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Microstructure-dependent dynamic behaviour of torsional nano-varactor

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Abstract

Experiments depict that the physico-mechanical response of miniature devices is microstructure-dependent. However, the classic continuum theory cannot correctly predict the microstructure-dependency. In this paper, the strain gradient theory is employed to examine the dynamic behavior and instability characteristics of miniature varactor with trapezoidal geometry. The governing equation of the varactor is obtained incorporating the effects of Coulomb force, van der Waals (vdW) attraction, squeeze film damping and structural damping. The influences of microstructure on the dynamic instability of equilibrium points are studied by plotting the phase portrait and bifurcation diagrams. It is found that increase in the microstructure parameter enhances the torsional stability. In the presence of the applied voltage, the phase portrait shows the saddle-node bifurcation while for free-standing varactor a subcritical pitchfork bifurcation is observed.

Keywords: nano-electromechanical varactor; microstructure; strain gradient theory; dynamic instability; van der Waals force.

1. Introduction

Ultra-small electrostatic torsional actuators due to the high sensitivity, high quality factor, low actuation voltage and small possibility of stiction have wide applications in the micro/nano-electromechanical systems (MEMS/NEMS) such as tunable torsional capacitors, digital light processing chips and torsional radio frequency switches used in micro-satellite communications and radar systems [1-5]. Among these systems, torsional NEMS varactors are being considered as potential ultra-small devices with promising applications in fabrication of smart structures such as confocal microscopy, wireless communications, optical telecommunication, bar code reading, laser printing and endoscopic bio-imaging, integrated circuits, switching devices, nano-robots, etc. Therefore, many researchers have focused on the numerical, theoretical and experimental analysis of such systems through different assumptions and methods [6-14]. The torsional nano-varactor is composed of movable conductive electrode (mainplate) which is suspended over a fixed conductive electrode (substrate) using torsional nano-beams. In the equilibrium position, the electrostatic and restoring forces/torques are identical. However, if the potential difference exceeds its critical value, the nano-varactor becomes structurally instable and the flexible plate adheres to the fixed substrate i.e. pull-in instability occurs. Actually, pull-in is an unstable state at which the elastic torque can no more balance the electrical torque [15, 16]. The pull-in instability phenomenon is a crucial issue in the design and fabrication of NEMS/MEMS. Recently, many investigations have extensively focused on the prediction of pull-in state of electrostatic torsional NEMS/MEMS [17-22]. Sedighi and Shirazi [18] investigated the nonlinear behavior of double-sided-actuated torsional nano-switches with different actuation voltages. Guo et al. [19] studied the pull-in instabilities of a rotational MEMS/NEMS in the presence of capillary effects. The chaotic behavior in torsional MEMS mirrors near the instability condition was developed by Shabani et al. [20].

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