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

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Abstract. Thermal roughening of epitaxial GaAs film surface is studied under anneals at temperatures 700-775 °C in the presence of saturated Ga-As melt. Surface roughening consists in the formation of spiral "inverted piramids" on the initially flat surface due to 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 the equilibrium towards sublimation. The estimated relative Ga vapor undersaturation is equal approximately to –0.02 and –0.06 at T = 750 °C and T = 775 °C, respectively.

1. Introduction

Atomically flat semiconductor surfaces are needed for fundamental surface science, device applications and reproducible fabrication of nanoscale structures. In Ref. [1] GaAs surfaces with atomically flat terraces separated by steps of monatomic height were obtained by thermal smoothing GaAs substrates in the conditions close to equilibrium with Ga and As vapors, in order to avoid surface depletion with arsenic. These conditions were provided by the presence of a saturated Ga-As melt. So far this smoothing technique was demonstrated only on chemo-mechanically polished epi-ready GaAs substrates with small root mean square roughness $\rho \leq 0.15$ nm. To apply this method to substrates or epitaxial films with larger surface roughness and to speed up the smoothing process, one should increase the annealing temperature. However, at increasing temperature $T \geq 700$ °C surface smoothing is gradually changed to surface roughening, which revealed itself in step meandering, formation of deep pits and complete destruction of step-terraced morphology [1]. This roughening may be due to thermodynamic roughening transition [2] 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. The present study is aimed at clarifying the reasons of the roughening by observation of spiral structures induced by screw dislocations and characteristic of step-flow sublimation under annealing epitaxial GaAs films.

2. Experimental

GaAs films grown by liquid phase epitaxy were used in the annealing experiments. The as-grown surface contained areas with atomically flat terraces and screw dislocations intersecting the surface, with mean dislocation concentration of about 5×10^4 cm^{-2}. The anneals were performed in a quasi-closed volume, in the presence of the saturated Ga-As melt. The morphology of the initial and annealed GaAs surfaces was studied *ex situ* by atomic force microscopy (AFM). The details of the anneals and AFM measurements are described in [1].

3. Results and Discussion

To elucidate the reasons of high-temperature GaAs surface roughening, one hour anneals of samples cut from the same GaAs epitaxial film were performed at various temperatures. The results are shown in Fig. 1. The as-grown surface (Fig. 1a) contains wide (~ 7 μm) atomically flat terraces. Marked by the white dashed circle is the emergence point of a "screw dislocation", which is not