Droplet nucleation on a vicinal surface: temperature-activated transitions of a density dependence

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Droplet Epitaxy (DE) is a well-established technique to self-assemble shape-engineered III-V semiconductor nanostructures. DE permits the use of a large variety of substrates, including (111) exact and vicinal surfaces. Peculiar effects of nanostructure formation dynamics on GaAs(111)A and its distribution are observed due to the symmetry of (111)-oriented surface and the presence of high-density steps on the vicinal one.

The nucleation of Ga droplets deposited on the on-axis and vicinal GaAs(111)A show different behavior. In the case of the vicinal surface, there is a temperature-activated crossover in the dimensionality of the scaling parameters that control the dependence of the droplet density on temperature and flux from two to one dimension. We correlate the crossover to the presence of the temperature-activated restriction onset in an adatom diffusion related to the presence of the regular terraces and steps. The latter, due to the associated ES barrier, induces a strong spatial anisotropy in the adatom diffusivity at the origin of the dimensionality change [1].

A different influence of steps is observed on singular GaAs(111)A. There is no change in the diffusion dimensionality. But the presence of stepped hillocks with wide terraces (tens of nm) generated by the stacking faults results in the bimodal size distribution of GaAs islands at intermediate temperatures connected with a sharp increase of the disorder of the island sites, as measured by the Hopkins–Skellam (HS) index. It is also attributed to the presence of the ES barrier at the terrace step edges, which limits Ga adatom diffusion on the terraces, thus inducing strong differences in the capture zone size for droplets are nucleated on the terraces or at the terrace step edges [2].

Indium droplets display a complex non-monotonic dependence in terms of density vs. temperature. The usual temperature density dependence behavior of DE is maintained only until the islands remain in the liquid phase (≈160°C). When the islands are solid, strong coarsening phenomena take place, leading to the broadening of the island distribution and to a reduction in the island density. At lower temperatures (below 80°C), indium island density increases again due to the reduction of the diffusion length which limits the range of mass transfer phenomena. The origin of the coarsening effect active only in the solid phase is related to the presence of strain and rapid strain relaxation due to a large lattice mismatch between indium and GaAs (almost 19%) which activates a strong mass transfer between islands [3].

[1] Tuktamyshev A et al. Temperature activated dimensionality crossover in the nucleation of quantum dots by droplet epitaxy on GaAs(111)A vicinal substrates. Sci. Rep. 2019;9:14520.
[2] Tuktamyshev A et al. Nucleation of Ga droplets self-assembly on GaAs(111)A substrates. Sci. Rep. 2021;11:6833.
[3] Tuktamyshev A et al. Reentrant behavior of the density vs. temperature of indium islands on GaAs(111)A. Nanomaterials 2020;10:1512.