Formation of Coherent PbTe Nanocrystals in MBE-Grown PbTe/CdTe Heterostructures

H. Groiss[1], F. Schäffler[1], G. Hesser[2], N. Zakharov[3], P. Werner[3], K. Koike[4], M. Yano[4]

[1]Institute of Semiconductor Physics, Johannes Kepler University, Linz, Austria
[2]ZONA, Johannes Kepler University, Linz, Austria
[3]Max Planck Institut für Mikrostrukturphysik, Halle, Germany
[4]Osaka Institute of Technology, Osaka, Japan

We have demonstrated a novel approach for the synthesis of epitaxial quantum dots, which is based on phase separation between two lattice-type mismatched, immiscible materials in a coherent heterostructure fabricated by molecular beam epitaxy [1]. This principle is applied to the PbTe/CdTe semiconductor system, a combination of a rock salt and the zinc blende lattice of CdTe, which show almost identical lattice constants. Upon thermal annealing, 2D PbTe epilayers are transformed into quantum dots (QD) with highly symmetric shapes (see Fig. 1) and atomically sharp heterointerfaces [2], [3]. Efficient photo- [1] and electroluminescence [4] from the QDs in the mid infrared spectral range has been demonstrated.

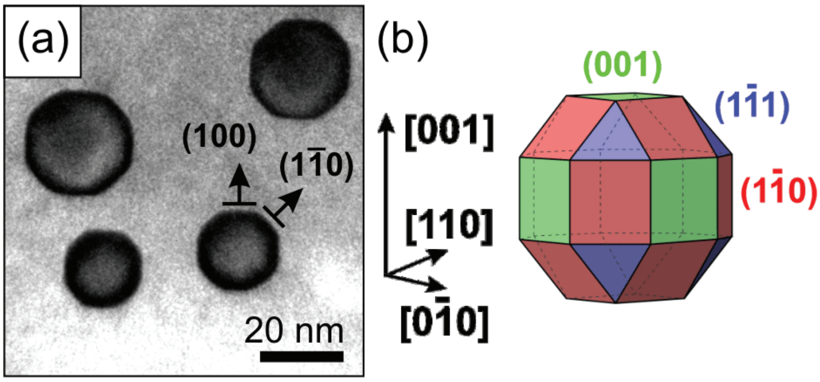

Fig. 1: (a) Plan view, bright field TEM image of PbTe QDs coherently embedded in a CdTe host. (b) Rhombi-cubo-octahedral shape of the highly symmetric QDs.

To monitor the formation kinetics, we performed in situ annealing experiments with a heatable TEM sample holder. Time resolved measurements reveal the kinetics of the complete disintegration process, which is either governed by interface or bulk diffusion processes. The starting points of this evolution are small CdTe columns penetrating the PbTe epilayer. These columns start to grow laterally and merge, which leads to local trapping of PbTe regions in the form of elongated islands. These islands then develop constrictions and finally small islands are separated. Subsequently, the islands evolve into the highly symmetric equilibrium shape of a small rhombi-cubo-octahedron, which is defined by atomically sharp {011}, {011} and {111} interfaces (Fig. 1).

We monitored the different stages from the breaking-up of the 2D layer over the ripple-like PbTe network towards the formation of PbTe QDs in their equilibrium shape. The formation processes are governed by interface diffusion until dots with their final material volume are separated from the PbTe network. The breaking-up of the 2D layer and the disintegration of the wire-like structure are induced by capillary instabilities and driven by interface energy minimization. Separated dots can also reconnect under special conditions and can use the fast interface diffusion to reach the equilibrium shape. Only ripening processes of separated islands, which need longer annealing times or higher temperatures in comparison to the dot formation parameters, are governed by bulk diffusion. These can be quantified by following the disappearing of small dots below a critical radius.

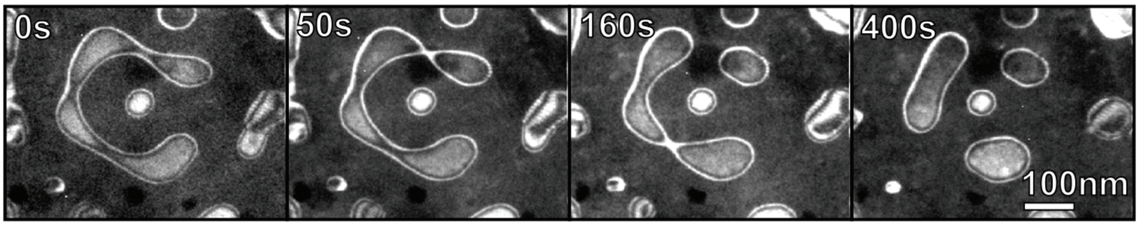

Fig. 2: Formation of three PbTe QDs from one precursor PbTe island. The precursor island shows three constrictions caused by capillary instability. One constriction disappears after separation of two QDs. The following shape transformation leads to a decrease of the distance to the dot in the centre. Also, the disappearing of a small island near the lower border of the frame is observed.

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