TEM investigations of Ga(Sb,As) quantum dots grown on a seed layer of (In,Ga)As quantum dots

I Häusler, H Kirmse, R Otto, W Neumann, L Müller-Kirsch, D Bimberg, M Lentzen, K Urban

Microsc. Microanal. 9 (Suppl. 3), 2003
DOI: 10.1017/S1431927603022086

TEM investigations of Ga(Sb,As) quantum dots grown on a seed layer of (In,Ga)As quantum dots

I. Häusler[1], H. Kirmse[1], R. Otto[1], W. Neumann[1], L. Müller-Kirsch[2], D. Bimberg[2], M. Lentzen[3], K. Urban[3]

[1]Humboldt-Universität zu Berlin, Institut für Physik, AG Kristallographie, Newtonstraße 15, 12489 Berlin, Germany
[2]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstraße 36, 10623 Berlin, Germany
[3]Institut für Festkörperforschung, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

Quantum dots have a lateral size of a few nanometers. Hence, quantum mechanical effects have a great influence on their optical and electronic properties. Self-organized quantum dots (QDs) form due to the relaxation of the strain field caused by the lattice mismatch between the substrate and the layer. This self-organized formation of islands is the Stranski-Krastanov growth mode. One endeavour of the growth experiments is to control the structural and chemical properties of Ga(Sb,As) QDs on the GaAs substrate. This materials system is of special interest because of the type II band structure of Ga(Sb,As) QDs (high localization of holes and spatial indirect excitonic transition). The wavelength being one of the most decisive parameter of an optoelectronic device is strongly affected by the size of the dots.

Contrary to Ga(Sb,As) quantum dots the size and the area density of (In,Ga)As quantum dots can be controlled during metal organic chemical vapour deposition (MOCVD). Therefore an (In,Ga)As QD layer capped by a GaAs spacer was introduced as a seed layer for provision of favourable locations for the formation of Ga(Sb,As) QDs. In order to exhibit the influence of the spacer on the arrangement of the QDs the thickness of the spacer was varied between 3.5 and 19.5 nm for a series of samples. The concept of a seed layer bases on the extension of the strain field of the (In,Ga)As QDs to a certain distance into growth direction. Thus, the vertical correlation of the Ga(Sb,As) QDs should depend on the thickness of the GaAs spacer.

In Fig. 1 dark-field images of cross-sectional samples with different GaAs spacer thicknesses are given using the strain sensitive 004 reflection. A direct vertical correlation is visible between the (In,Ga)As and the Ga(Sb,As) quantum dots for a spacer thickness of 3.5 nm. The area density determined from plan-view TEM images is about $6.8 \cdot 10^{10}$ cm^{-2}. For a slight increase of the spacer thickness to 4.5 nm the area density is doubled to about $12.3 \cdot 10^{10}$ cm^{-2} (see Fig. 1b). This increase is due to the presence of anticorrelations (A) additionally to the vertical correlations (K) given. Anticorrelation means that an (In,Ga)As quantum dot overlies a Ga(Sb,As) quantum dot in the plane of projection perpendicular to the growth direction. Finally, no correlation exists between the dots for a GaAs spacer thickness of 19 nm (cf. Fig. 1c). Here, the area density decreases down to about $6.4 \cdot 10^{10}$ cm^{-2}.

The results of plan-view TEM investigations are summarized in Fig. 2. Fig. 2a-c show the 220 dark-field images. The corresponding size distributions are given in Fig 2d. It is obvious that one and the same average lateral size of about 7 nm is found for all GaAs spacer thicknesses.

Fig. 3a shows one example of an HRTEM image visualizing the 002 lattice planes. The sample was aligned for a 3 beam case which was done by centering the 002 beam on the middle of the Kikuchi-band. Thus the 000 and the 004 beam were positioned at the edges of the band. Fig. 3a shows two intensity scans across the wetting layers of both (In,Ga)As and the Ga(Sb,As) layer. In order to fit the simulation to the experimental intensity profile the contribution of the wetting layer to the intensity is described by an error function (erf(x)). Assuming a symmetric error function an agreement is found with an $R^2=0.81$ (see fig. 3b). A further conclusion from the simulation is that the lattice constant of the (In,Ga)As layer is close to that of InAs. Moreover the thickness of the wetting layer amounts to about 0.81 nm using the half-width of the error function.

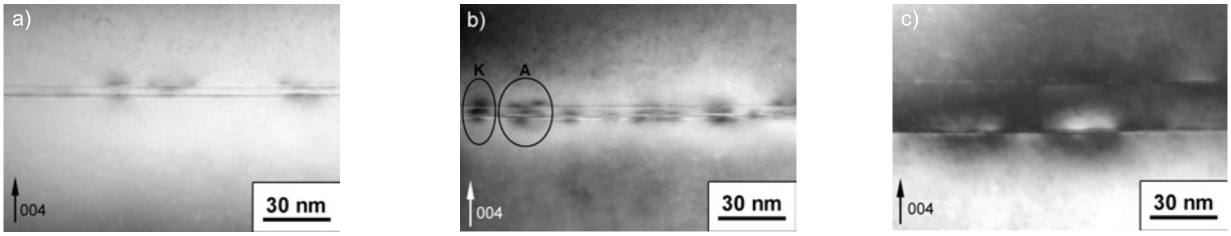


Fig. 1: 004 dark-field images of Ga(Sb,As) quantum dots on a (In,Ga)As seed layer with a varied GaAs spacer thickness in cross-sectional view:
a) 3.5 nm, b) 4.5 nm with direct correlation (K) and anticorrelation (A) between the (In,Ga)As and Ga(Sb,As) quantum dots, c) 19.5 nm

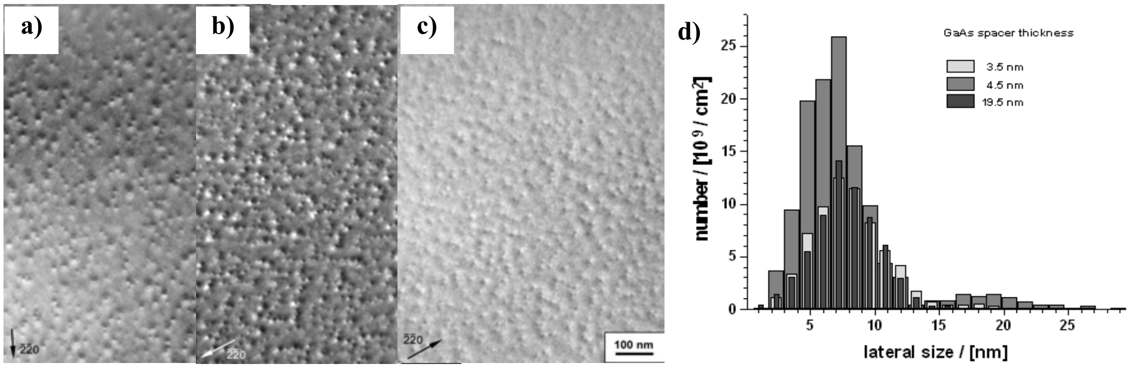


Fig. 2: 220 dark-field images of Ga(Sb,As) quantum dots on a (In,Ga)As seed layer in plan view with varied GaAs spacer thickness:
a) 3.5 nm, b) 4.5 nm, c) 19.5 nm, d) size distribution

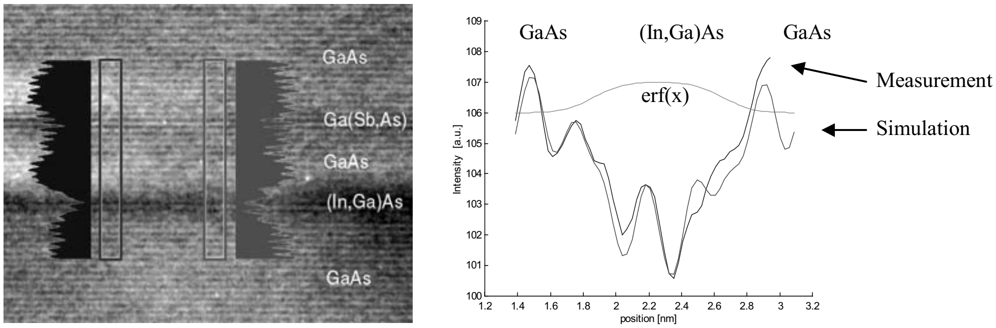
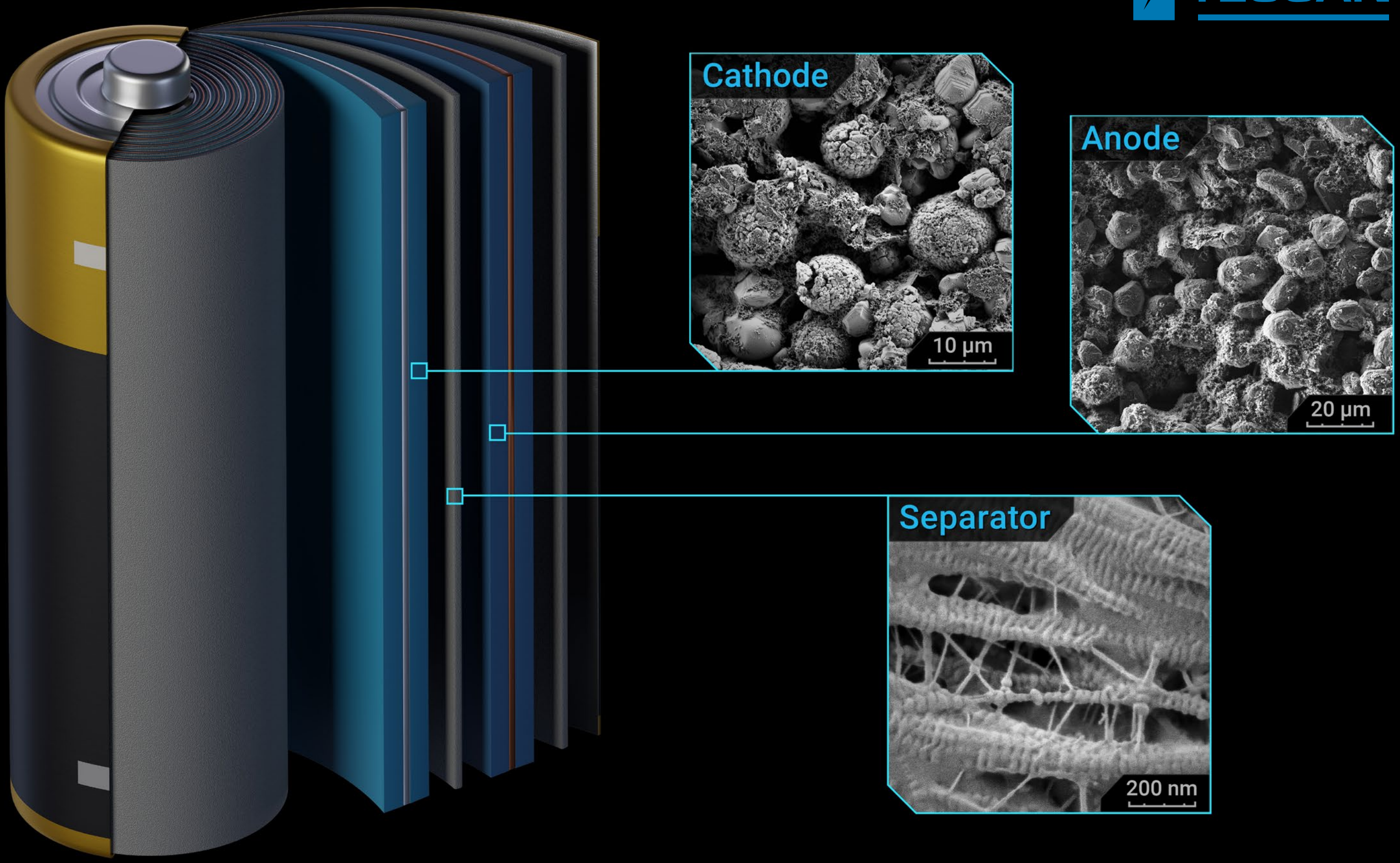


Fig. 3: 002 lattice plane imaging of Ga(Sb,As) quantum dots and corresponding simulation of the intensity profile

TESCAN



TESCAN Solutions for Battery Industry

Power your Advanced Battery Technology
and Research with TESCAN Solutions

info.tescan.com/batteries

Scan for more information