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Formation and interaction of dislocation-induced and vicinal monatomic steps on a GaAs(001) surface under stress relaxation

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ABSTRACT

Formation and interaction of curved vicinal and straight dislocation-induced steps of monatomic height on smooth GaAs(001) surface is studied under thermo-mechanical stress relaxation in GaAs/AlGaAs heterostructures bonded to glass. Typical dislocation phenomena, like transverse glide, are revealed in the slip steps patterns. At elevated temperatures, slip steps keep their straight shape, while curved vicinal steps acquire distinct small-scale (~10 nm) undulations caused, presumably, by kink bunching. Annihilation of steps with opposite signs and anticrossing of slip steps with each other and with vicinal steps are studied.
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Semiconductor surfaces with atomically flat terraces separated by steps of monatomic height are needed for fundamental surface science, device applications and reproducible fabrication of nanoscale structures [1]. In particular, straight monatomic steps are highly desirable for assembling adatoms into one-dimensional "quantum wires" [2]. Step-terraced surfaces with monatomic vicinal steps can be prepared at elevated temperatures by allowing surface diffusion on chemo-mechanically polished substrates with small root mean square (rms) roughness, comparable to or smaller than inter-atomic distance. Nearly perfect step-terraced silicon surfaces are prepared by annealing in a vacuum [3,4]. Step-terraced GaAs surfaces can be obtained by annealing at sufficiently high pressure of arsenic-contained vapor components to avoid surface depletion with arsenic [5–8]. However, at real surfaces, vicinal steps are not perfectly straight because their shape is determined by long-period undulations of the surface relief, which cannot be reduced at reasonable temperatures and durations of annealing.

In principle, a straight monatomic step — a slip step — can be produced on a crystal surface by generation of a dislocation half-loop under relaxation of mechanical tensions. Generation and subsequent motion of slip steps are believed to be the mechanisms underlying "cross-hatched" morphology formation during epitaxial film growth on lattice-mismatched substrates [9]. However, in most cases, the cross-hatched relief of grown films is relatively rude, with typical roughness heights much larger than interatomic distance. Generation of monatomic slip steps due to introduction of single dislocation loops was found by Lutz et al. [10] in AFM images of the partially relaxed 80-nm GeSi film grown on a Si substrate at early stages of cross-hatched relief formation, but distinct step-terraced morphology was not observed.

In the present study we experimentally proved the opportunity of forming a rectangular grid of straight monatomic slip steps induced by generation of dislocations due to thermo-mechanical stress relaxation in GaAs/AlGaAs heterostructures bonded to glass substrates.

We used $Al_xGa_{1-x}As$/p-GaAs/$Al_xGa_{1-x}As$ double heterostructures with the GaAs and $Al_xGa_{1-x}As$ layer thicknesses in the range of 0.5–2 μm and Al content $x \sim 0.5$, which were epitaxially grown on GaAs(001) substrates. The heterostructures were bonded to glass plates by means of thermocompression bonding. The GaAs substrate and AlGaAs stop layer were removed by selective wet etching [11]. Such glass-bonded *p*-GaAs/AlGaAs heterostructures with the surface of *p*-GaAs activated by cesium and oxygen to the state of negative effective electron affinity are used as transmission-mode photocathodes in image intensifiers and in the sources of ultra-cold and spin-polarized electrons [11–13]. Due to the AlGaAs interlayer, which is lattice-matched to the GaAs emitting layer (the relative mismatch is below 10^{-3}), electron recombination velocity at the back *p*-GaAs/AlGaAs interface of the emitting *p*-GaAs layer is substantially reduced as compared to a free *p*-GaAs surface or direct GaAs/glass interface, and this facilitates the increase of photocathode quantum efficiency [11,12]. The dislocation network in the structure after bonding, chemical etching and anneals was monitored by photoluminescence (PL) intensity

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