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# Anisotropy in Ostwald ripening and step-terraced surface formation on GaAs(0 0 1): Experiment and Monte Carlo simulation

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ABSTRACT

Ostwald ripening and step-terraced morphology formation on the GaAs(0 0 1) surface during annealing in equilibrium conditions are investigated experimentally and by Monte Carlo simulation. Fourier and autocorrelation analyses are used to reveal surface relief anisotropy and provide information about islands and pits shape and their size distribution. Two origins of surface anisotropy are revealed. At the initial stage of surface smoothing, crystallographic anisotropy is observed, which is caused presumably by the anisotropy of surface diffusion at GaAs(0 0 1). A difference of diffusion activation energies along [1 1 0] and [1 $\bar{1}$ 0] axes of the (0 0 1) face is estimated as $\Delta E_d \approx 0.1$ eV from the comparison of experimental results and simulation. At later stages of surface smoothing the anisotropy of the surface relief is determined by the vicinal steps direction. At the initial stage of step-terraced morphology formation the kinetics of monatomic islands and pits growth agrees with the Ostwald ripening theory. At the final stage the size of islands and pits decreases due to their incorporation into the forming vicinal steps.



## 1. Introduction

Fundamental surface science, nanostructures fabrication and device applications require high-quality, atomically flat crystal surfaces [1–5]. An efficient technique for GaAs surface smoothing at elevated temperatures was developed in Refs. [6,7]. Incongruent evaporation of GaAs was prevented by maintaining equilibrium between the surface and Ga and As vapors, when mean fluxes of evaporated and deposited atoms were equilibrated, so neither surface sublimation, nor growth occurred. This technique allowed us to obtain GaAs(0 0 1) surfaces with atomically smooth terraces separated by steps of a monatomic height.

In Refs. [8,9] it was shown that surface smoothing and step-terraced morphology formation can be qualitatively described by Monte Carlo simulation performed on a simple Kossel crystal. It was proved that successive stages of surface smoothing consist in recombination of adjacent adatoms and vacancies, formation of islands and pits, their growth in size and incorporation into steps, and straightening the steps. Full length of monatomic steps and mean size of islands and pits were used for quantitative description of surface relief evolution [6,7,9]. The parameters of the model, which govern surface smoothing, were estimated by fitting the experimental kinetics of step length and island and pit size measured on GaAs(0 0 1) with simulated kinetics [8,9]. These parameters include effective diffusion activation energy $E_d = 1.3 \pm 0.05$ eV, lateral bond energy $E_b = 0.32 \pm 0.02$ eV and adatom desorption energy $E_{des} = 2.1 \pm 0.05$ eV.

However, a number of questions related to the mechanisms of step-terrace morphology formation on GaAs(0 0 1) remains open. In particular, in the previous analysis [9], crystallographic anisotropy of GaAs(0 0 1) surface relief along [1 1 0] and [1 $\bar{1}$ 0] directions was not considered, although this anisotropy was clearly revealed in the morphology of epitaxially grown films [10,11] and was also noticed in the shape of atomic step undulations in course of step-terraced morphology formation [6]. A possible microscopic reason of the observed anisotropy is the anisotropy in the surface diffusion coefficient. As the surface anisotropy was not taken into account in the simulation [9], the comparison with the experiment yielded only averaged values of the model parameters. Further analysis and comparison of the experiment with the result of Monte Carlo simulation would help to estimate the anisotropy of these parameters.

Another question is related to the peculiarities of Ostwald ripening in course of step-terraced morphology formation. Both the

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