Modeling, Design and Experimental Characterization of Bending Resonant Circular Nano Cantilevers

N. Lobontiu*[,1], B. Ilic[2], T. Reissman[2], E. Garcia[2], Y. Nam[3] and H.G. Craighead[2]

[1]University of Alaska Anchorage, USA; [2]Cornell University, USA; [3]Kangwon National University, Korea

Abstract: This work reports on a new type of nano cantilever, the symmetric circular one, and provides results of its out-of-plane bending natural frequency by means of analytical modeling and experimental testing. The cantilever, with a 225 nm thickness and planar dimensions smaller than 10 µm, can be implemented in dynamic nano electromechanical applications such as atomic force microscopy, surface topology characterization or resonance-shift mass detection. An analytic model is proposed that considers the distributed stiffness and inertia properties through an accurate distribution function. The model also captures the short-beam character of this structure and the related shear effects. Several silicon nitride nano cantilevers have been surface-micromachined and tested by using in-vacuum laser excitation and interferometric measurement of the bending resonant response. The model predictions and the experimental results indicated minimal errors. Based on this agreement, the analytical model was utilized to further analyze the influence of the basic geometric parameters on the cantilever's natural frequency.

Keywords: MEMS, NEMS, cantilever, circular, resonator, bending.

1. INTRODUCTION

This report presents results on the modeling, design, experimental and simulation of the *out-of-plane bending natural frequency* for a *novel nano cantilever* design, the *constant-thickness circular cantilever*, which can be implemented in a variety of applications, such as resonant detection of minute amounts of attached substance or dynamic atomic force microscopy (AFM) transduction. The main advantage of this specific cantilever over existing designs consists in its ability to produce a wide range of resonant frequencies by changes in the circular notch radius and in the notch center position. Another advantage is the analytical model, which takes into consideration the short-beam character of this particular design by means of the exact deformation distribution function, and thus enables accurate simulation to be performed.

At micro and nano scale, under specified fabrication constraints, and for a given geometrical envelope, say of rectangular shape, the main modality of altering a cantilever's natural frequency is through shape modification. Shapes that can be described by analytical curves present the advantage that closed-form equations, which are often times sufficiently-accurate for conducting first-stage model simulation, can be obtained for the amount of interest of a given structure, be it the stiffness in a static application, or a certain resonant frequency in a dynamic problem. The procedure of selecting specific geometric shapes is therefore extremely important in producing designs that are capable of matching pre-defined performance criteria (such as specified static deflections or natural frequencies), as well as in refining the geometrical set of parameters in view of optimizing the structural response.

Cantilevers with dimensions in the micrometer and nanometer range have been used lately for substance characterization or recognition through dynamic operation in viscous fluids [1-4], for imaging/sensing, data writing/storage or material properties evaluation through scanning-probe microscopy, atomic-force microscopy [5-10] or model identification [11]. Two physical principles are usually being applied in micro/nano-scale cantilever-based transduction: (a) the deflection change is statically monitored; or (b) the shift in a relevant natural frequency (most often the one corresponding to the out-of-plane, weak-axis vibrations) is determined [12, 13]. The cantilever deflection alters as a result of a variety of external factors such as micro-temperature variation, molecular adsorption, micro-corrosion, phase change or stress-induced surface property changes [14-17]. Natural frequency shift methods have successfully been applied in detecting the quantity (to the level of attogram) and position of matter that deposits on a cantilever [18-30] or in physical/chemical sensors [31, 32].

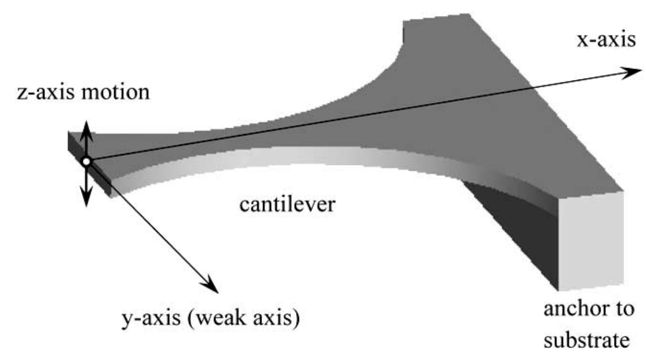

Fig. (1). Three-dimensional view of a circular nano cantilever.

Studied here is a new cantilever design, the symmetric circular nano cantilever, which is pictured in the three-dimensional rendering of Fig. (**1**). For a specified thickness, this configuration provides dimensional and therefore operational variability through modifications of a few geometric parameters, as it will be discussed shortly. Particular emphasis of this research falls on the out-of-plane bending resonant frequency (about the y-axis, the weak axis), which is investigated through a mathematical model and experimental testing.

*Address correspondence to this author at the University of Alaska Anchorage, USA; E-mail: afnl@uaa.alaska.edu

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