Chapter 7

Conclusion and Outlook

In this work, the growth of sub-monolayer Co on Cu(111) was investigated by means of variable temperature fast-scanning tunneling microscopy at several temperatures between 120 K and 300 K. I also studied the shape fluctuations of medium-sized two-dimensional vacancy islands on Ag(100) within a temperature range from 165 K to 177 K.

In chapter 4, I presented an extensive data set for the growth of Co on Cu (111) at a coverage between 0.03 ML and 0.04 ML from 120 K to 300 K for understanding the growth of this important material combination in a wide range of temperatures. Co islands nucleate heterogeneously at step edges and homogeneously on terraces. The height and area distribution difference between these two types of differently nucleated islands is attributed to an step edge alloy. I showed that surface alloy formation is an important factor to be considered in nucleation at the step edges already at cryogenic temperature. I determined a rather low activation energy for upward layer mass transport of $E_A = (0.19 \pm 0.04) \text{ eV}$ at low temperature. I explained this low value by the kinked nature of the step edges at low temperature, which leads to a different value than calculated [12]. At 120 K and 150 K, the islands are pure Cu in contrast, at room temperature islands larger than $\approx 120 \text{ nm}^2$ alloy at their border. This alloying will influence the magnetic properties of the nanostructures.

In chapter 5, I showed that the step formation energy can be determined by a shape fluctuation analysis of medium-size vacancy islands on Ag(100) in the size range of $\approx 10$ to $\approx 50$ atoms at cryogenic temperature. It shows both that the equilibrium shape can still be reached at $\approx 170$ K and that the equilibrium theory is valid for nanometer sized island. The experimental result of $\beta = (273 \pm 48) \text{ meV/nm}$ is consistent with EMT calculations and with other experimental studies that analyzed two orders of magnitude larger islands. The determination of the
step formation energy as presented in this study can be applied to examine vacancy islands of similar size on other surfaces.

In the final chapter of this thesis, chapter 6, I revealed the quantitative determination of the Co island shapes based on the convexity and the fractal dimension factors at different temperatures. These results confirm that Co atoms grow dendritic shaped island at 150 K due to diffusion-limited aggregation. At higher temperature, the dendritic shaped islands become more compact with very thick branches due to the diffusion of Co atoms along the step edges of the island. At room temperature, the dominance of diffusion along the island edges and the upward mass transport result in the formation of compact islands. The results revealed a shape transition of Co islands from 150 K to 300 K. In this temperature range, the increase of the convexity from \((0.55 \pm 0.05)\) to \((0.93 \pm 0.02)\) and of the fractal dimension from \((1.75 \pm 0.02)\) to \((1.93 \pm 0.02)\) showed an exponential dependence of the island shapes on temperatures. The quantitative determination presented here can be used for examining the shape of a large variety of supported nanostructures.

The results obtained in this thesis open new interesting questions for future investigation. The approaches used in the growth study can be applied to investigations of the growth of Co on other metal substrates. On a more general footing, alloying is an important issue to consider in transition metal growth. The shape fluctuations methods used to determine the step formation energy can be extended to larger time scales in order to investigate down to which sizes the scaling of the diffusion constant is valid. Finally, the quantitative determination of island shapes can be applied to examine the shape of other nano-objects adsorbed on surfaces.

Furthermore, for extension of the shape fluctuation method, it can be applied to examine the similar-size vacancy island fluctuations on different surfaces such as metal surfaces or semiconductor surfaces. For Co/Cu(111) growth, the influence of Co islands at different temperatures on spin polarization and local density of state (LDOS) induced by the growth of the two island types on terraces at 300 K will be a very interesting topic for further studies. Furthermore, the investigation of molecules adsorbed on these systems will answer the question of interaction between the surface and adsorbate.

All in all, based on the findings presented in this thesis, the atomistic kinetics far from equilibrium of nanostructures on noble metal surfaces have been enlightened by means of fast scanning tunneling microscopy. In other words, the presented strategies brings a great chance to discover origins hidden behind the physical processes at the nanoscale, which promises to bring many astonishing discoveries for
catalysis and growth studies.