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TUNING THE STATIC AND MODAL REPSONSE OF MICROCANTILEVERS THROUGH LUMPED-PARAMETER MODEL-BASED DESIGN

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ABSTRACT

The paper introduces the circular-notch microcantilever design that can be utilized in mass detection and atomic force microscopy (AFM) microsystems. The microcantilever is modeled as a three degree-of-freedom member which is sensitive to bending and torsion. A lumped-parameter model is formulated that gives directly the stiffness closed-form equations and the inertia fractions about the degrees of freedom. It is thus possible to qualify and tune the static and modal responses of this specific microcantilever design in order to match or, on the contrary, to avoid, stiffness and frequency ranges that are of interest by means of only geometry alterations. The microcantilever's sensitivity to bending and torsion can also be modified by simple manipulation of the defining geometric parameters. The analytical model predictions are confirmed through limit calculations and finite element simulation. The stiffness factors of the circular-notch microcantilever design are compared to the ones of a similar constant rectangular cross-section configuration by means of the analytical model developed herein.

INTRODUCTION

The microcantilevers are presently utilized in many micro/nano applications such as, atomic force microscopy (AFM), nanoindentation, sub-Angstrom resolution optical position detection, sensing/actuation devices based on piezoresistive, piezoelectric or thermal principles, surface topology imaging, measurement/probing of material properties, surface writing/reading, material chemical/electrochemical characterization, micro-lubrication/tribology or cell adhesion/imaging. In detection/measuring applications the microcantilevers can be operated either in the static/quasi-static regime – when they can measure deflections, or in the vibrating mode – when they can capture modifications of the modal frequencies. Figure 1 shows the simplified schematic of two microcantilever applications, namely the mass deposition detection (left in Fig. 1) and AFM read/write heads (right in Fig. 1).

In essence, the microcantilevers are structural members that take advantage of their flexural compliance in order to accomplish a pre-designed functional task. For a given material and microfabrication technology, the only way of changing their static or modal responses is through variation of the geometric parameters. While for the vast majority of microcantilever applications the analysis is performed by means of commercially-available finite element-based software, there have been several attempts over the years to study these members as flexure hinges through lumped-parameter modeling. A few examples whereby analytical techniques have been employed to model the static and modal response of flexure hinges are mentioned in the following. Paros and Weisbord [1] characterized the elastic response of symmetric circular flexure hinges by analytical modeling and derived the spring rates or compliances for this type of flexure hinge. They produced closed-form equations, both exact and approximate, in terms of the geometry and material properties. By extrapolating the approach of Paros and Weisbord [1], Smith, Badami, Dale and Xu [2] formulated the approximate equations of the compliances corresponding to symmetric right elliptic flexure hinges, and assessed the model accuracy by means of finite element simulation and experimental testing. Xu and King [3] compared the right circular, corner-filleted and elliptic flexure hinges in terms of stiffness and precision of motion by