Thermal roughening of GaAs surface by dislocation-induced step-flow sublimation

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Abstract. The thermal roughening of epitaxial GaAs film surface is studied under anneals at temperatures 700-775 °C in the presence of a saturated Ga-As melt. Surface roughening consists in the formation of spiral "inverted pyramids" on the initially flat surface due to the step-flow sublimation induced by screw dislocations. The observed roughening indicates that, despite the presence of As and Ga vapors provided by the melt, the annealing conditions are shifted from equilibrium towards sublimation.

1. Introduction

Atomically flat semiconductor surfaces are needed for fundamental surface science, device applications and reproducible fabrication of nanoscale structures [1, 2]. Close to ideal ones, silicon surfaces with atomically flat terraces separated by steps of monatomic height were obtained by annealing chemo-mechanically polished Si substrates in vacuum [3, 4]. The application of this method to III-V semiconductors is problematic because, due to a high evaporation rate of the volatile V component, it is difficult to find the vacuum annealing temperature range, in which the surface diffusion is sufficiently effective for surface smoothing, while the sublimation is still negligible [5]. To avoid the surface morphology deterioration due to depletion with arsenic, GaAs thermal smoothing, which yields GaAs step-terraced surfaces, can be performed under overpressure of arsenic-containing vapors in the MBE or MOCVD growth chambers [6, 7].

Thermal smoothing experiments in the growth chambers of MBE or MOCVD set-ups are expensive and time-consuming. A more efficient technique of GaAs surface thermal smoothing was proposed and developed in Refs. [8-12]. This technique consists in annealing GaAs substrates in the conditions close to equilibrium with Ga and As vapors, provided by the presence of the saturated Ga-As melt. So far, this smoothing technique has been demonstrated only for chemo-mechanically polished epi-ready GaAs substrates with a small root mean square roughness $\rho \leq 0.15$ nm. To apply this method to substrates or epitaxial films with a larger surface roughness and to speed up the smoothing process, one should increase the annealing temperature. However, at an increased temperature $T \geq 700$ °C, GaAs surface smoothing is gradually changed to surface roughening, which reveals itself in step meandering, the formation of deep pits and complete destruction of step-terraced morphology [8]. This roughening may be due to the thermodynamic roughening transition [13, 14], or to kinetic instabilities caused by deviations from equilibrium at high temperatures. On a step-terraced surface, the deviations from equilibrium towards growth or sublimation can be detected by the atomic step motion towards lower of higher lying terraces, respectively. Various origins of atomic steps are possible at a crystal surface. Misorientation of the vicinal crystal surface from a singular face may result in a regular set of straight equidistant atomic steps, which separate terraces with the width determined by the misorientation angle. However, the step motion under step-flow growth or sublimation on an ideal vicinal surface does not change the character of the homogenous step-terrace relief. Therefore, it is difficult to determine the direction and velocity of the step motion by studying