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Inspection of a micro-cantilever's opened and concealed profile using integrated vertical scanning interferometry

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Abstract

In this paper, we describe a method based on the proposed vertical scanning interferometry (VSI) for the measurement of both surface profile of the micro-cantilever and corresponding etching sacrificial layer beneath the cantilever by only one scanning. A white light source illuminates a micro-cantilever at a certain incident angle through a Mirau interference objective. With this arrangement the top surface of the cantilever and a normally obstructed surface profile beneath the cantilever can be assessed in the same system. A digital filtering technique based on Fourier transform and a Gaussian fit are implemented to simultaneously retrieve an envelope of two series of interferograms at the top surface of a cantilever and as well as area of interest underneath the cantilever. The retrieved envelope peaks, which represent the height information of points on the test surface, are plotted to show whole field surface contour and demonstrate its effectiveness as a means for micro-electro-mechanical systems (MEMS) dual/multi-layer inspection. Results obtained agree well with those of a commercial instrument and show that the proposed method is simple and accurate.
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1. Introduction

Micro-cantilevers are important components used in micro-electro-mechanical systems (MEMS) [1–4]. Micro-cantilevers are normally fabricated by etching technique [5] and the surface quality of a micro-cantilever directly affects the performance of a micro-cantilever. Fig. 1 shows a side view of a structure of a micro-cantilever. On a plane view, the substrate below the micro-cantilever is obstructed. From fabrication point of view it is important to have a clear view of the surface profile below the cantilever in order to detect any incomplete etching or defects. The incomplete etching would produce non-uniform medium between the bottom surface of the cantilever and the substrate, and forms a plate-capacitor actuator. This would affect the deforming characteristics of the cantilever. Hence, it is important to have an available technique which is able to provide an evaluation on the concealed profile beneath the cantilever and hence assess etching process. Ultrasonic technique is a possible method for such an investigation [6]. However, ultrasonic method includes complicated set-up, such as ultrasonator and receiver, and is a pointwise method. Optical methods, which are non-contact and non-destructive, are usually used for surface profiling. In this study, the surface of interest is obstructed by a cantilever, hence penetrated light source such as infrared or ultraviolet beam, might be used to illuminate the surface. However such beams are mostly invisible, which makes initial adjustment, such as centralizing the optical components, searching area of interest difficult.

Optical interferometry is a non-contact and high resolution technique for measuring surface profiles [7–10].

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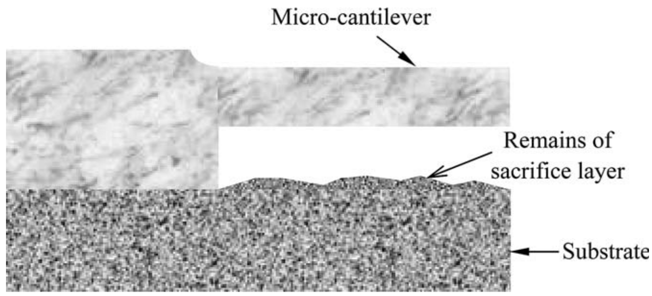

Fig. 1. Side view of a micro-cantilever structure.

Vertical scanning white light interferometry, which uses an incoherent white light to illuminate a test sample, is a common optical method for surface profile measurement without phase ambiguity which is encountered in monochromatic interferometry.

Numerous works on the use of white light interferometry for surface profiling can be found in the literatures. Broadly they can be classified into three basic types based on Michelson, Linnik and Mirau interferometer [11,12]. Groot and Deck applied the method to the measurement of a moth's eye [13], while Windecker and Tiziani measured the roughness of surfaces in an engineering structure [14]. Olszak proposed a lateral scanning white light interferometer to obtain a large field of view [15]. However, all the methods mentioned above are only applicable to unobstructed surfaces. This paper presents a method using a vertical scanning white light interferometer to simultaneously obtain the profiles of both the top surface of a micro-cantilever and the substrate obstructed underneath the cantilever.

2. Principle of method and data processing

In vertical scanning white light interferometry, the intensity field along z-axis (vertical scanning direction) is given by [16]

$$I(z) = I_0 + \gamma I_0 g(z - z_0)\cos[2k_0(z - z_0) + \varphi_0] \quad (1)$$

where I_0 is the background intensity, γ is the fringe contrast, k_0 is the mean wave number of the light source, z is the vertical scanning position along the optical axis, z_0 is the peak position of the intensity field, and φ_0 is a phase offset. $g(z - z_0)$ is the coherence envelope, which depends on the spectrum of the light source [17,18]. In our experiment, a halogen light source with a Gaussian spectrum is used, and hence the intensity field can be expressed as

$$I(z) = I_0 + \gamma I_0 \exp\left[-\left(\frac{z - z_0}{l_c}\right)^2\right]\cos[2k_0(z - z_0) + \varphi_0] \quad (2)$$

where l_c is the coherence length of the light source. Fig. 2 shows the intensity field of a white light interferogram (solid line) and its coherence envelope function (dashed line). It is seen that the intensity can be regarded as a Gaussian signal modulated by a high frequency cosine signal. Since the DC components can be easily removed from the intensity signal, the intensity response can be rewritten as [19]

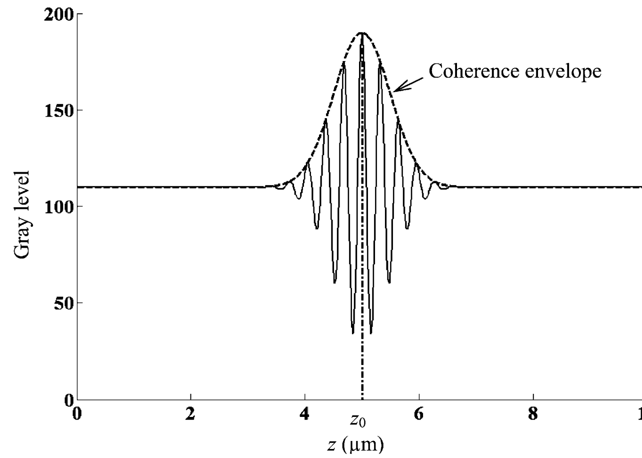

Fig. 2. White light interference intensity response and its coherence envelope.

$$I(z) = g(z - z_0)\cos[2k_0(z - z_0) + \varphi_0] \quad (3)$$

A squaring operation is implemented to rectify the intensity signal as follows

$$I^2(z) = \tfrac{1}{2}g^2(z - z_0)\{1 + \cos[4k_0(z - z_0) + 2\varphi_0]\} \quad (4)$$

A coherence envelope can be extracted from the modulated signal by removing the high frequency component of the signal in Eq. (4) using a suitable low-pass filter. The envelope is a Gaussian function, and hence a Gaussian fit is utilized to obtain more accurate value of z_0.

If the sample has two reflective surfaces, the beams reflected from the two surfaces will, respectively, interfere with a reference beam if the optical path between two surfaces is more than the coherence length of a light source. Hence, the intensity response along scanning direction would have two interference areas as shown in Fig. 3. Using the method mentioned above, two inference peak positions, z_1 and z_2, can also be obtained simultaneously and hence two surface profiles of a sample can be reconstructed.

Digital filtering based on fast Fourier transform (FFT) is used for data processing as shown in Fig. 4. Fast Fourier transform was first applied to the intensity signal to obtain the frequency distribution, and an inverse FFT was then implemented after the low (background) and high frequency (noise) components were removed. A squaring operation was then carried out and a second FFT was applied. An inverse FFT was subsequently implemented after high frequency components (low-pass filtering) have been removed. It should be noted that although the high frequency components can be removed by a low-pass filtering in the final step, for more accurate results it is necessary to remove the high frequency components in the initial

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