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Nondestructive Evaluation of Surface Roughness of Thin Films through Fractal Analysis

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Abstract

Fractal geometry developed by Mandelbrot has emerged as a potential tool for analyzing complex systems in the diversified fields of science, social science, and technology. Self-similar objects having the same details in different scales are referred to as fractals and are analyzed using the mathematics of non-Euclidean geometry. In the present work Fractal analysis has been carried out on the Atomic Force Microscopic (AFM) images of zinc sulphide (ZnS) film, with different concentration of copper incorporation, prepared by Radio Frequency (RF) sputtering technique. It is found that the fractal dimension decreases with copper (Cu) incorporation. The fractal dimension is also found to have strong correlation with surface roughness of the film. The analysis shows that greater the fractal dimension lesser is the surface roughness

1. INTRODUCTION

For the analysis of complex structures, Mandelbrot developed fractal geometry. The fractal being self-similar objects holds similar details in different scales. The fractal dimension (d) can have non-integer values that are greater than the topological dimension but less than the Euclidean dimension. Fractal dimensions are associated with the complexity of the system which enables the analysis of smoothness and roughness of a surface. Today fractal geometry has evolved as a potential tool for the study of the morphology of objects of irregular shape. Among the several techniques for fractal analysis of irregular objects, Box-counting is more popularly used technique [1-5].

Nanostructured materials have gained significant attention and applications in various fields because of their unique properties in the nanoscale. The thin films of these nanostructured materials find wide range of applications in electronics and photonics. Hence, structural, morphological and physical characterizations of thin films are important. Among various morphological characterizations, AFM technique is popularly used for estimating the root mean square (RMS) surface roughness. In the present work, fractal analysis is carried out to understand the surface morphology of Zinc sulphide thin films prepared by RF magnetron Sputtering technique.

The nanocrystalline thin film of zinc sulphide has attracted much attention recently as a potential material for filters, sensors, field emission displays, LEDs and solar cells. Physical properties of ZnS films are – (i) refractive index -2.35, (ii) optical bandgap energy - 3.7 eV, (iii) high transmittance in the visible range, (iv) wide wavelength pass band - 0.4-13 μm and (v) large exciton bond energy – 37 meV [6-10]**.**

2. EXPERIMENTAL DETAILS

Nanostructured ZnS thin films with different concentrations of copper (0.2, 0.5, and 3 wt %) are prepared by RF magnetron sputtering technique [6]. The AFM images of the films are subjected to fractal analysis by Box-counting method. The Box-Counting method is one of the popularly used methods for finding the fractal dimension of self-similar objects. It works by superimposing the image to be analyzed with boxes (squares) and the counting the number of boxes needed to cover the fractal image completely. Repeating the process with boxes of varying in dimension $(\in)$ and counting the number of boxes $(N(\in))$ to cover the entire area of the image, a graph is plotted with $\ln\left(\frac{1}{\in}\right)$ along the x-axis and $lnN(\in)$ along the y-axis [3].

$$N(\in) \propto \in^{-d} \quad \text{; Where d is fractal dimension} \qquad (1)$$

Taking logarithm we get

$$lnN(\in) = d\ln\left(\frac{1}{\in}\right) + constant \qquad (2)$$

Such that $\lim_{\in\to 0}\frac{N(\in)}{\ln(1/\in)}$

From the slope of the $\ln\left(\frac{1}{\in}\right)$ Vs $lnN(\in)$ graph, the fractal dimension (d) can be calculated.

3. RESULTS AND DISCUSSIONS

In the present work we have synthesized Cu incorporated ZnS nano thin films (with doping concentration 0.2, 0.5, and 3 wt%) by the RF magnetron sputtering technique. The surface roughness of the film is analyzed by AFM microscope. The AFM images are shown in fig 1 are taken for analysis from the paper cited as reference 6. The fractal dimensions of the AFM images are computed by Box-counting technique. The $\ln\left(\frac{1}{\in}\right)$ Vs $N(\in)$ plot for the three samples with different concentration of Cu incorporation are also given in fig. 1. From the slope of that $\ln\left(\frac{1}{\in}\right)$ Vs $lnN(\in)$, the fractal dimension (d) can be calculated.

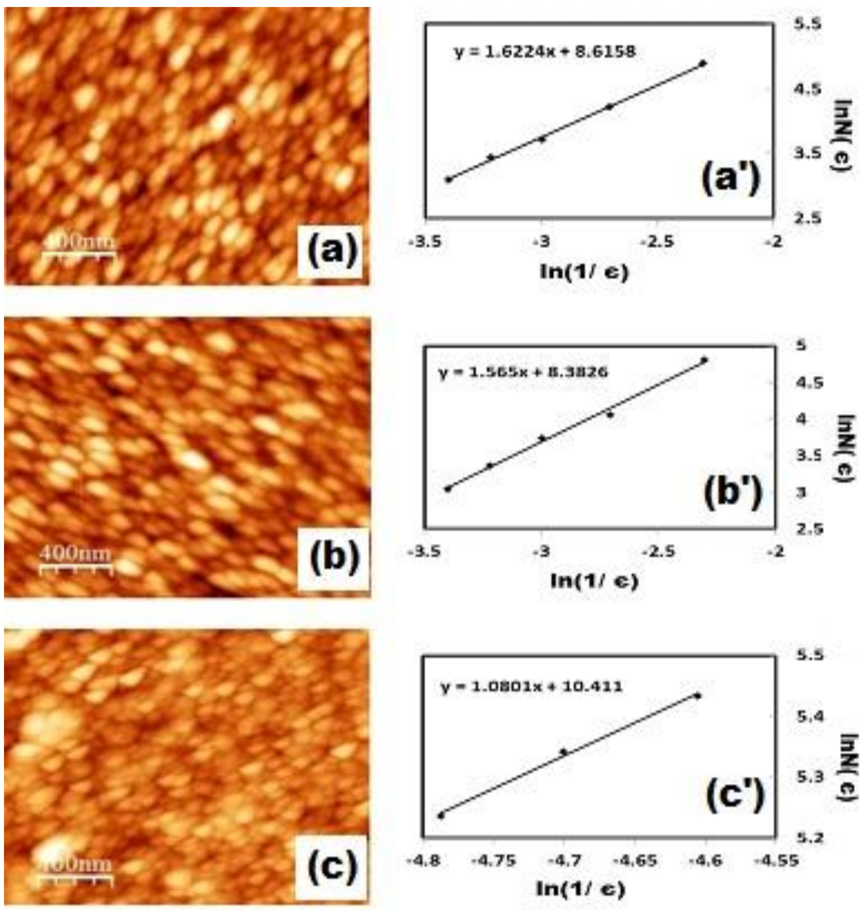

Fig. 1. The AFM images [6] and $\ln\left(\frac{1}{\in}\right)$ Vs $lnN(\in)$ plot – (a & a') at 0.2 %wt; (b & b') at 0.5 %wt; (c & c') at 3 %wt;

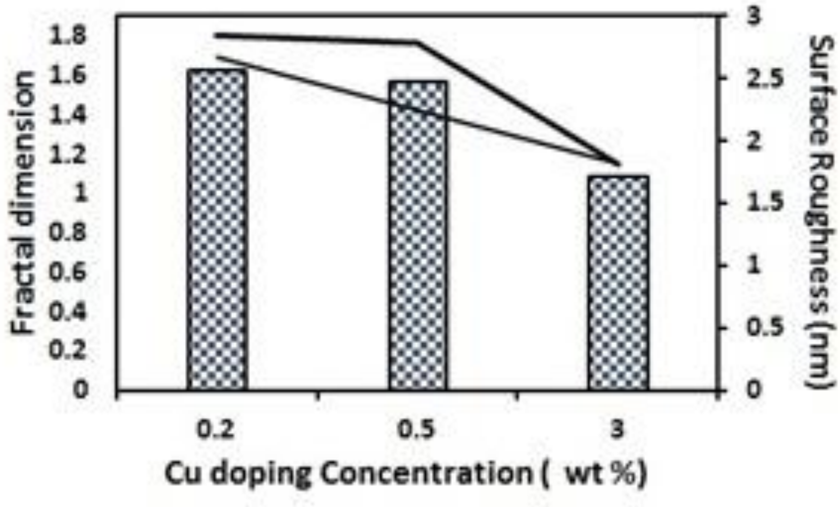

Fig. 2. Variation of fractal dimension and surface roughness with different Cu doping concentration.

Figure 2 shows the variation of fractal dimension and surface roughness with different Cu doping concentration. The fractal dimension (d) and Cu doping concentration (C) shows strong correlation with R^2 = 0.9983. The regression equation connecting the two variables is given by eq. (3).

$$d = -0.0006\, C + 2.0013 \quad (3)$$

Fig. 2. shows the variation of fractal dimension (d) with surface roughness (r). The variables ‘d’ and ‘r’ also show strong correlation with R^2 = 0.998 and the regression equation is given by eq. (4).

$$d = 1.9383\, r + -0.2705 \quad (4)$$

Thus, from eq. (4) it is evident that the surface roughness of the ZnS film coated by RF sputtering technique increase with decreases of fractal dimension. In other words, higher the fractal dimension the higher is the complexity and surface smoothness of the surface.

4. CONCLUSION

In the present work, ZnS film prepared by RF magnetron sputtering technique and the surface smoothness or surface roughness are analyzed at different copper incorporation are estimated from AFM data using the software WSxM 40 .Beta 6.2. The effect of copper incorporation on the fractal dimension and surface roughness are studied. By correlating the surface roughness with fractal dimension, the surface analysis by AFM can be made simpler.

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