International Journal of Engineering Science 130 (2018) 33–50

Contents lists available at ScienceDirect

International Journal of Engineering Science

journal homepage: www.elsevier.com/locate/ijengsci

On dynamic analysis of nanorods

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A R T I C L E I N F O

Article history:
Received 7 March 2018
Revised 23 April 2018
Accepted 20 May 2018

Keywords:
Size dependency
Nanorod
Vibration
Nonlocal elasticity
Different boundary conditions

A B S T R A C T

In the present study, longitudinal free vibration behaviors of one-dimensional nanostructures with various boundary conditions are investigated based on Eringen's nonlocal theory. The governing differential equation of motion is analytically solved for a number of different boundary conditions like clamped, free, attached mass and/or spring. It is noted that some of these solutions for the nonlocal frequencies of nanorods with attachments ones are the first in the literature. Effects of nonlocal parameter, attachments, boundary conditions, and length on the natural frequencies of nanorods are studied in detail. It can be emphasized that the inclusion of attachments decreases the longitudinal frequencies of nanorods, especially in higher modes.

1. Introduction

Extraordinary rapid developments in technology, such as the discovery of Atomic Force and scanning tunneling microscopes in the 1980 s, have allowed the ability to measure and model at the atomic level. After the discovery of carbon nanotubes (CNTs) in 1991, modelling and analysis of micro-/nano-sized structures have attracted a lot of interest from researchers (Iijima, 1991). Small-sized structures as nanorods, nanotubes, nanowires, nanobeams, and nanoshells are one of the essential structural elements in nano- and micro-electromechanical systems (NEMS/MEMS) (Ghayesh, Farokhi, & Alici, 2016; Ghayesh, Farokhi, & Amabili, 2013; Kahrobaiyan, Asghari, Rahaeifard, & Ahmadian, 2010; Mojahedi, 2017; SoltanRezaee & Afrashi, 2016; Uzhegova, Svistkov, Lauke, & Heinrich, 2014).

Nanorods and nanowires are well-known one-dimensional nanostructures, which are frequently used not only in NEMS such as nanotransistors (Tao, Wang, & Zhu, 2016), nanosensors, nanogenerators (Khan et al., 2012), and nanocapacitors but also in biomedical treatments, dentistry, production of energy from solar cells, and humidity sensitive analysis (Krahne et al., 2013; Wang, 2008). For instance, gold and ZnO nanorods based nanosensors are developed (Lupan, Chai, & Chow, 2007; Thatai, Khurana, Prasad, & Kuinar, 2014). These sensors are very useful for sensing of hydrogen gas and Fe (III) ions. Also, nanorods can be used in display technologies. The reflectivity of the rods can be altered, resulting in superior displays due to varying the orientation of the nanorods by an applied electric field. Moreover, Olson et al. (2014) developed full color display technology using nanorods made of aluminium.

On the other hand, gold nanorods have great potential in biomedical applications like tumor molecular imaging and photothermal therapy (Gui & Cui, 2012). Fluoridated hydroxyapatite nanorods are employed as novel fillers to improve the mechanical properties of dental composite (Taheri et al., 2015).

A composition of vertical gallium nitride nanowires (GaN NWs) can be used as a transverse force sensor. The behavior of the piezotronic effect in GaN NWs under transverse force is investigated (Zhou et al., 2013). As seen in Fig. 1, a GaN NW is subjected to a bending force at the end of it by Atomic Force Microscope (AFM).

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https://doi.org/10.1016/j.ijengsci.2018.05.001

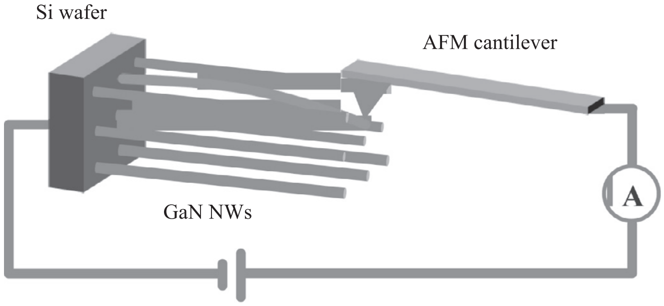

Fig. 1. A GaN nanowire under a bending force at the end of it by AFM.

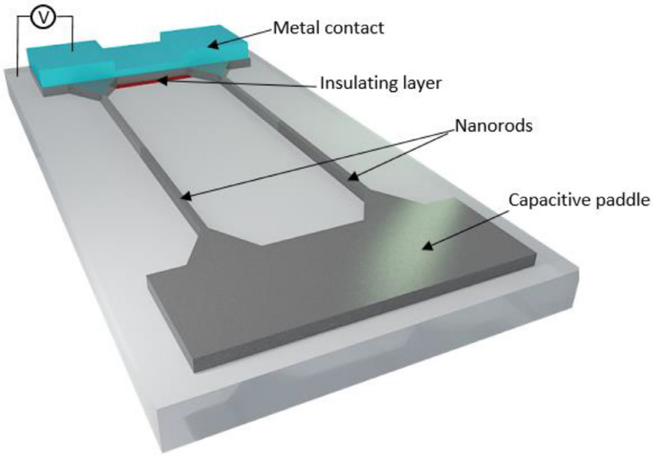

Fig. 2. Schematic and design of a nanoswitch with U-shaped dual silicon nanorods.

These nanostructures can also be produced from metallic or semi-conductor materials with the help of various substrates. The production of gold (Au) nanorods from Anodic Alumina Membrane (AAM) can be given as an example. Silicon (Si) is widely used as a semiconductor device material due to the relatively high modulus of elasticity as 130–188 GPa (Hopcroft, Nix, & Kenny, 2010) and other useful properties (Pishkenari, Afsharmanesh, & Tajaddodianfar, 2016). The schematic configuration of a nanoswitch is illustrated in Fig. 2. Two parallel silicon nanowires (Si NWs) are clamped and electrically connected by a metal contact at one end. The other end of the Si NWs are bonded by a movable capacitive paddle (Qian, Lou, Tsai, & Lee, 2012).

Nanoscale energy harvesting is a developing field where efficient energy conversion is a tough task (Wang & Wang, 2017). Piezoelectric nanogenerator (PENG) is a nanoscale energy collator that converts kinetic energy from mechanical vibrations in the environment into a usable electric energy form using a piezoelectric material. A schematic configuration of a nanocomposite electrical generator occurred by vertically grown piezoelectric ZnO NWs, metal plate electrodes at the top and bottom of nanowires, and an epoxy matrix is displayed in Fig. 3 (Roji, Jiji, & Raj, 2017).

It is important that these systems can be modeled to understand the behaviors of these one – dimensional nanostructures under mechanical, electrical, and thermal loadings and these models can be analyzed under the related external influences. Solving the mathematical models is important to carry out the analysis and these mathematical models can be solved for boundary conditions of nanostructures. The new structure that formed by another nano-scaled materials at its tips of nanorod, can be modeled as nanorod with attached mass. In addition to AFM (see Fig. 4a), nanodumbell is another example for nanorods with attached mass (see Fig. 4b).

As mentioned above, substrate materials are heavily used for nanorod growth. As seen in Fig. 5, growth of nanorod attached to the electrode and thin film element by strong substrate materials at their ends has offered the idea of modeling the electrodes as the clamped end, and substrate as the spring attached end.

The micro and nanobridges that can be encountered in computer processors, nanorod placed between the electrodes can be given as example for both ends clamped (see Fig 6a). The nanocantilevers, which encountered heavily in medicine and electronics in particular, can be considered as cantilever nanorods (see Fig. 6b).

The mechanical characteristics of them must be well known for optimum design and functionality of these systems. Consequently, many experimental works, atomistic and continuum mechanics modelling have been carried out to determine the mechanical properties of nanostructures. Experimental studies at nanoscale are very difficult and need very sensitive