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Surface roughness of nickel/copper nanostructures

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ABSTRACT

Nickel/Copper (Ni/Cu) nanostructures with constant total nominal thickness were fabricated with different Ni and Cu layers of equal thickness in the ratio of 1:1 per nanostructure. Throughout the study, the total nominal thickness was kept at 2 400A° whilst the Ni/Cu layers were varied maintaining the 1:1 ratio of the Ni and Cu layer thicknesses. The surfaces of the nanostructures were characterised using the Atomic Force Microscope. It was found that the surface roughness behaved differently for Ni and Cu layers less 5A° than that of Ni and Cu layers greater than 5A°.

KEYWORDS

Nanostructures;
Electrodeposition;
Surface roughness;
Scaling.

INTRODUCTION

Nickel/Copper nanostructures alloys fabricated by electrodeposition were studied by Kazeminezhad et al.[1] and Kazeminezhad[2]. In the research the surface profiles of the nanostructures were studied to see how the surface roughness evolves with changes in the thickness of the nickel and copper layers being deposited using the electrodeposition method.

Surface roughness as we know is a length scale dependent quantity characterised by a parameter called the surface width which is defined mathematically by equation (1)[3-8].

$$\mathbf{w(l)} = \sqrt{\left\langle \left(\mathbf{h(x)} - \langle \mathbf{h(x)} \rangle \right)^2 \right\rangle} \qquad (1)$$

where w is the surface width, l is the length scale over which w is measured, $h(x)$ is the surface height at position x and $\langle\ \rangle$ denotes the average over the area measured.

The surface width exhibits a behaviour that obeys the conditions given by the equation (2).

$$\mathbf{w(l)} = \begin{cases} l^H, & \text{for } l \ll l_c \\ w_{sat} & \text{for } l \gg l_c \end{cases}, \qquad (2)$$

where w_{sat} is the saturation surface width, l_c is the transition (or cross-over or correlation) length at which w changes from the power law dependence on l to w_{sat} and H is the Hurst exponent.

Family[3] refers to l_c as the wavelength of the surface fluctuations whilst other authors see l_c as being indicative of the average mound size[8-10]. The mounds can be perceived as microscopic hills on the film surface with the saturation surface width, w_{sat}, giving the average height of the hills whilst the cross-over length, l_c, gives the average base width dimension of the hills.

When the surface width graphs coincide for $l < l_c$ but not for $l > l_c$, then the surface width is said to ex-

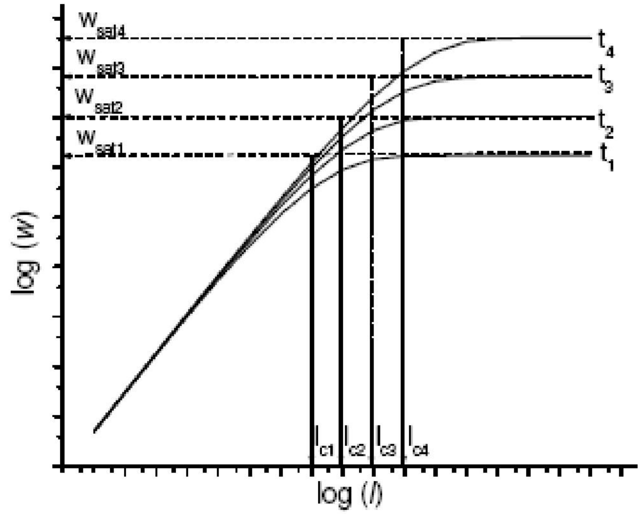

Figure 1 : Graphical representation of normal scaling of the surface width. The graphs of the surface width versus the length scale show divergence in the value of the saturation values of the surface width, whilst exhibiting convergence below the cross-over length of the film with the smallest thickness. The dashed lines with arrows indicate the w_{sat} and l_c values.

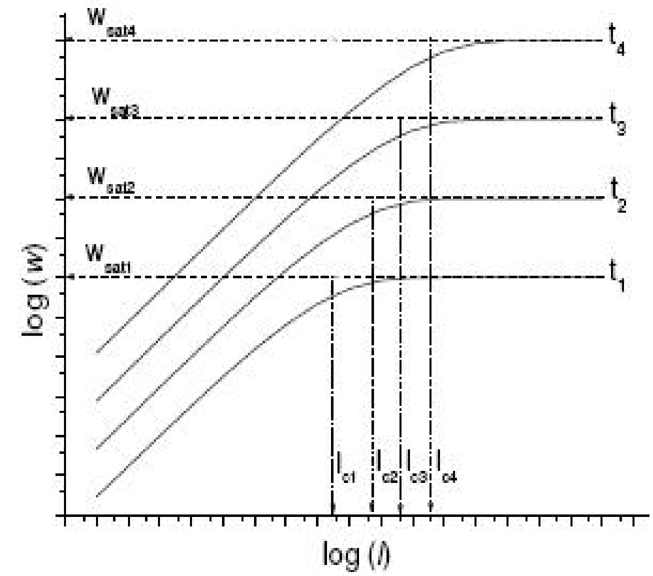

Figure 2 : Graphical representation of the anomalous scaling behaviour of the surface width. The graphs of the surface width versus the length scale do not converge as for normal scaling behaviour. The dashed lines with arrows indicate the w_{sat} and l_c values.

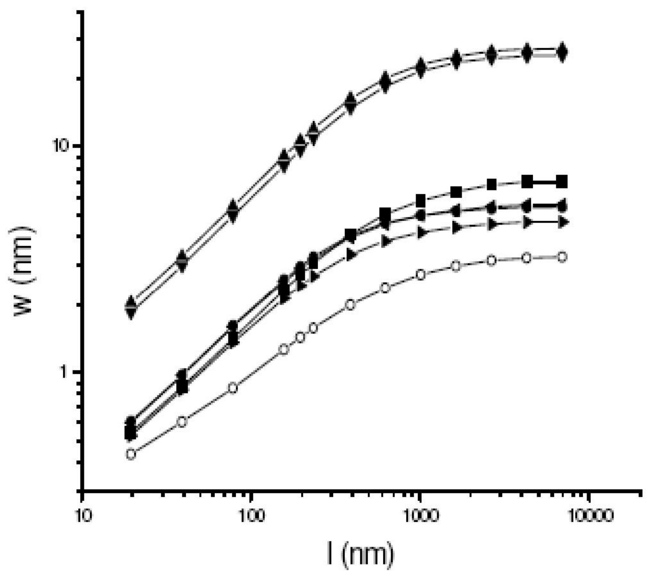

Figure 3 : Surface roughness for Ni/Cu nanostructures with constant total nominal thickness and variable repeat layer (t_{Ni} + t_{Cu}) thickness. (▼) Ni = Cu =1.25A° [2.5A°], (▲) Ni = Cu = 2.5A° [5.0A°], (○) Ni = Cu = 5.0A° [10A°], (▶) Ni = Cu = 10A° [20A°], (◀) Ni = Cu = 20A [40A°], (•) Ni = Cu = 40A° [80A°], (■) Ni = Cu = 80A° [160A°]. The numbers in square brackets are the repeated layer thickness.

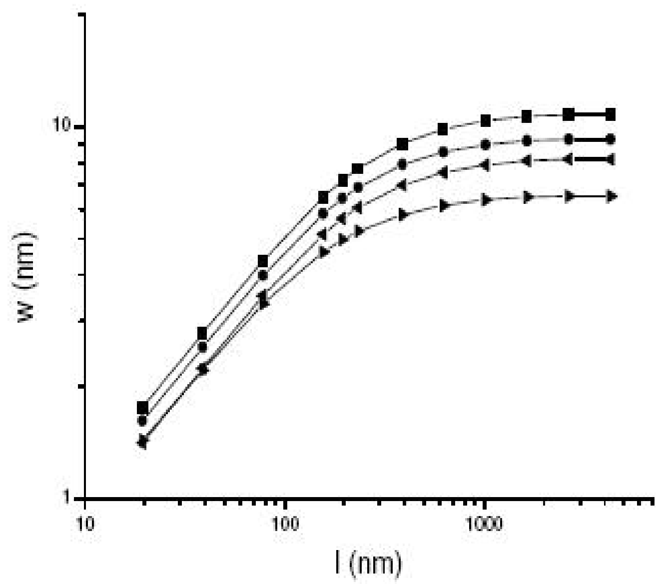

Figure 4 : Ni/Cu nanostructures with layer thicknesses of t_{Ni} (=t_{Cu}) = {(▶) 10A° [20A°], (◀) 20A° [40A°], (●) 40A° [80A°], (■) 80A° [160A°]}. The numbers in square brackets are the repeated layer thickness.

hibit normal scaling[4,11] with respect to *l*. This behaviour is illustrated in figure 1. The surface width can also exhibit behaviour that differs from normal scaling which occurs when the entire surface width graphs are displaced throughout their entire length; when this happens, the surface width is said to exhibit anomalously scaling[4,5]. This behaviour is illustrated in figure 2.

The cross-over (correlation) length, l_c, features in both the normal and anomalous scaling regimes. Some authors, Jeffries et al.[8] and Siegert[12], interpret l_c as a boundary between two regimes. One regime charac-

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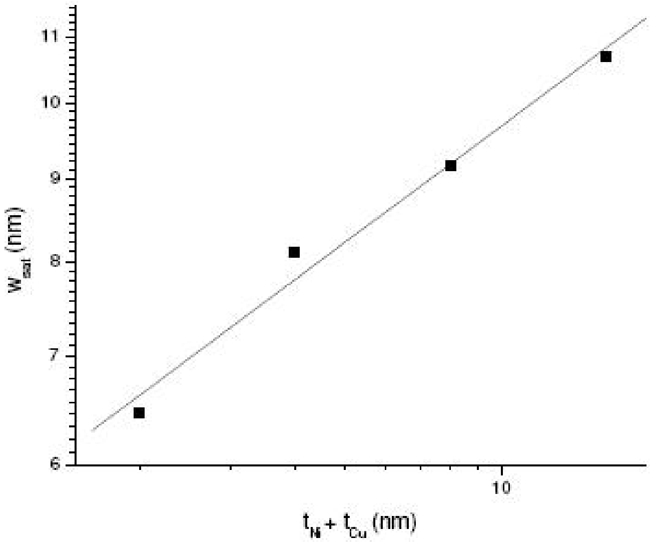

Figure 5 : The graph of W_{sat} versus repeated layer thickness ($t_{Ni} + t_{Cu}$) (■) data points from TABLE 1 and (-) linear fitting of the log-log plot of W_{sat} versus repeated layer thickness.

terized by $l << l_c$ occurs as a result of surface diffusion effects which slow down once l_c has been attained. The other regime characterized by $l >> l_c$ is indicative of the absence of surface diffusion effects which result in the mounds on the surface growing in height after having reached the maximum base size. The conclusion that above l_c the surface diffusion effects have almost ceased is based on the fact that in the length scales greater than the correlation length, the surface characterization functions are lateral length scale independent whilst below l_c they show dependence on lateral length scales.

EXPERIMENT AND RESULT ANALYSIS

The alloy program, developed Kazeminezhad[2] by was used to deposit Nickel/Copper nanostructures with active monitoring of Ni dissolution and appropriate compensation. The reduction of the deposited Ni and Cu layer thickness resulted in the Ni/Cu nanostructure being more of an alloy than a multilayer because the Ni and Cu layers were not distinguishable. The surface morphology of the Ni/Cu nanostructures was characterised using the atomic force microscope (AFM) in contact mode.

Nanostructures of Ni/Cu with constant total nominal thickness and variable repeated layer thickness were deposited and then characterised using the AFM. The repeat layer ($t_{Ni} + t_{Cu}$) was varied whilst maintaining the

TABLE 1 : Shows surface morphology parameters obtained from figure 4.

$t_{Ni} + t_{Cu}$ (Å)	w_{sat} (nm)	l_c (nm)	H (eq. 4.1)
20	6.46±0.03	120±3	0.75±0.02
40	8.10±0.04	159±3	0.78±0.02
80	9.17±0.04	158±3	0.78±0.01
160	10.70±0.05	175±3	0.78±0.01
	Ave H	→	0.77±0.02

Ni:Cu ratio of 1:1; that is, t_{Ni} equal to t_{Cu}. The total nominal nanostructure thickness was held constant by varying the number of repeats. The Ni/Cu nanostructures with t_{Ni} (= t_{Cu}) =1.25A° and t_{Ni} (= t_{Cu}) =2.5A° were found to have higher surface roughness than other samples in the set. Figure 3 shows the set of Ni/Cu nanostructures with fixed total nominal thickness; in this figure we see the Ni/Cu nanostructures with t_{Ni} (= t_{Cu}) =1.25A° and t_{Ni} (= t_{Cu}) =2.5A°; (that is, repeat layer of 2.5A° and 5.0A° respectively) showing larger surface roughness whilst nanostructures with t_{Ni} (= t_{Cu}) greater than 2.5A (repeat layer greater than 5.0A°) show an increase in roughness with increasing repeated layer thickness. The graphs in figure 3 with repeat layer thickness greater than 10.0A° are shown in figure 4 and the surface roughness parameters for these samples are given in TABLE 1.

The Ni/Cu nanostructures with repeated layer thicknesses of 2.5A° and 5.0A° show higher surface roughness as measured by the surface width. The observed anomaly that is exhibited by the Ni/Cu nanostructures with repeat layers of 2.5A° and 5.0A° can be explained in part by the nature of the surface that result from the deposition. When the Ni layer is deposited, due to it being inadequate to cover the deposition surface, result in the formation of mound that are spread over the entire surface. When the Cu layer gets deposited, it tries to fill the valleys that were created during the Ni deposition; however, the affinity between the Ni and Cu result in the mounds growing in height whilst the valleys are not filling up as anticipated.

The other Ni/Cu nanostructures with repeat layers of 10A° to 160A° show the expected scaling behaviour, where the surface roughness increases with increasing deposited layer thickness. This particular observation tends to point to the fact that the system treats the repeat layer thickness as the de-facto thickness that can be used in the analysis of the nanostructures' surface profile. Following this line of thinking, nanostructures that follow the expected scaling behaviour have been extracted and their graphs plotted in figure 4.

The data represented in figure 4 was used to calculate the entries of TABLE 1.

The values of the repeated ($t_{Ni} + t_{Cu}$) layer thickness and the saturated surface width (W_{sat}) were used to plot figure 5 from which the value of β' was determined using equation (4) and the dynamic scaling exponent (z') was calculated using equation (6) which turned out to be 0.24±0.02 and 2.9±0.3 respectively. Using the values of l_c from TABLE 1 and equation (5) z was calculated to be 6.1±2.2; this value is different from the value obtained using equation (6). Equation (5) cannot be applied in this study because the total film thickness is constant.

CONCLUSION

This study has shown that scaling laws can be applied to nanostructures with constant nominal thickness when consideration is limited to the thickness of the repeat layers; which in this case were the Ni and Cu layers. It can be argued that this is inappropriate; however, consideration would have to be made of the fact that continuity of deposition can be stretched to apply to the repeat layers being deposited. This being so because the last repeat layer to be deposited is seen as being deposited on a substrate that is formed by the previously deposited layers.

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