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Pull-in instability of CNT nanotweezers modelled by the two-phase nonlocal theory of elasticity

Radi E.[1], Mikhasev G.[2]

[1]*University of Modena and Reggio Emilia. DiSMI via Amendola 2, 42122 Reggio Emilia, Italy*
[2]*Harbin Institute of Technology, 92 West Dazhi Street, 150001 Harbin, China*

enrico.radi@unimore.it, mikhasev@hit.edu.cn

A nanotweezer is a tiny nanoscale device used to manipulate nanoscale objects, such as nanoparticles, nanowires, or biological entities, with nanometer-scale accuracy. Accurate modelling of the behavior of a nanotweezer under electrostatic force and van der Waals (vdW) force, considering the effects of nonlocal theory of elasticity, is extremely important for assuring high precision and control over the nanotweezer's movements. Due to their excellent mechanical and electrical properties, carbon nanotubes (CNTs) are often used as main components for nanotweezers [3]. This work investigates the electromechanical response and pull-in instability of an electrostatically-actuated CNT tweezer modelled by using a two-phase nonlocal (TPNL) elastic constitutive model [1, 2]. The nonlocal response of the material introduces two additional parameters in the formulation, which are effective in capturing the size effects observed at the nanoscale and to provide an accurate description of its electromechanical response. This constitutive model for the the Bernoulli-Euler type beam combines the purely nonlocal (PNL) theory of elasticity with classical elasticity, taking into account the nonlocal effects in the axial direction of a nanobeam, and does not suffer from the inconsistencies of the PNL model applied for nanobeams based on the kinematic hypotheses. The problem is governed by a nonlinear integrodifferential equation, which can be reduced to a sixth-order nonlinear ODE with two additional boundary conditions accounting for the nonlocal effects near to the CNT edges. A simplified model of the device is proposed based on the assumption of a quadratic loading distribution (QLD) acting on the CNTs. This assumption allows us to formulate the problem in terms of a linear ODE subject to two-point boundary conditions, which can be solved analytically. To validate the assumption on the QLD, we compared the adopted QLD and the loading function provided by the deflection obtained by the QLD, which turn out to be quite close each other, thus proving the accuracy of the QDL model. The results show that strong coupling occurs between the intermolecular forces and the characteristic material lengths as smaller structure sizes are considered. Considering the influence of the nonlocal constitutive behavior and intermolecular forces in CNT tweezers will equip these devices with reliability and functional sensitivity, as required for modern engineering applications.

References

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