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Fractal Analysis of Surface Morphology of Nano-structured BST Thin Films.

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1. Introduction

The irregular shape of thin film surfaces requires new methods for description. Recently, the concept of fractal dimension has been used to describe the statistical configuration [1][2][3][4][5].

Fractal descriptions characterize surfaces by a non-integer dimension, called the fractal dimension, which differ from the topological dimension. In order to determine fractals several methods have been developed, obtaining several results. Typical dimensions are the box dimension, the similarity dimension, the Hausdorff dimension and the spectral density. Investigations into the dependence of the fractal dimension on the deposition parameters show the applicability of fractal models to qualitative and quantitative descriptions of thin film surfaces [6].

In this study, a fractal method is presented to understand more clearly the effects of variation in surface characteristics on (Ba Sr)TiO_3 (BST) thin films. For structural images from a scanning electron microscope (SEM), the fractal morphology provides quantity information on grain shapes, void density and grain density. Using the SEM image, the 3D image of 256 level as brighten value for the analysis of surface morphology were represented (300 × 300 nm surface plots). The surface morphology (X, Y and Z) plots the colored parametric surface defined by three matrix arguments.

2. Experimental Conditions

The BST thin films was prepared for a sol-gel process of $(Ba_x, Sr_{1-x})TiO_3$$(0.7 \leq x \leq 0.9)$. Spin coating and drying operations with 3 times were performed in atmosphere and the partially hydrolyzed alkoxide solution was dropped on the substrate with a speed of 4,500rpm. In order to investigate the surface image, samples were chemically etched with $HClO_4$. The surface morphology of the thin films was observed by the SEM, and then transformed by a binary image to obtain the fractal morphology image. Particularly, the fractal morphology was used to extract quantitative information on the microstructures on the thin film surface.

The photomicrograph of SEM is a specialized form of a bitmap image to be a size of 256×256 RGB colors. The bright intensity of bitmap image is determined by means of threshold value of histogram.

3. Results and Discussion

Fig. 1 shows the SEM cross sections of BST thin films grown on the $Pt/SiO_2/Si$ substrate. The surface of BST thin film is relatively smooth. The BST thin film, for the most part, is more than one grain thick, while some grains extend from the bottom of the film. Grain growth was increased in proportion to additive materials of Sr, and the void in BST thin film surface was increased. The thickness of BST thin films was 260~280nm. The BST thin films exhibit a well-defined interface.

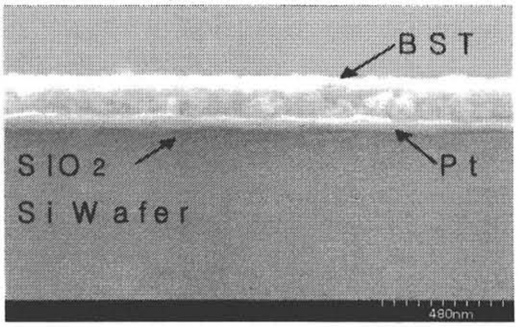

Fig. 1. SEM cross-sections of $(Ba_{0.8}\ Sr_{0.2})\ TiO_3$ thin films.

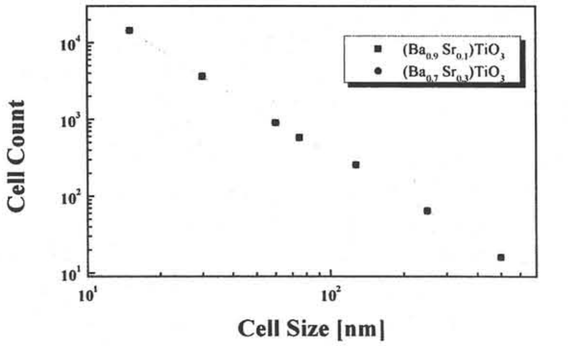

Fig. 2. The cell size and the cell count of the binary image of BST films.

Both r and N(r) in Fig. 2 each indicate the pixel range and pixel number computed from a box-counting method [7]. A plot exhibiting some relationships between them reveals that they are sub-linearly related.

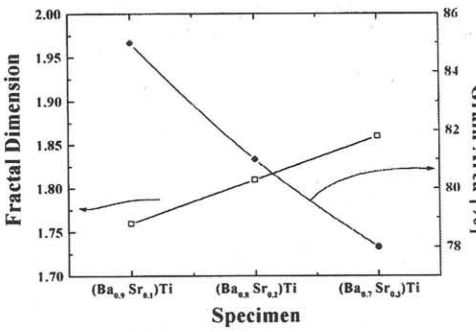

Fig. 3. Fractal dimension and coating areas of the BST film surface.

The grain areas are computed by a percentage, a partition comprising cubic grid cells, and dimension by 256 × 256 pixels. For a data set embedded in an E-dimensional space, fractal dimension was determined by using the Hausdofff dimension D_H, which was computed by the box-counting method [8]. This method imposes an E-dimensional grid with cubic grid cells of side r, and counts the number N(r) of those cells that are penetrated by the set of points. By repeating this process for the grids of different sides, a box-counting plot, N(r) versus r, is typically obtained. Its negative slope then defines the D_H, which is expressed as

$$\boxed{D_H = -\log(N(r)) / \log(r)}$$

Fractal dimension was increased with the Sr doping, and grain areas were decreased because of grain growth and porosities. The fractal dimension and grain areas of the $(Ba_{0.8}\ Sr_{0.2})\ TiO_3$ thin film were 1.81 and 80.5%.

The surface morphology (X, Y and Z) plots the colored parametric surface defined by three matrix arguments. The X and Y, it is determined by the range of selected area. The height determined the range of depth focus of SEM. The scaled color values are used as indices into the color maps.

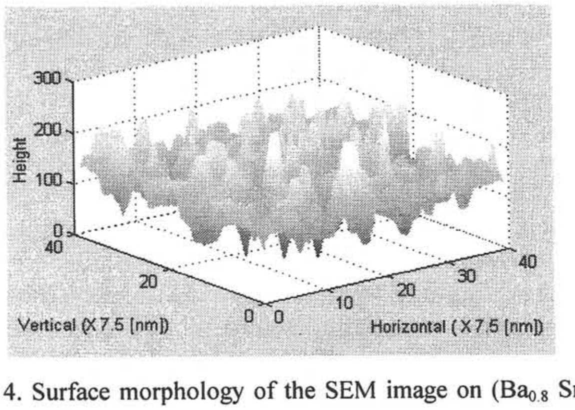

Fig. 4. Surface morphology of the SEM image on $(Ba_{0.8}\ Sr_{0.2})\ TiO_3$.

Fig. 4 depicted the 3D image representations (300 × 300 nm surface plots) of 256 levels as brighten value. The surface morphology image revealed surface roughness of less than 10nm because the maximum value of depth profile of SEM on the surface is about 10nm. The surface morphology has been formed very complexity as like high fractal dimension.

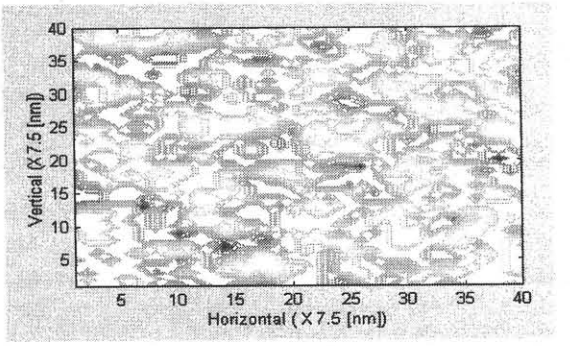

Fig. 5. The surface morphology by contour plots on $(Ba_{0.8}\ Sr_{0.2})\ TiO_3$.

Fig. 5 shows the contour plots of BST thin films. The lines and black part of contour plots depict the slope of hillock in surface morphology. It is indicate that height roughness and slope of hillock are strongly affected by the grain sizes and its degree of their aggregation.

4. Conclusions

The grain structure of BST thin films showed 48∼50nm. The thickness of BST thin films was 260∼280nm. Fractal dimension was increased according to additive material Sr, and coating areas were decreased. The quantitative information on the fractal dimension and grain areas of the $(Ba_{0.8}\ Sr_{0.2})\ TiO_3$ thin film was 1.81 and 80.5%.

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