Exploring the Effect of RF Power in Sputtering of Aluminum Thin films-A Microstructure Analysis

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Abstract

In this article, a detailed image analysis on the field emission scanning electron microscopy of aluminum thin films sputtered on stainless steel substrates was presented. The effect of RF power on the structural and topography characteristics of the films was described. The physical observations of the surface micrographs, quantitative particle size and distribution, fractal dimensions, average surface roughness and widths of the multifractal spectra of all the films were related to the change in RF power. There existed a correlation between increasing RF power and fractal dimension and multifractal spectrum whereas there was no relationship established between power and height roughness of the films. Fractal and multifractal approaches appeared to provide better description of the effect of RF power on the sputtered Al thin films.

Keywords
Aluminum thin film, Sputtering, Temperature, Power.

1. Introduction

Deposition of aluminum thin films through sputtering method has been embraced extensively due to the potential to obtain high quality films for various applications (Kelly and Arnell 2000). It is possible to tune the sputtering parameters to achieve the required properties of the Al thin films. There are various parameters of the sputtering process which can influence the characteristics of the Al thin films. Some of the parameters include the base pressure, sputtering gas pressure, argon gas flowrate, target temperature, substrate temperature, bias voltage, radiofrequency (RF) power, substrate type and among others (Mwema et al. 2018a). A lot of effort has been put in understanding how various parameters influence the formation of Al thin films during magnetron sputtering (Mwema et al. 2018a). It is noted that consensus does not exist in most of the published data since researchers have reported different combinations of parameters. As such, there is need for continued investigation and documentation of various parameters on sputtering of Al thin films to offer a sufficiently large resource for future academics and industry in thin film sputtering.

As a step towards this goal, this article reported on a detailed microstructural analysis of the influence of RF power on the Al thin films deposited on stainless steel substrates by RF magnetron sputtering technique.

2. Experimental Procedure

The Al thin films were deposited on stainless steel substrates by radiofrequency (RF) magnetron sputtering process using HHV TF500 deposition facility. The deposition was undertaken at varying RF powers of 150 W, 200 W, 250 W and 350 W at constant substrate temperature of 90 °C for 2 hrs. The details of substrates, sample preparation, pre-sputtering and facility operation were described in our earlier publication (Mwema et al. 2018b). The microstructure of the Al thin films was obtained using Field Emission Scanning Electron Microscope (FESEM) as described in reference (Mwema et al. 2019a) whereas the surface topography was obtained via non-contact optical surface profiler. Image analysis was undertaken on the surface microstructures to study the structural growth of the films during the sputtering process.

3. Results and Discussion

Figure 1 shows the representative microstructures of the Al thin films at various RF power obtained using FESEM. The FESEM micrographs showed a considerable influence of the RF power on the microstructure of the Al thin films. All the films appeared smooth and crack-free with clear grains observed at 150, 250 and 350 W. The grains at 150 W, 250 W and 350 W appeared more distinct than those observed at 200 W. The structure at 200 W appeared uniformly distributed compared to the rest of the films while those obtained at 350 W films appeared the finest. The films at 250 W exhibited the largest sizes of grains, highest roughness and non-uniformly distributed.

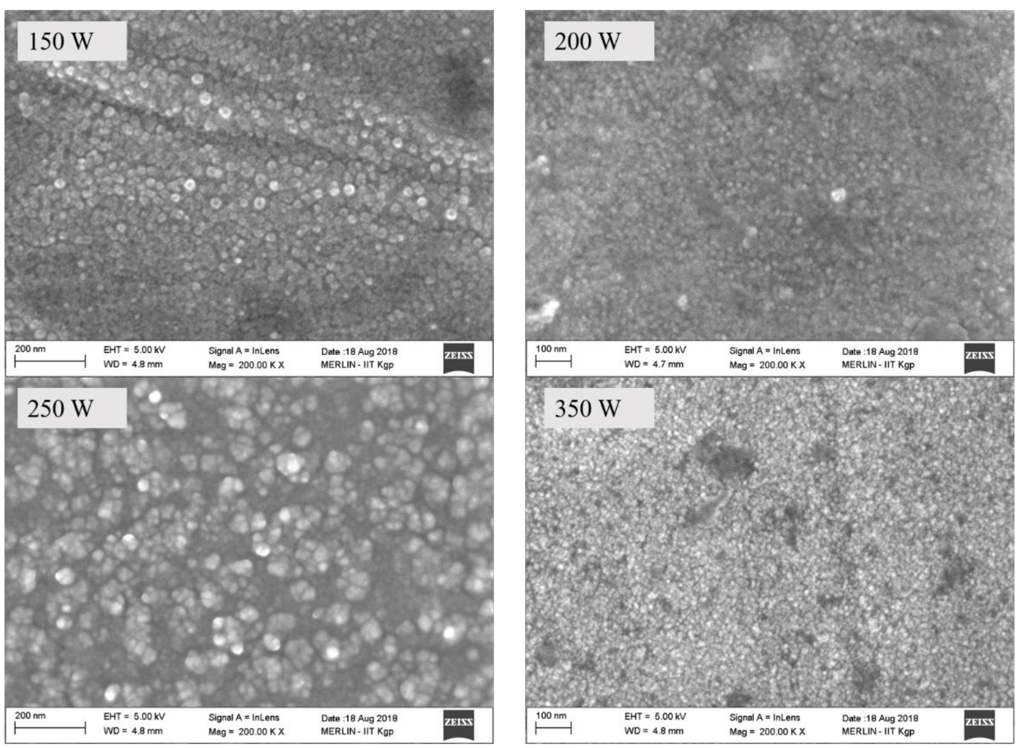

Figure 1. Representative FESEM micrographs of surfaces of Al thin films sputtered on stainless steel at different RF powers.

To further understand the structure of the films from FESEM technique, fast Fourier transform (FFT) bandpass filtering to 40 pixels followed by image thresholding techniques was applied in *ImageJ* on all the FESEM images in Figure 1 to obtain the results presented in Figure 2. The particle analysis undertaken on the data revealed the grain sizes of 475.84, 492.80, 788.79 and 380.49 nm for the films deposited at 150, 200, 250 and 350 W respectively. The circularity of the particles was computed as 0.690, 0.693, 0.749 and 0.715 for 150, 200, 250 and 350 W films respectively. These results revealed that the highest circularity and size of the particles were obtained at 250 W while the lowest circularity was obtained at 150 W and the lowest particle sizes at 350 W. The corresponding gray value profiles along the horizontal distance across the surface of the films revealed a close and densely packed structures in films deposited at 150, 200 and 350 W whereas those deposited at 250 W consisted of sparsely packed particles. The films deposited at 350 W revealed highly serrated profiles since at higher powers higher density of sputtering and sputtering yield are expected due to faster momentum transfer between the plasma ions and target atoms (Mwema et al. 2019b).

To understand the spatial distribution of the films, box-counting method (using 1000 grids) was applied to the images in Figure 2 and the fractal dimensions were computed as 1.8147±0.018, 1.8049±0.002, 1.7447±0.018 and 1.696±0.024 for films prepared at 150, 200, 250 and 350 W respectively. The results indicated a decreasing fractal dimension with the increasing RF power, which implies that as the power increased, there was more spatial development of the structure. The optical surface profiling results in Figure 4 revealed average roughness values of 1.172, 2.665, 3.562 and 2.533 μm for the respective RF powers. The highest roughness occurred on films consisting of large particle sizes and circularity (250 W). The was no a direct correlation of the average roughness to the fractal dimension. Additionally, there was no direct relationship between the RF power and average roughness. That implies that RF power significantly affected the spatial distribution and development, rather than the vertical growth, of the Al thin films (Hosseinabadi et al. 2017).

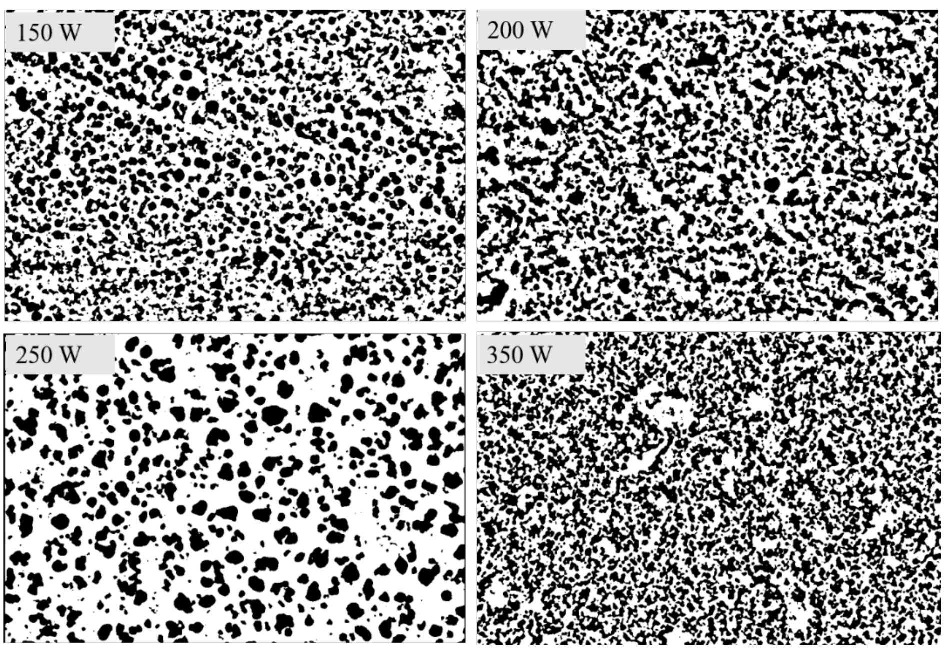

Figure 2. Particle detection through fast Fourier transform bandpass filter and image segmentation.

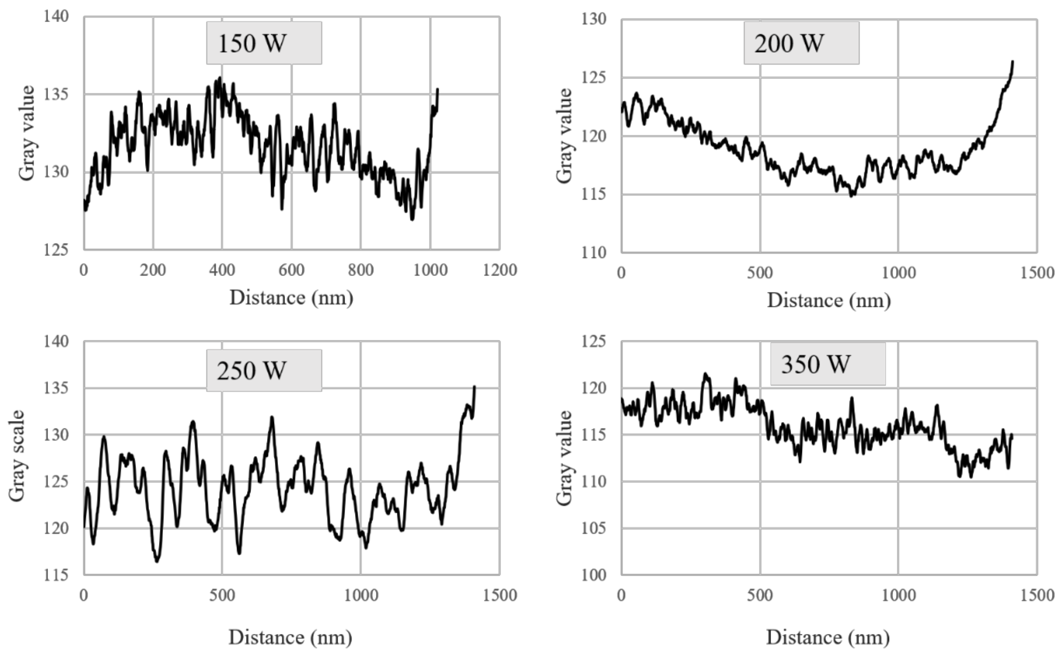

Figure 3. Profile plots across the surface of the images shown in Figure 2.

Multifractal analysis was performed on the images in Figure 2 using the algorithm described in the recent literatures (Ţălu et al. 2019) (Mwema et al. 2019c). The multifractal spectra (f(α)) shown in Figure 5 show that the Al thin films deposited on stainless steel substrates appear like hooks to the left and as observed the shapes and widths ($\Delta\alpha = \alpha_{max} - \alpha_{min}$) of the plots were different for various RF powers. The values of the widths (Δα) of the multifractal spectra were obtained as 0.4632, 0.6025, 0.6529 and 0.3915 for films deposited at 150, 200, 250 and 350 W respectively. These results indicate a general decrease in the widths (except at 250 W) of the spectra implying lateral growth of the films with the increase in RF power. The sudden change in the width of the spectrum at 250 W can be attributed to height roughening as reported via the surface profiler and that the height probability of the films becomes more non-uniform (Raoufi et al. 2008) (Raoufi 2009).

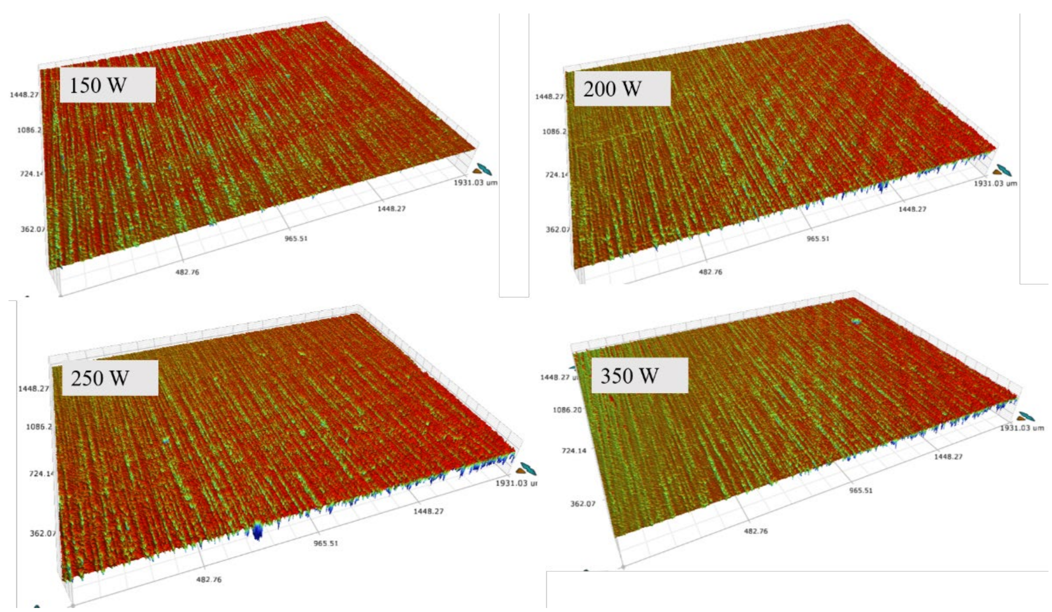

Figure 4. Optical surface profiles of Al thin films deposited on stainless steel substrates at different RF powers.

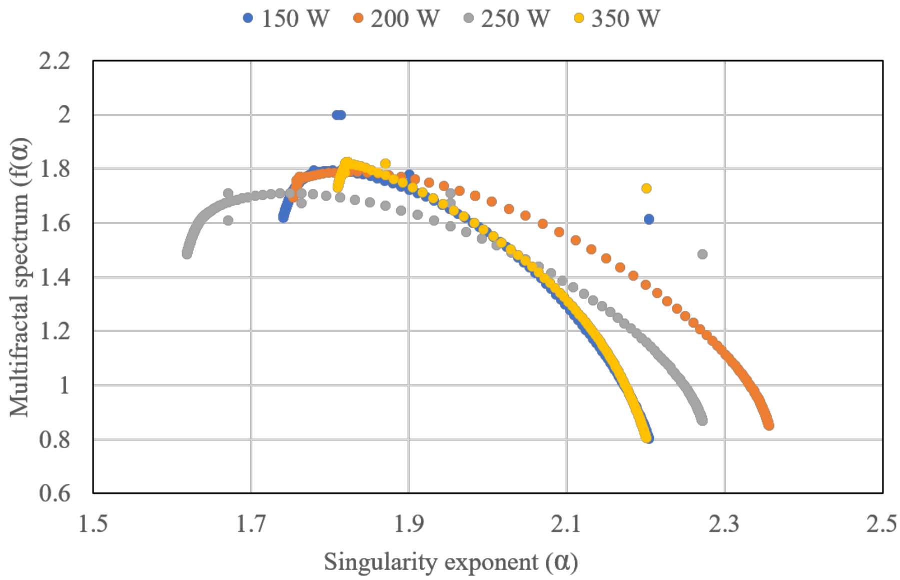

Figure 5. The multifractal spectra of the Al thin films deposited at various RF powers.

4. Conclusions

Aluminum thin films were deposited on stainless steel substrates via RF magnetron sputtering (HHV TF500) facility at RF powers of 150, 200, 250 and 350 W for 2 hrs. The films were characterized by FESEM and optical surface profilometry techniques. The surface microstructure, topography and structure distribution were described. It was reported that RF power does not exhibit direct relationship with average roughness, particle size and circularity. However, RF power was shown to have a correlation with one-dimensional fractal dimension and the widths of multifractal spectrum.

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Biographies

F.M Mwema is a doctoral candidate at the University of Johannesburg, Auckland Park, Kingsway Campus, South Africa. His PhD research focuses on the deposition of thin films using magnetron sputtering technology. He holds a Bachelor of Science and Master of Science degrees in Mechanical Engineering from Jomo Kenyatta University of Agriculture & Technology (JKUAT), Nairobi, Kenya. He is an assistant lecturer in the department of mechanical engineering, Dedan Kimathi University of Technology, Nyeri, Kenya and has several taught undergraduate courses for more than 7 years. Mr. Mwema has published more than twenty-five (25) articles in peer-reviewed journals, conferences and book chapters. His research interests include thin films, material characterization, advanced and modern manufacturing. He is a graduate engineer with Engineers Board of Kenya (EBK) and a member of International Society for Stereology & Image Analysis (ISSIA).

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O.P. Oladijo is with the Department of Chemical, Material and Metallurgical Engineering at Botswana International University of Science and Technology (BIUST), Palapye, Botswana. Prior to that, he completed his postdoctoral fellowship in School of Chemical and Metallurgical Engineering at University of the Witwatersrand, South Africa. He received his PhD degree in Material Science and Engineering field from the University of the Witwatersrand, South Africa in 2013. Until now, he has published several peer-reviewed publication and research project. His research interest focused on hard materials, coatings, residual stress analyses using diffraction techniques, tribology, corrosion, self-healing of materials and material characterization.