The Role of Surface Tension in Nanoscale Pattern Formation of Aluminum Electropolishing

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The objectives of our work are to study the mechanism of nanoscale pattern formation during the electropolishing of aluminum. It has been shown that under the proper conditions, ordered hexagonal and striped patterns form on the surface of the aluminum. These patterns are separated by approximately 100nm and can vary in depth. The small size and the order of the patterns have found many potential uses in magnetic recording media[1], electronic and electrooptical devices[2]. Because of these many uses, a thorough understanding of the mechanism is needed to better predict and control the pattern formation.

The existing theory[3,4] hypothesizes that the onset of the patterns forms as a competition between electrochemical dissolution and surfactant adsorption (Fig. 1). As the electric field is intensified at the peaks of the interface, the reaction rate is higher at the peaks and therefore, the reaction tends to flatten the interface. However, the higher electric field also increases the surfactant adsorption onto the peaks; blocking potential reaction sites. The surfactants therefore tend to destabilize the interface causing the peaks and valleys to amplify.

We have shown that the surface tension of the material must be included in this model to correctly predict the hexagonal patterns. The addition of the surface energy term in the reaction rate equation stabilizes the interface and decreases the growth rate of the patterns. Based on the existing theory, we have derived the nonlinear partial differential equation that describes the evolution of the interface over time and space. A linear stability analysis was used to predict the wavelength of the patterns, and a weakly nonlinear analysis was used to predict the type and stability of the patterns (i.e. hexagons or stripes). Additionally, a full nonlinear simulation of the evolution equation was performed and we found that the results agree with the weakly nonlinear analysis (Fig. 2).

We will conclude by introducing some recent experimental results that may bring the entire theory into question. For example, AFM images of the interface will show ordered stripe patterns formed in the complete absence of surfactants. The influence of the crystal orientation at the interface on the pattern formation will also be introduced.

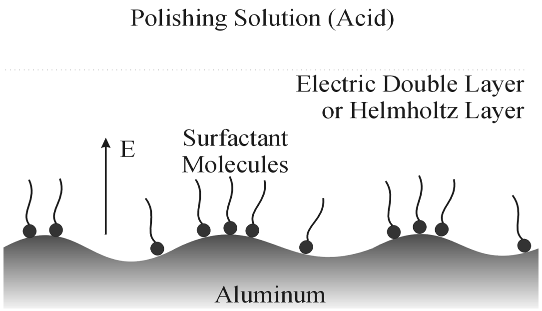
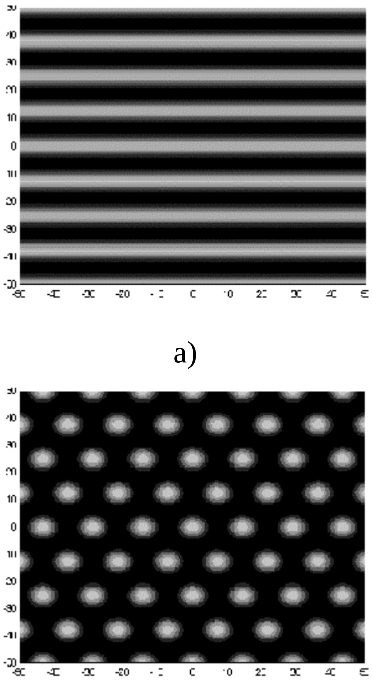


Fig. 1 Schematic of the mechanism of pattern formation.



a)

b)

Fig. 2 Results from nonlinear simulation with surface tension included. a) stable striped patterns and b) stable hexagonal patterns.

References

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