Thin Films and Coatings

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In situ transmission electron microscopy study on solid-state dewetting of Au thin films

F. Niekiel[1], S.M. Kraschewski[1], B. Butz[1], E. Spiecker[1]

[1]Center for Nanoanalysis and Electron Microscopy, Universität Erlangen-Nürnberg, Department of Materials Science and Engineerging, Erlangen, Germany

florian.niekiel@ww.stud.uni-erlangen.de

Solid-state dewetting describes the instability of thin films to transform into an energetically favorable set of droplets or particles well below the melting temperature of the bulk material. The effect of solid-state dewetting becomes more severe as the film thickness decreases and thus plays an important role in the rising focus on nanotechnology [1]. There are two different perceptions of solid-state dewetting in the field of applications:

On the one hand metallic and semiconducting thin films are the key building block of modern electronics, magnetics and optics applications, whose lifetime can be drastically decreased by solid-state dewetting as a failure mechanism. Exposure to raised temperature cannot only occur in the final application but as well during the production process, making the usage of thin films a challenge. One example is the increase in sheet resistance of a NiSi thin film contact on Si due to solid-state dewetting at temperatures above 700°C [2].

On the other hand controlled solid-state dewetting of thin films can be employed to produce regular arrays of functional nanoparticles on large area substrates via a simple deposition process followed by appropriate annealing. Recent advances allow to control the order, shape and spacing of the produced nanoparticles with possible applications in the field of plasmonics [3] or as templates for the growth of other nanostructures [4].

In this work we report on the use of advanced *in situ* transmission electron microscopy (TEM) techniques to study the fundamental physics underlying the phenomenon of solid-state dewetting. Au thin films on a silicon nitride substrate (fabricated via sputtering) are heated in the transmission electron microscope using a DENSsolutions sample heating system. The samples are imaged using annular dark field scanning transmission electron microscopy (ADF-STEM) *in situ* while undergoing heat treatments at constant temperatures in the range of 200°C to 500°C.

Figure 1. shows ADF-STEM images of the as deposited Au thin film (left) and after annealing for 50 min at 300°C in the electron microscope (right). The phenomenon of solid-state dewetting is clearly visible leading to a set of separated islands of sizes between 30 and 150 nm. It has to be noted that the initial Au film was not continuous but already showed elongated voids due to the production process. This has been exploited to directly study the process of void growth without having to consider void nucleation which is the first step in solid-state dewetting [1]. The in situ experiments have been evaluated calculating difference images, as shown in figure 2., to follow the material transport. Thresholding of the images has been used to extract information such as area coverage and perimeter length to evaluate the edge velocity, a key quantity in models for solid-state dewetting. The temperature dependence of the edge velocity has been employed to estimate the activation energy giving a quantity in the range for surface self-diffusion of Au.

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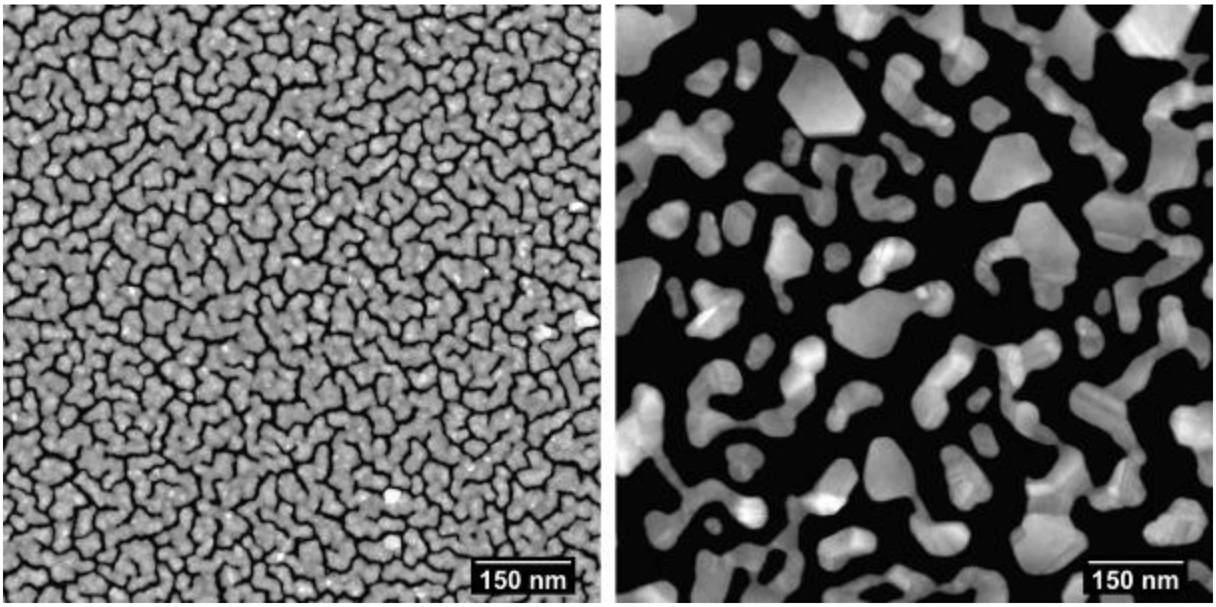

Figure 1. ADF-STEM image of (left) as deposited discontinuous Au thin film on silicon nitride membrane, (right) after annealing at 300°C for 50 min in the TEM.

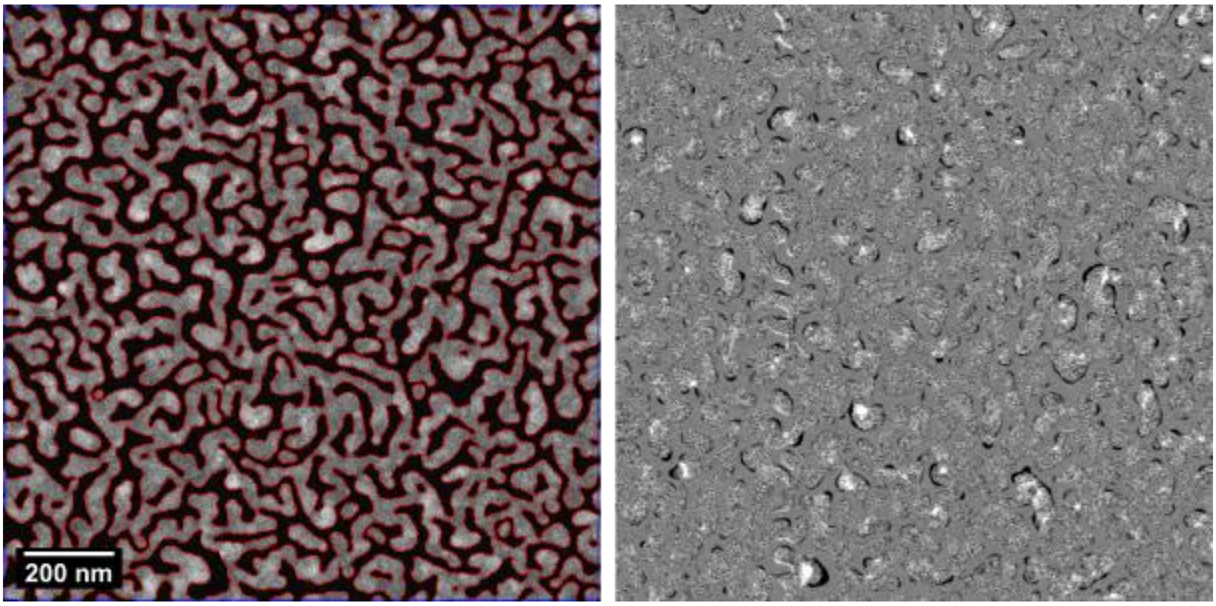

Figure 2. (left) In situ ADF-STEM image of Au thin film on silicon nitride membrane at t = 18 s at 300°C, frametime 2 s, detected perimeter used for velocity determination is overlaid in red, (right) differential image showing contrast changes from t = 16 s to t = 18 s, black corresponds to an decrease in contrast, white to an increase.