Shape optimization of microcantilevers for mass variation detection and AFM applications

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ABSTRACT

The paper proposes an analytical model-based, lumped-parameter algorithm which enables identifying a microcantilever design that will give the optimized performance with regard to stiffness and resonant frequency values in terms of a corresponding shape and its related geometric parameters. The targeted microcantilever applications are mass variation detection and atomic force microscopy (AFM) whereby the monitored system parameters are the changes in deflection and/or the natural frequency. A design set comprises several configurations, each of them being defined by analytical curves, such as straight lines, circular or elliptical arcs, and which are quantified in terms of compliances/stiffnesses and resonant frequencies by algebraic equations. The model is capable of discerning both the intensity of external excitation and the first resonant frequencies for a given microcantilever. Finite element simulation results of the static and resonant response for these microcantilevers confirm the analytical model predictions. The optimization algorithm, which is based on this model, focuses on maximizing the master bending compliance and on spacing out the first resonant frequency from the subsequent ones in order to increase the response sensitivity of the microcantilever. The model-based optimization algorithm is a relatively low-cost and sufficiently-accurate calculation procedure, which is formulated as an alternative to existing finite element simulation.

Keywords: MEMS, microcantilever, AFM, shape optimization

1. INTRODUCTION

The microcantilevers are extensively utilized in atomic force microscopy (AFM) involving reading/writing with, often times, sub-Angstrom resolution, as well as in other micro-transduction applications such as detection of minute amounts of extraneous substances. More concrete microcantilever application examples include surface topology imaging, material property probing, cellular engineering, surface adhesion, grain growth or metrology. In either actuation or sensing the microcantilever behavior can be conditioned/monitored in the quasi-static regime or in the modal one. The deflection or the slope of a microcantilever are amounts experimentally determined in the quasi-static regime, whereas in the modal one, the bending-related natural frequency is the amount of interest.

Raitieri et al. [1] presented a review with applications where the microcantilevers are employed for biosensing, and also discussed the main methods designed at assessing the quantity of deposited mass. Ilic et al. [2] analyzed and experimentally characterized several microcantilever designs in terms of the defining geometry, by monitoring the resonant response alterations in the presence of various attached substances and quantities. Baselt et al. [3] reported the experimental results obtained by monitoring the static response of a microcantilever array as a consequence of the absorbed hydrogen. Similarly, Britton et al. [4] investigated the multiple-input chemical sensing using selectively-coated microcantilevers due to shape changes by absorbtion-induced stresses. King et al. [5] designed and characterized several AFM microcantilever arrays for combined thermomechanical writing and thermal reading. Peterson et al. [6] proposed the V-shaped metallic-wire microcantilevers for AFM and Fowler-Nordheim imaging as design alternatives enhancing robustness and reducing RMS imaging noise. Other examples of microcantilever utilization in read/write AFM MEMS are detailed by Morita, Wiesendanger and Meyer [7], van de Water and Molenaar [8], Ried et al. [9] or Garcia and Perez [10]. More recently Garcia, Lobontiu and Nam [11] and Lobontiu and Garcia [12] used an analytical model to predict both the static and the modal responses of some new microcantilever geometries that depart from the constant cross-

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