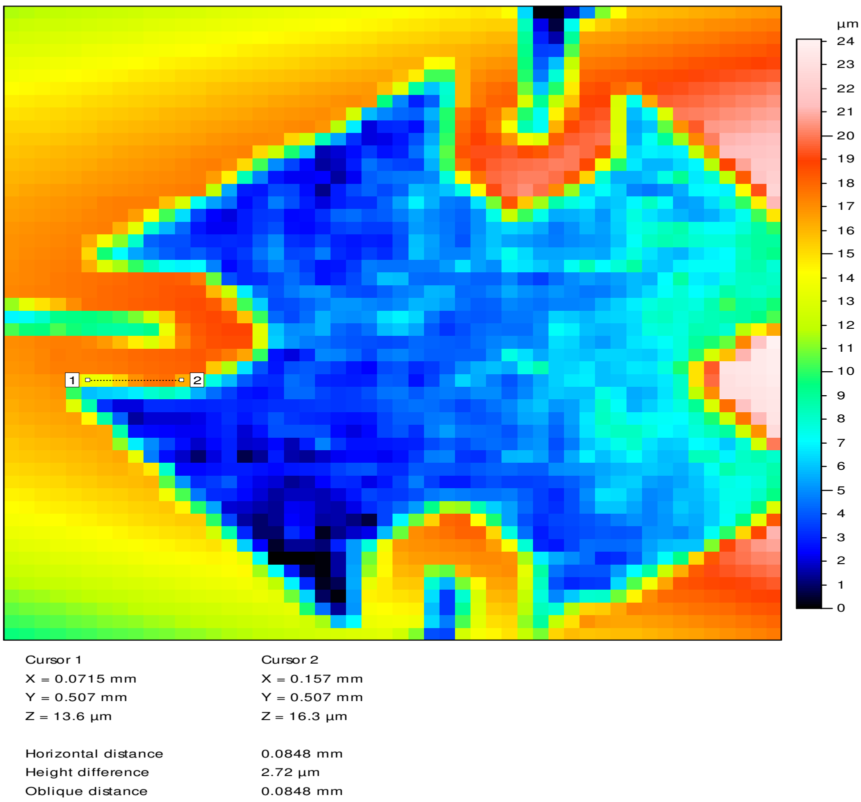

Figure 7. Length measurement of Micro cantilever.

A two-dimensional profile to recover the depth information is depicted in Figure 8.

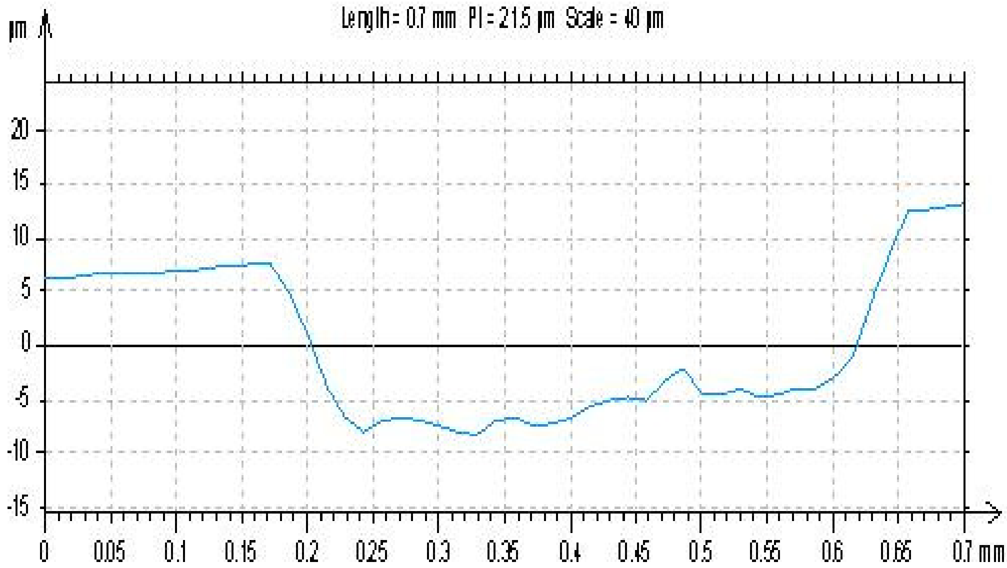

Figure 8. Etch-profile of Micro cantilever.

Table 1 depicts the designed and measured dimensions using the proposed method.

Table 1: Dimensions of Micro cantilever: Designed and Measured Using proposed Method

	Micro-Cantilever		
Sr.No.	Dimensions	Designed	Measured after micro-machining
1	Length	200 micrometers	184 ±0.01 Micrometers
2	Width	60 micrometers	50 ±0.01 Micrometers
3	Step-height	200 Nanometres	180±0.01 Nanometres

V. CONCLUSION

In summary, Micro-cantilevers array have successfully been fabricated on silicon <100> substrate using bulk micromachining technique, deposited with a chrome-gold layer using the RF magnetron sputtering method. These Micro-cantilever arrays were surface functionalized using 1 micro-mole Thio phenol in ethanol solution for 3 Hours, after rinsing with ethanol solution for 2 minutes. The Micro cantilever Surface become functionalized for mass sensing. The Length, Width and Step-height measurement of micro-cantilever is obtained with the proposed high-resolution and accurate two-point optical non-contact method.

Etch profile is very important in assessing the etch-uniformity, side-wall smoothness and etch-depth. Etch-profile also infers the shape, the slope and the etch-depth of the micro cavity, in which the micro cantilevers are free-standing. It is obvious, from the inspection of etch-profile of the trapezoidal micro cavity, that the side-walls of this anisotropically etched trapezoidal micro cavity are smooth, since the profile is not jagged. However, the bottom of the anisotropically etched micro cavity is not smooth, since the profile line is jagged containing hills and dales where surface tension in the inks or paints causes either a rounding or dimpling of the "step", and the stresses caused by the curing process can cause distortion in the substrate. The curvature of the substrate might well be sufficient to prevent the use of the simple least-squares line fit. The step and substrate areas are then treated as line segments, allowing the curvature of the substrate to be removed, resulting in a straight-line representation of the substrate. The step heights are calculated from this line in the areas adjacent to each step.

The inspection of Etch-profile and Scanning Electron Micrograph confirm that the side-walls are smooth and at the bottom of the trapezoidal micro-cavity there is some etch product reminiscent. With this substantial conclusion, we propose a high-resolution accurate method for exact measurement of

Length, Width and Etch-Depth of the micro-machined micro-cantilever. Further, this method can be extended for the measurement of significant parameters of other out-of-the-plane MEMS structures. The principal disadvantage with use of under sampled data is of course a reduced signal-to-noise ratio not only because fewer data are acquired but also because of aliasing of noise at higher frequencies than the sample rate. However, this reduction in signal-to-noise ratio may in many circumstances be offset by the ability to average several scans during a shorter period and with less computer storage than is required by conventional methods. The rapid scans also reduce the sensitivity of the instrument to certain environmental effects, such as mechanical drift due to temperature and vibration.

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