International Journal of Applied Engineering Research, ISSN 0973-4562 Vol. 9 No.26 (2014) pp. 8803-8806

Finite Element Based Analysis of Nanobeam with Fractal Roughness

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Abstract: **The present study considers stress analysis of nanobeam with fractal roughness using commercial finite element package ANSYS. Fractal roughness is created using three dimensional modified two-variable Weierstrass-Mandelbrot function with given fractal parameters. The present results are validated with available literature. Longitudinal stress and displacement are obtained for nanobeams with different fractal roughness parameters simulating various roughness density and depth. The present results may be useful to designers of nanostructures.**

Keywords: **Nanobeam, Roughness, Fractal, Finite element method.**

INTRODUCTION

Nanostructures are used in micro electromechanical systems (MEMS) and nano electromechanical systems (NEMS) applications. These devices are used in many applications like accelerometers, MEMS gyroscope, silicon pressure sensor etc. As these devices require high reliability, the nanostructures require reliability. Load applied on the devices during use may lead to component failure. So for the device to be reliable and able to resist the loads in daily usage, one needs to design the MEMS devices and the nanostructures taking into consideration of roughness features. Thus it is required to perform stress and deformation analysis of the nanostructures with roughness for optimal designing.

Mechanical properties of nanostructures are scale dependent. Young's modulus and bending strength of the nanobeam was measured by Sundararajan and Bhushan [1] using atomic force microscopy. Finite element analysis (FEA) of nanostructures is required for consideration of roughness on nanobeams. FEA is done conventionally down to micrometre scales and its application to nanoscale is questionable. However FEA has been used to predict residual stress and strain introduced in MEMS devices during fabrication [2], mechanical strain due to silicon doping [3], displacement and bending stress of nanostructures [4], analysis of micromechanical and nanomechanical experiments data [5-7].

Conventionally, surface roughness is characterized by statistical parameters like standard deviations of surface height, slope and curvature. But it has been found that the variance of slope and curvature depends on the resolution of the surface measuring instrument and is not unique to the surface. It is seen that power spectra of surface follows power law. Thus when the surface is magnified appropriately the magnified image is very similar to the original surface. This is expressed in terms of self-similarity and self-affinity [8]. Here fractal dimension and fractal roughness are used to characterize rough surfaces. Thus the present study aims at analysing the elastic deformation, displacement and stress on a nanobeam with fractal surface roughness with variations in fractal parameters, by using commercial ANSYS software. 3D rough surface is generated using modified two-variable Weierstrass–Mandelbrot function [9] with given fractal parameters. The effect of consideration of roughness as well as the variation in fractal parameters on the stress and deformation of the nanobeam is studied in the present paper.

SURFACE MODELLING

A 3D fractal surface topography can be generated using a modified (truncated) two-variable Weierstrass–Mandelbrot function that can be written as [9].

$$z(x,y) = L\left(\frac{G}{L}\right)^{D-2}\left(\frac{\ln\gamma}{M}\right)^{1/2}\sum_{m=1}^{M}\sum_{n=0}^{n_{\max}}\gamma^{(D-3)n}\left\{\cos\phi_{m,n}-\cos\left[\frac{2\pi\gamma^{n}\left(x^{2}+y^{2}\right)^{1/2}}{L}\cos\left(\tan^{-1}\left(\frac{y}{x}\right)-\frac{\pi m}{M}\right)+\phi_{m,n}\right]\right\} \quad (1)$$

Here L is the sample length, G is the fractal roughness, D is the fractal dimension ($2 < D < 3$), γ (γ>1) is a scaling parameter, M is the number of superposed ridges used to construct the surfaces, n is a frequency index, with n max= int [log (L/Ls)/logγ] representing the upper limit of n, where Ls is the