Substrate topography and heterogeneous nucleations in ion induced dewetting

L. Repetto, R. Lo Savio, E. Piano, G. Firpo, U. Valbusa

Physics Department and Nanomed Labs, Università di Genova, Via Dodecaneso 33, 16146 Genova, Italy

Corresponding author: L. Repetto
E-mail: luca.repetto@unige.it

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Introduction

Thin metal films under ion irradiation undergo morphological modifications that cannot be simply ascribed to atom sputtering. In particular, experimental evidence indicates that for a proper combination of film and substrate materials and ion species and energy, the morphology evolution during bombardment can be considered a dewetting phenomenon [1,2]. In fact, as it happens for liquids [3], and metal films that have been brought to a molten state by laser irradiation [4], the film can dewet from his substrate following two different mechanisms: heterogeneous nucleation and spinodal dewetting. In this paper, we will focus on the former mechanism and we will show how the substrate topography can make it favorable with respect to spinodal dewetting. In particular Atomic Force Microscopy (AFM) has been used to acquire the topography of the substrates used in the dewetting experiments, and these data will be employed in numerical simulations implementing a model where the dewetting is induced by the concurrent and contrasting actions of surface tension and Van der Waals forces on the local molten patches produced by the ion impacts [1]. The resulting simulated dewetted patterns show heterogeneous nucleations as it happens in the experiments whereas simulations employing numerically generated substrates, with the same RMS roughness, but without the characteristic features of real substrates, can only produce patterns of spinodal dewetting.

Materials and Methods

Silicon substrates were prepared according to the procedure described in [1] and their surface topography was analyzed by AFM, by using a Dimension 3100 microscope (Veeco Instruments, Plainview, USA) equipped with the Hybrid XYZ closed-loop scanner, and operating in tapping mode. Figure 1 (a) and (d) show two typical topographies whose roughness analysis gives RMS values of 0.19 nm and 0.26 nm respectively.

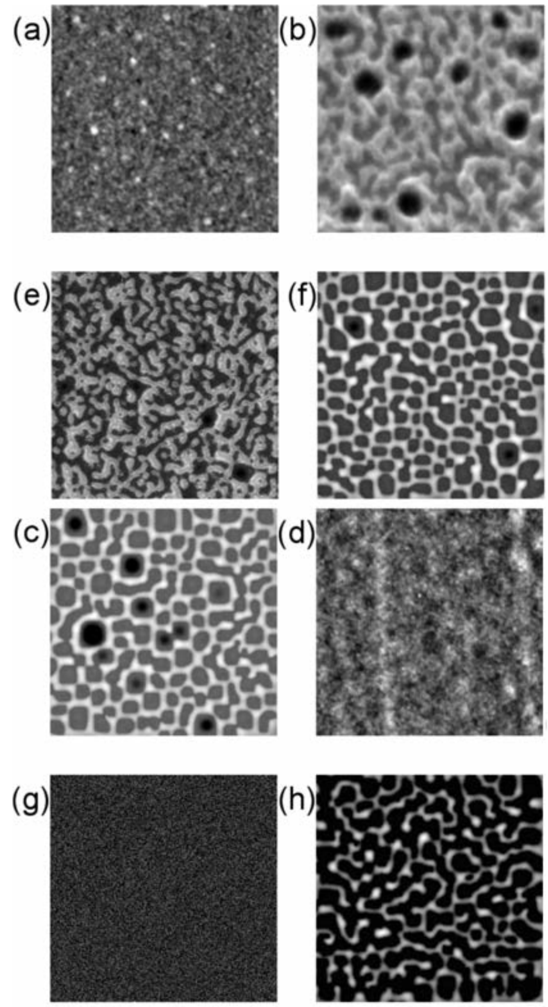

Figure 1. (a) and (d) AFM topographies of two different silicon substrates. (b) and (e) SEM images of 30 keV Ga ion induced patterns for 10 nm Cr films deposited on the substrates in (a) and (d). (c) and (f) corresponding simulations, using the experimental substrate in (a) and (d), where a dewetting phenomenon is induced by the concurring actions of surface tension and Van der Waals forces. (g) numerical white noise substrate and corresponding simulated dewetting pattern. Each panel has a width of 1.5 µm. AFM images z-scale ranges from 0 to 2 nm.

The topography in (d) is rather uniform, while isolated, elevated regions, with a typical height of

0.8 nm, are present on the surface of the former substrate, probably caused by residues of the cleaning procedure. No further action was taken for their removal, as they could serve as possible nucleation centers for the subsequent dewetting experiments. On these substrates we deposited a 13 nm chromium film by a turbo pumped magnetron sputtering system (Emitech K575X, Emitech Ltd., Ashford, Kent, UK) equipped with a quartz crystal microbalance for stopping the deposition at the desired thickness. The samples so obtained underwent ion irradiation with 30 keV Ga ions in a focused ion beam-scanning electron microscopy (FIB-SEM) system (CrossBeam 1540xb, Carl Zeiss AG, Oberkochen, Germany). The ion beam was impinging at normal incidence in a rastering beam with a spot defocused to an 800 nm diameter (size much wider than the chosen pixel size of 12 nm). SEM imaging was performed during the irradiation in order to follow the film morphology evolution in real time.

Results and Conclusions

In Figure 1 (b) and (e) we report the SEM images of the patterns produced by the ion irradiation of the Cr films deposited on the substrates whose topography is shown, respectively, in panels (a) and (d). It is evident as different substrates can favor the occurrence of heterogeneous nucleation as in (b) rather than an evolution of the film morphology according to a spinodal dewetting scheme as in (e). This behavior is confirmed by the simulated patterns, reported in panels (c) and (f) obtained with the program implementing the model described in [1], in this case using the experimental topographies as basis for the simulations. Interestingly, with white noise substrates with comparable RMS roughness (Figure 1 (g) and (h)), heterogeneous nucleations were much more difficult to be identified in simulations (as dry patches occurring in advance with respect the spinodal dewetting). We believe that this behavior is caused by the different spectral weights in the substrate topography, which in the experimental case can show a local unbalance towards longer wavelengths.

In conclusion, we showed that the substrate topography has a prominent role in determing if a thin metal film can undergo spinodal dewetting rather than dewetting by heterogeneous nucleations under ion irradiation. This result can be used to determine the proper experimental conditions for the fabrication of functional surfaces by ion irradiation of thin solid films.

References

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