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Grain Sizes and Surface Roughness in Platinum and Gold Thin Films

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Abstract

We have used silicon and glass as substrate for gold and platinum thin films deposition. The film thickness are between 40 and 440 nm for gold and between 26 and 220 nm for platinum. We have analyzed these samples by scanning tunneling microscopy and by X ray diffraction. The crystallographic and morphological grain sizes are discussed.

1. Introduction

In this work we have analyzed crystallographic and morphological grain sizes and surface roughness of platinum and gold thin films, as a function of the film thickness T. The growth dynamics of theses films have been studied in recent papers [1 – 8]. We verified that the grain sizes play a major role in the noise spatial correlation length. In growth dynamics morphological grain sizes are more relevant than the crystallographic ones. This occurs because the arriving particles that are being deposited on the film surface are exposed to the morphological grain profiles. The crystallographic grain sizes have been also measured, since it is a very important parameter to understand the film nanostructure. In addition, we give the surface film roughness as a function of the thickness T and also the specific preferential crystallographic orientation of the deposited films.

2. Materials and Methods

We have used two kinds of substrate for the films deposition. The first one was monocrystalline silicon and the second one was ordinary glass microscope slide. The second substrate, being amorphous, allows us to verify if any preferential orientation for the films crystallography comes from the substrate epitaxy or not.

The technique for films deposition was "Metal Plasma Immersion Ion Implantation and Deposition" (MePIIID) [9 – 12]. This technique is highly effective for producing high quality films, including metals, alloys, oxides, nitrides, carbides and diamond-like carbon. In this approach, plasma is formed from a vacuum arc plasma gun, and allowed to stream toward a substrate. The plasma gun has a cylindrical cathode made of the material that will be deposited on the substrate. The anode has also a cylindrical shape; the cathode is surrounded by a ceramic tube, isolating the cathode from the anode. A discharge initiates when the system is triggered, producing a plasma of the cathode material. A coil surrounding the anode, in series with the arc, focuses the plasma. A particle filter is located on the exit of the plasma gun, to remove the macroparticles produced with the plasma. This particle filter is basically a quarter-torus coil in series with the arc, producing a curved magnetic field to guide the plasma to the substrate, while the macroparticles travel in straight line due to their inertia. Finally, the substrate is located in front of the particle filter. The plasma gun operates in a repetitively pulsed mode.

In this work, the parameters used for the platinum and gold depositions were: 200 A for the arc current, with 5 ms for arc duration and the frequency of the pulses was 1 Hz.

The characterization techniques used for this work were scanning tunneling microscopy (STM) to measure the morphological grain size and surface roughness, and X ray diffraction do

measure the crystallographic grain size and orientation. The microscope used was a Scanning Probe Microscope, Nanoscope IIIA from Digital, in the STM mode [13]. Commercial platinum-iridium (STM) tips and tungsten, fabricated in our laboratory, were used. The X-ray diffraction measurements were carried out in a Rigaku diffractometer, with 0,05° step. The Cu λKα beam was produced by conventional x-ray generator and monochromatized with a graphite crystal. The grain size was evaluated by Scherrer Equation [14].

The thicknesses T of the films were measured placing a piece of silicon, with an ink mark, close to the samples and, after the deposition, the ink was removed and the step obtained was measured. An Atomic Force Microscope was used for this measurement.

3. Results and Discussions

Figures 1 and 2 present STM images of platinum and gold thin films, respectively. In Figure 1(a) the platinum film is 6.6 nm thick and in Figure 1(b) the platinum film is 76.0 nm thick. Figure 2 presents gold films (a) 38 nm thick and (b) 200 nm thick. Note that the z scale, in these figures, is between 0 and 10 nm, and the scales in the plane of the surface are (0.5 x 0.5) μm^2 for the platinum films and (1 x 1) μm^2 for the gold films. So, the contrast is expanded in the z direction, emphasizing the film profile. These images show clearly the nanostructured nature of our Pt and Au thin films and its dependence on the film thickness.

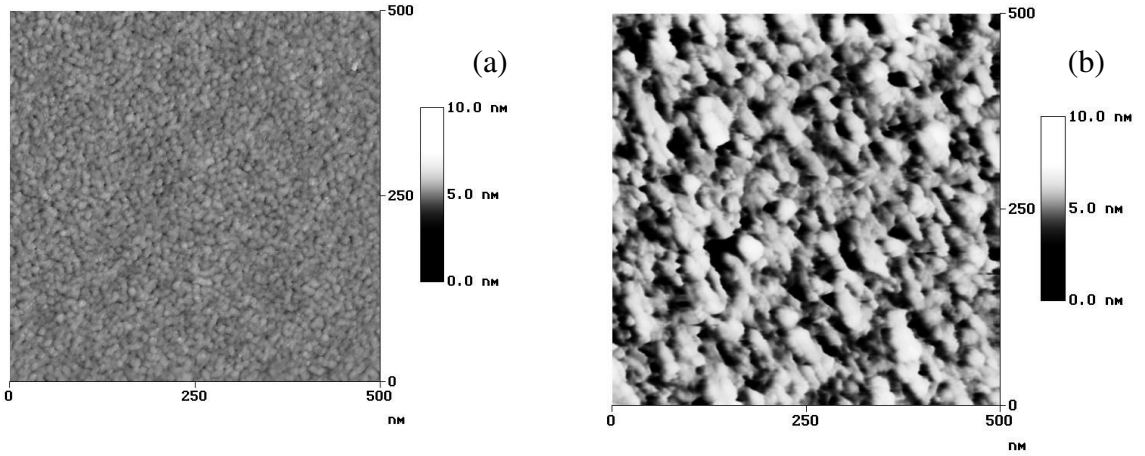


Figure 1: STM images of platinum thin films: (a) 6.6 nm thick and (b) 76.0 nm thick.

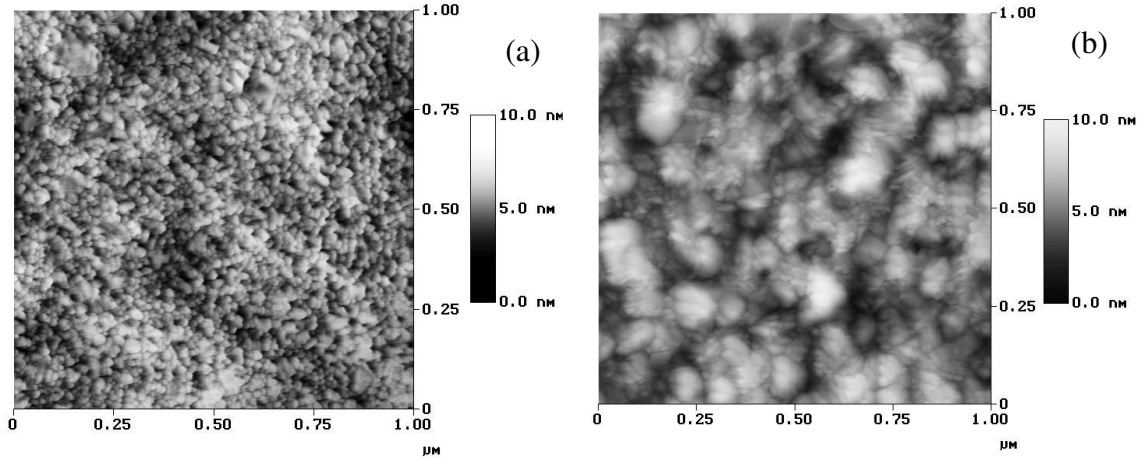
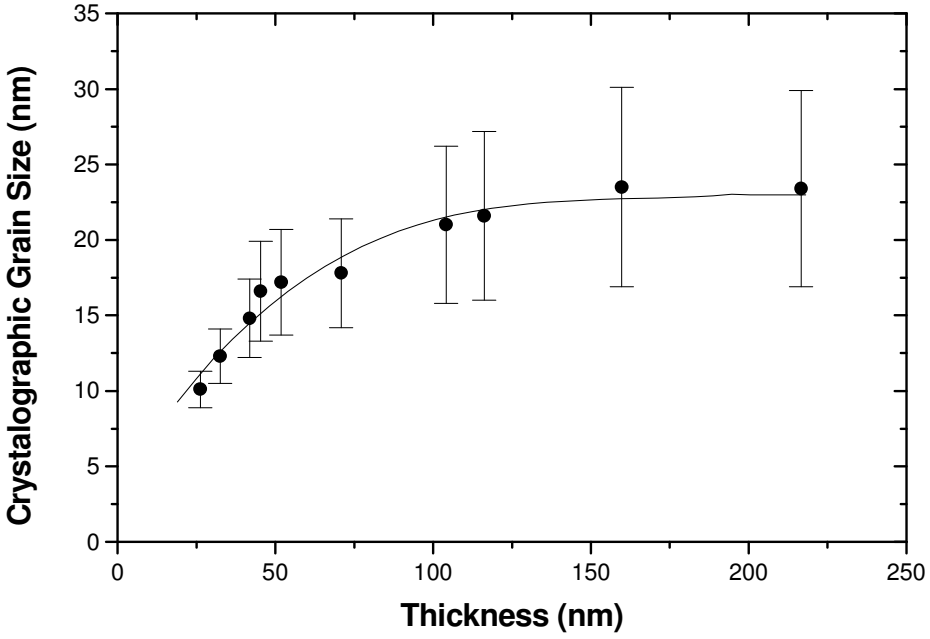


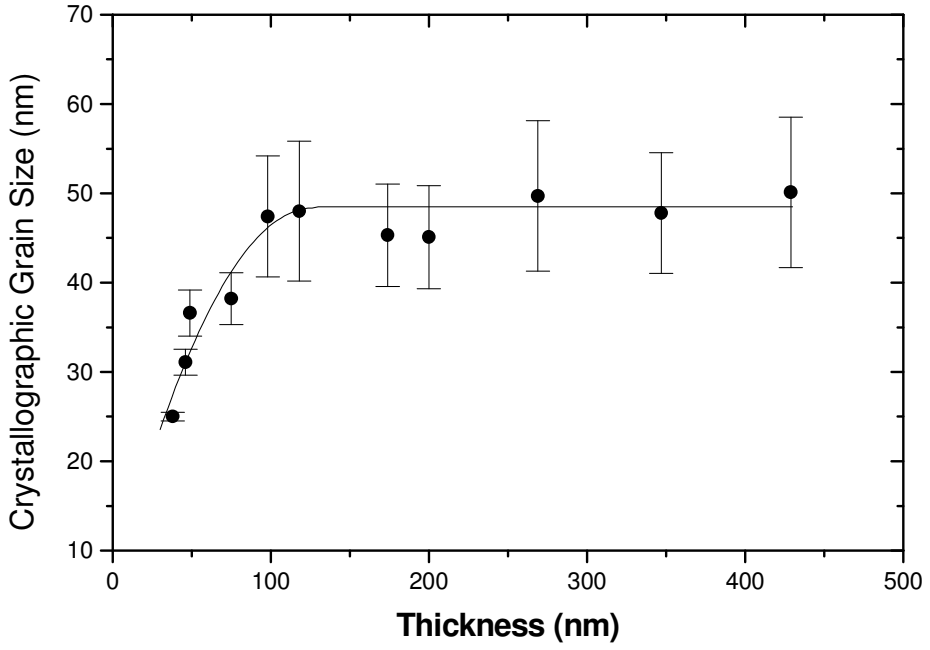
Figure 2: STM images of gold thin films: (a) 38 nm thick and (b) 200 nm thick.

Figures 3 and 4 present crystallographic grain size as a function of the film thickness for platinum and gold, respectively. It is clear from these figures that the grain sizes saturate for large

thickness [15]. For platinum films (Figure 3), the saturation occurs for thickness about 160 nm, with a maximum grain size around 23 nm. For gold films (Figure 4) this saturation occurs for thickness about 100 nm, and maximum grain size around 48 nm. It is important to note that, for X ray diffraction, some crystalline defects are interpreted as grain boundaries, so the grain size saturation could be thought as high density crystallographic defects.



Figures 3: Platinum crystallographic grain size as a function of the film thickness.



Figures 4: Gold crystallographic grain size as a function of the film thickness.

Interesting information obtained from the X ray analyses was that both metallic films, Pt and Au, present preferential orientation in the direction (111). This occurred for silicon and glass substrates, so we can conclude that this is not an epitaxial effect. It means that the films have a self-orientation during the growth process.

Figures 5 and 6 show the roughness (w) as a function of the films thickness T, for platinum and gold thin films, respectively. In these figures $w \sim T^b$, where , $b_{Pt} = 0.52$, and $b_{Au} = 0.49$, shown by the continuous lines.

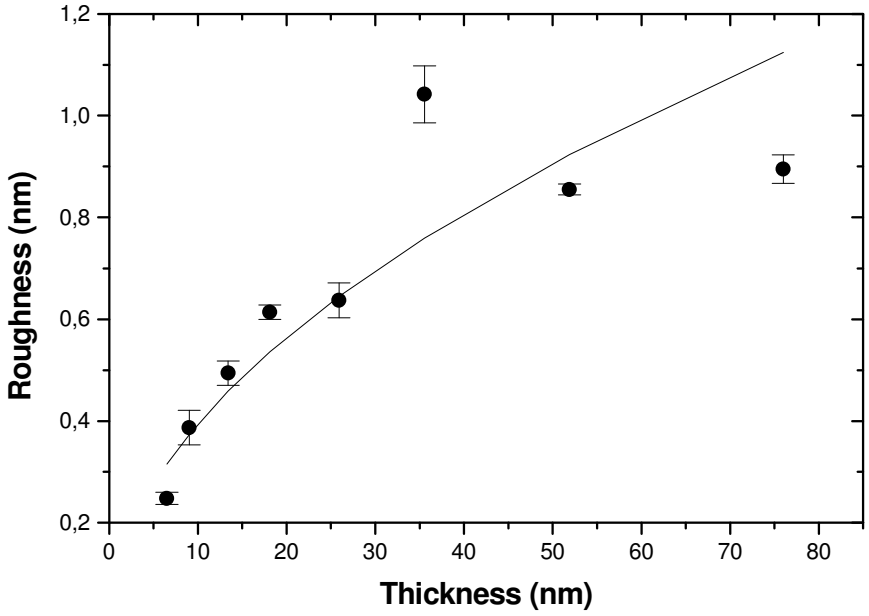


Figure 5: Graphics of the platinum films roughness in function of the films thickness.

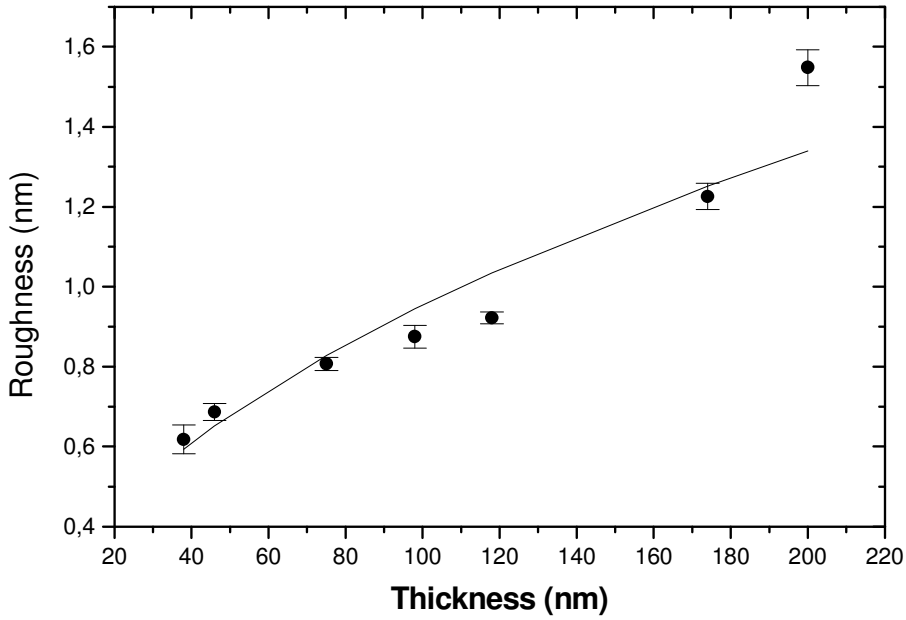


Figure 6: Gold film roughness as a function of the thickness.

Finally, we have measured the morphological grain sizes using STM images. Table 1 presents crystallographic and morphological grain sizes, as a function of the film thickness, for some samples of gold films. The results show that the morphological grain size increases with the film thickness and that there is no saturation. As can be seeing from Figure 7, that is an example of gold thick film (200 nm thick), the morphological grains seem to be an agglomerate of crystallographic grains, justifying, in some sense, that the grain sizes saturate in the crystallographic analyses.

Table 1: Crystallographic and morphological grain sizes of gold thin films in function of the film thickness.

Thickness (nm)	Crystallographic grain sizes (nm)	Morphological grain sizes (nm)
38	25.0	16
98	47.4	46
118	48.0	47
200	45.1	109

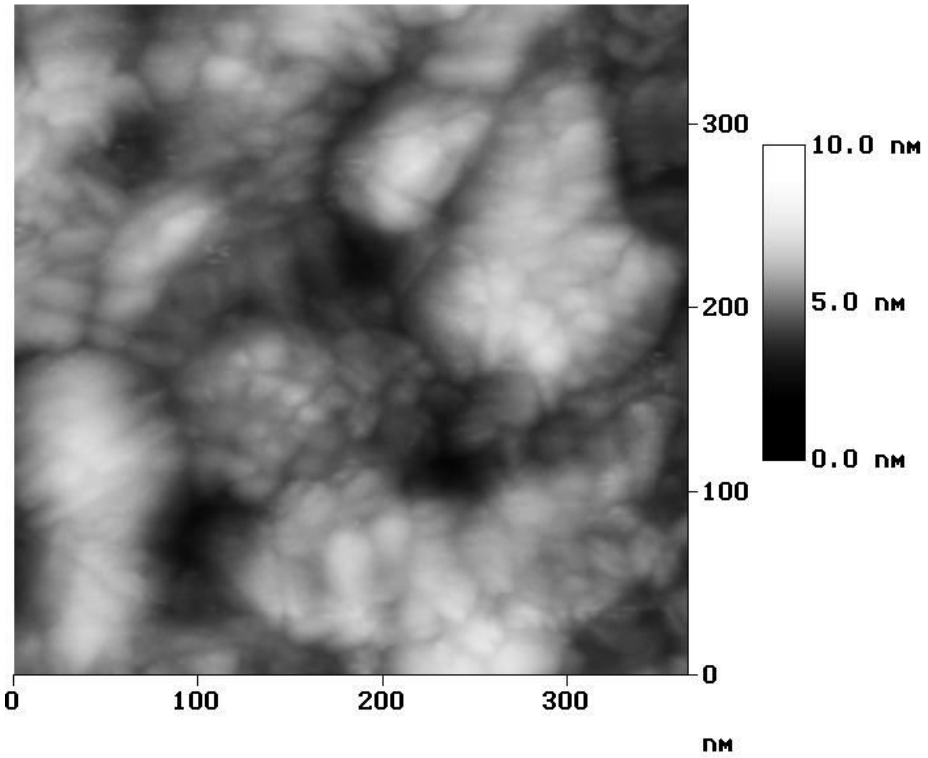


Figure 7: Example of gold thick film (200 nm thick), where the morphological grains seem to be agglomerated of grains.

4. Conclusions

In this paper we have measured the grain sizes of gold and platinum thin films using X ray diffraction and STM images. The crystallographic grain sizes saturate for large thickness, for both metals. The morphological grain sizes were measured for some gold samples and they increase monotonically with the thickness. The surface roughness as a function of the thickness was also presented for these two metals. Finally, it was also observed, from the X ray analyses, that Pt and Au films present preferential orientation in the direction (111).

Acknowledgments

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