Optical Diffraction based single image method to obtain nanometer resolution deflection profiles in Micro-cantilever based sensors

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Abstract: Profiling of Micro-cantilever (MC) based sensor bending due to molecular recognition induced surface stress changes by OBD method requires multiple measurements along the length of the microstructure. A single image Optical Diffraction based profiling method is proposed employing a double micro-cantilever structure achieving deflection resolutions of **1nm** and surface stress changes of **50µN/m** in a typical MC.

OCIS codes: (120.0120) Instrumentation, Measurement, and Metrology; (120.3930) Metrological Instrumentation

Introduction:

Micro-cantilever based bio-sensors have attracted considerable interest lately due to their potential as an extremely sensitive sensor platform for various biological and chemical detections. Such sensors translate molecular recognition events into a nanomechanical response by the use of microcantilever structures [1]. Measurement of deflection at a cross section along the length due to bending enables the detection of atomic level interactions and also leads to the estimation of generated differential surface stresses at that cross section.

Recent developments by Calleja et.al [2], shows the use of SU-8 polymer based microcantilevers where measurement of surface stress signals of the order of **1-10mN/m** generated by single layer molecular interactions have been reported. The authors envisaged to achieve surface stress resolutions of **50µN/m** by measuring **1nm** deflections in structures of the same material, but thickness reduced by a factor of **5**.

In the most common deflection sensing Optical Beam Deflection Method (OBDM) [3,4], reducing the reflecting surface dimension degrades the measurement sensitivity which simultaneously increases the deflection sensitivity of the microstructure involved[3]. Measurement sensitivity depends on pointing stability of the laser spot and on the illumination position of the laser spot on the cantilever surface along the length, which is maximum at the free end of the cantilever. At the free end, the finite dimension of the focused laser beam leads to losses of part of the beam to the free space beyond the length of the microstructure. Hence the illumination positioning becomes a compromise between measured sensitivity and signal intensity [6]. Also, determining the deformation at all cross sections along the length of the MC involves multiple measurements along the length of the microstructure. To overcome these drawbacks an Optical Diffraction based measurement technique is proposed which employs a double MC structure.

Method:

The double MC structure as shown in Fig 1.with a gap of **1µm** between the two, acts as a double slit aperture mask to an incident planar wavefront , resulting in the formation of Fraunhofer diffraction pattern on a screen behind the microstructure. The obtained intensity pattern is uniform along the length of the microstructure unlike that in the OBD method since it depends only on the structure dimensions and its distance to the screen. Spatial extent of intensity maximas of the Fraunhofer diffraction pattern depends on the dimension of the fabricated structures (thickness in the proposed method), the gap between the two structures and also the distance between the screen and the microstructure. The deflection of one of the micro-cantilevers relative to the other due to surface stress changes, alters the gap between the two structures and the resulting spatial shift of intensity maxima is linear with respect to the deflection. Calculations are done based on well known Fourier Optics principles [7,8].

The input source function g(x_0) is

$$g(x_0) = \frac{1}{b}\left[II\left(\frac{x_0}{a}\right) * III\left(\frac{x_0}{b}\right)\right] \cdot II\left(\frac{x_0}{c}\right) \qquad 1$$

The Fourier transform of the input source function giving the Fraunhofer pattern is given by

$$G(f) = ac\left[\sin c(af) \cdot III(bf)\right] * \sin c(cf) \qquad 2$$

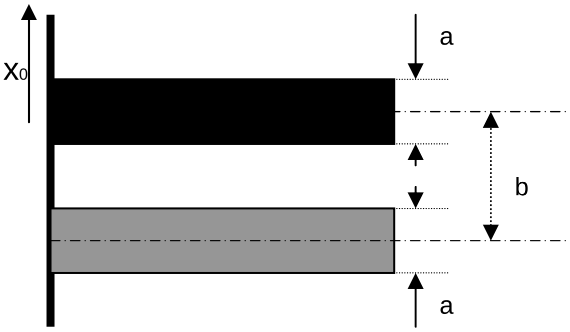

Fig 1. Double MC structure cross sectional view, a=1µm, b=2µm, L=100µm

The distance between the central maxima and the first order maxima of the Fraunhofer diffraction pattern of the proposed structure is given by

$$s_0 = \frac{\lambda D}{b}$$, where λ is the wavelength of light used, D is the distance of the microstructure and the screen, b is the gap between the two structures. The spatial shift in **δs_0** due to **1nm** variation in b is of the order of **0.0167mm** when the distance between the structure and the screen is 10cm. Measurement of such shifts due to deformations of the order of **1nm** at free end of a MC of length 100**µm,** width 40**µm** and thickness 1**µm** gives surface stress resolutions of the order of 50**µN/m.**

Measurement of such shifts in the intensity maxima of a particular order, along the length of the structure can be determined from a single image of the obtained diffraction pattern after deformation by comparing the same with the image of the diffraction pattern of the non-deformed structure. The complete profile of the uniformly deformed microstructure along the length due to surface stress changes can also be obtained from a single image of the deformed optical diffraction pattern.

Simulation and Results:

Simulation was done using MATLAB to obtain the Fraunhofer diffraction pattern of the proposed double MC structure for various screen distances and output screen dimensions.

Table 1. Simulation results for various structure to screen distances and output screen dimensions. Here a is the cantilever thickness, d is the gap between the two structures, λ is the wavelength of light used and D is the distance to the screen.

a, d=b/2, λ, D	**s_0 (mm)**	**s_0^+ (mm)**	**s_0^- (mm)**	**δs_0^+ (mm)**	**Δs_0^- (mm)**	**Output screen dimension (cm)**
1µm,1µm 670nm, 10cm	31.9484025	31.9384030	31.9584020	0.0099995	0.0099995	201
1µm,1µm 670nm, 1cm	3.19484025	3.19384030	3.19684015	0.00099995	0.0019999	21
1µm,1µm 670nm, 10cm	31.9460054	31.9360079	31.9560054	0.00999875	0.00999875	81

The measurement of intensity maxima shifts of the order **0.01mm** can achieve deformation measurement resolutions of the order of **1nm** in typical microstructure based cantilever probes. Achieved surface stress resolution is of the order of 50**µN/m**. Scanning of the diffraction pattern image along each pixel gives the deformations at any cross section along the length by comparing it with the image of the non-deformed structure thus eliminating the need for multiple measurements as in OBD method.

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