Short communication

Comments on the paper “A comprehensive modeling and vibration analysis of AFM microcantilevers subjected to nonlinear tip-sample interaction forces” by Sohrab Eslami and Nader Jalili

Ali Passiana,b,c,*, Laurene Teted, Thomas Thundatd

a Oak Ridge National Laboratory, Oak Ridge, TN 37830, USA
b Department of Physics, University of Tennessee, Knoxville, TN 37996, USA
c Department of Chemical and Biomolecular Engineering, University of Tennessee, Knoxville, TN 37996, USA
d Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Alta., Canada T6G 2V4

ARTICLE INFO

Available online 4 April 2013

Keywords:
Microscopy
AFM
MSAFM
Imaging
Nonlinear dynamics
Nanomechanical forces

ABSTRACT

This comment on the paper “A comprehensive modeling and vibration analysis of AFM microcantilevers subjected to nonlinear tip-sample interaction forces” by Sohrab Eslami and Jalili (2012) [1] aims to: (1) discuss and elucidate the concept of “virtual resonance” and thus (2) avert a misinterpretation of the experimental results and findings reported in the Tetard et al. Physical Review Letters 106, 180801 (2011) [2].

© 2013 Elsevier B.V. All rights reserved.

1. Comment

In a recent Letter [3], Tetard et al. introduced a generalized approach to multifrequency atomic force microscopy (AFM) termed mode synthesizing AFM (MSAFM) with promising dynamic attributes for subsurface imaging [4]. The new modes of the MSAFM, or the synthesized modes, were shown to be a result of the nonlinear form of the probe-sample interaction force, giving rise to frequency mixing. Using a partial differential equation (PDE) description of the MSAFM, Tetard et al. showed that the multifrequency aspect of the dynamics of the MSAFM operation could be captured by assuming a semi-empirical nonlinear force [2,3,5]. The sum and difference frequency generation in the MSAFM operation [3], offers a number of dynamic advantages compared to traditional single or multifrequency microscopy [6,7], as demonstrated for example by the application of the MSAFM to biomass characterization [3,5]. An example of the versatility of the MSAFM is the experimental generation of an oscillation enhancement that was recently reported by Tetard et al. [2], an effect coined “virtual resonance”. Based on a careful measurement of this enhancement, the reported experimental results showed that, in principle, any synthesized mode of the MSAFM can respond in a resonance like fashion to a spectrally tuned external forcing, allowing the system to exhibit useful amplitude at frequencies completely outside the “original” resonances of the system [2].

While the concept of virtual resonance was presented based solely on the experiments of Tetard et al. [2], a semi-analytical solution to the above mentioned PDE, based on the Euler–Bernoulli model of the cantilever probe, was also presented in the same article to verify that the nonlinearity in the proposed force form could indeed generate the difference frequency. In the paper by Eslami and Jalili [1], the subject of our Comment, instead of the Euler–Bernoulli model of the microcantilever probe, the Timoshenko model for the microcantilever oscillations is solved under the same assumptions as the ones described in [2]. The authors report that both the Timoshenko and the Euler–Bernoulli beam models “had acceptable representation of the realistic behavior of the AFM system.” However, here, with reference to Fig. 1, the following comments are made for the benefit of the readers. First, it is crucial to distinguish the oscillation mode of the probe at the engendered difference frequency (Fig. 1c) from the enhancement achieved at the virtual resonance (Fig. 1e). The former process (Fig. 1c) has alternatively been referred to as scanning nearfield ultrasonic holography (SNFUH) [8–12]. Even more crucial is to treat the tuning of the difference frequency to the resonance frequencies of the probe (Fig. 1d) as a completely separate dynamic effect from the probe oscillation during the tuning to the virtual resonance (Fig. 1e) [2,3]. The former process (Fig. 1d) has also been referred to as resonant difference-frequency atomic force ultrasonic microscopy (RDF-AFUM) in [13]. Therefore, our comment specifically points out the distinction of such frequency overlap (Fig. 1d) from...
When stimulated with a weak applied forcing, the newly formed difference mode is amplified by exhibiting a resonance-like behavior, which can be described by a virtual resonance. Second, it is constructive to note that in order to advance the understanding of subsurface microscopy, the mechanical excitation of the sample must be adequately taken into account. Since no sample dynamics is included in [1], the presented calculations by Eslami and Jalili [1] bear no information regarding subsurface microscopy, in particular within the framework of the MSAFM [2,3,4,13,14]. Experimentally, the capability of MSAFM as an approach for high-resolution noninvasive subsurface microscopy has been demonstrated through characterizing nanoparticles in macrophages and red blood cells [8,9] and plant cell walls of biomass [3,5]. As for subsurface models, while a simplified computational model predicting the variation in the sample surface traction and velocity as a result of embedded nanoparticles in a sample was presented in the Supplementary material associated with [3], interesting developments are also noted in the recent work of Verbiest et al. [4] and others [13,15].

Acknowledgments

This work was sponsored by the BioEnergy Science Center (BESC) of the Oak Ridge National Laboratory (ORNL). Laurene Tetard would like to acknowledge partial support from the Wigner fellowship program. The BESC is a US Department of Energy (DOE) Bioenergy Research Center supported by the Office of Biological and Environmental Research in the DOE Office of Science. ORNL is managed by UT-Battelle, LLC, for the US DOE under contract DE-AC05-00OR22725.

References