

About surface engineering to tune the growth of semiconductor nanostructures

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Some combinations of lattice-mismatched semiconductors can exhibit, under specific epitaxial growth conditions, a sharp transition from a layer-by-layer 2D growth to the formation of 3D islands. This Stranski-Krastanow (SK) growth mode [1] allows the relaxation of highly strained 2D layers through the stress-free facets of 3D islands instead of generating misfit dislocations (MDs) [2]. These islands are expected to be dislocation-free and are thus of high structural quality. Usually their typical sizes are on the scale of a few nanometers, so that these self-assembled quantum dots (QDs) are attractive nanostructures for the study of zero dimensional effects. In particular the growth of these QDs, including the ability to tune their dimensions, their surface density and their positions, has been a topic of intense research effort in the last decades, in order to control their optical properties for optoelectronic applications.

The formation, above a critical film thickness, of such QDs by molecular beam epitaxy (MBE) has been first discovered by Goldstein *et al.* [3] by observing in situ the 2D-3D morphology change of an InAs layer grown on GaAs; the process is now well established for this III-V semiconductors system [4]. The large lattice mismatch ($\Delta a/a \approx 7\%$) between these two semiconductors is seen as the driving force which induces the 2D-3D change of the surface morphology with the formation of SK islands. However, in the case of II-VI systems, which can exhibit mismatch as large as 6% for CdTe/ZnTe or CdSe/ZnSe, the 2D-3D transition is much less obvious: no clear 3D RHEED pattern has been reported during growth although zero-dimensional behavior was obtained [5-7]. In II-VIs indeed, above a critical thickness h_c , MDs form easier than in III-Vs as clearly observed for CdTe/ZnTe by Cibert *et al.* [8], which corresponds to a plastic relaxation as first considered by Frank and van der Merwe [2]. On the other hand, there are systems such as GaN/AlN [9,10] or SiGe/Si [11], with lower misfit (respectively 2.4% and less than 4%), which can exhibit a clear SK transition with the formation of coherent islands.

There are therefore other parameters than the lattice mismatch in order to account for the 2D-3D transition. In this talk, a simple equilibrium model [12] will be presented, taking into account not only the lattice mismatch but also the dislocation formation energy E_{MD} and the cost in surface energy $\Delta\gamma$ associated with the creation of facets when forming the islands surface energy. This approach demonstrates the crucial importance of these parameters especially for II-VI systems: indeed in II-VIs, E_{MD} is smaller than in III-Vs, so that misfit dislocations are easier to form and the 3D elastic relaxation is short circuited by the plastic one. This

model explains the occurrence (or not) of this 2D-3D transition for various semiconductor systems. The limits of this approach are then discussed by showing on one hand some experimental data validating this thermodynamic model [13], and on the other one, the changes due to the contribution of kinetics effects.

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