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Research Paper

Scale-Dependent Dynamic Behavior of Nanowire-Based Sensor in Accelerating Field

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Abstract. The accelerating fields (e. g. centrifugal acceleration and constant acceleration) can change the physical performance of nano-sensors significantly. Herein, a new size-dependent model is developed to investigate the scale-dependent dynamic behavior of nanowire-fabricated sensor operated in an accelerating field. The scale-dependent equation of motion is developed by employing a consolidation of the strain gradient elasticity (SGE) and the Gurtin–Murdoch theory (GMT). A semi-analytical solution is extracted for calculating the stability parameters. Effects of different phenomena including centrifugal force, microstructure dependency, surface layer, length-scale-parameter, dispersion forces, squeezed film damping on the dynamic stability parameters are demonstrated.

Keywords: Nanowire, Accelerating field, Strain gradient elasticity, Dynamic instability, Surface energies

1. Introduction

With the novel manufacturing methods for producing ultra-small structures, the applications of nanowires and carbon nanotubes have extended rapidly in the various branch of nanotechnology [1-5]. A typical nanowire-fabricated sensor is manufactured from a deformable nanowire parallel to a solid plate. Nano-sensors have wide applications in modern measurement devices. These systems can be employed in satellites [6], automotive sensors [7], centrifugal separators [8], fault detection of roller bearing [9], CNC high-speed spindle errors detector [10], balancing power plant rotating equipment [11] and turbo-machinery angular speed detectors [12]. In these applications, the sensor operated in an accelerating field which can significantly alter the behaviour of the sensors.

The size effect (i.e. surface energies and microstructural dependency) can significantly change the mechanical performance of nano-sensors [13-16]. Various continuum theories have been presented for modelling the scale dependency of solids. An efficient theory for modelling the impacts of the surface layer on the mechanical behaviour of solids is Gurtin-Murdoch theory (GMT) [17]. For simulating the microstructural dependency the higher-order theories such as strain gradient elasticity (SGE) [15], nonlocal theory [18], couple-stress theory [19] and modified couple stress theory [20] can be employed. Among this theories, the SGE is more general and proposes some additional high order stress component in comparison with simple size-dependent models such as couple stress and modified couple stress theory. SGE can be degenerated to simplified models by neglecting this higher additional higher-order stress factors. Fu and Zhang employed GMT to study the instability of clamped-clamped nano-actuator. The pull-in behaviour of nano-actuators by considering the surface layer is investigated in Ref. [21]. Koochi et al. investigate the influence of surface energies on the electrostatic instability of NEMS operated in the Casimir regime [22]. Wang and Wang introduced a finite element simulation for incorporating the surface layer on the vibration and bending of nano-plate [23]. Shaat and Mohamed proposed a nonlinear model in the framework of the GMT and the modified couple stress theory to simulate both microstructure dependency and surface effect [24]. In Ref. [25] the pull-in of nanowire-

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