Relaxation mechanisms of InSb/GaSb quantum dots

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There is continued interest in expanding the usable wavelength of III-V optoelectronic devices into the mid- and far- infrared parts of the spectrum. To date, the II-VI $Hg_xCd_{1-x}Te$ has been the material of choice; replacing this technology with narrow band gap III-V materials may be expected to bring benefits in cost, reliability and performance. InSb quantum dots (QDs) are one of the most promising routes to achieve this goal. Here we report an analysis of InSb QDs grown on GaSb, in particular the mechanisms of defect formation - something which must be avoided in order to produce efficient and reliable devices. The InSb/GaSb lattice mismatch of 6.3% provides the driving force for Stranski-Krastanov growth, resulting in self-assembled QDs. Nevertheless, standard growth of InSb/GaSb (QDs) has proved difficult [1].

Growth was carried out using Molecular Beam Epitaxy on undoped GaSb (001) substrates following oxide removal at ~550°C. A GaSb buffer was grown at 500°C and the sample was then cooled to 320°C and allowed to stabilise with no Sb flux. InSb was then deposited at a growth rate of 0.11μ/h and immediately capped with GaSb once the desired InSb thickness had been deposited.

Standard preparation routes were employed to obtain a [110] thin section which was examined in a JEOL 2100 transmission electron microscope (TEM). A typical high resolution TEM image of a buried InSb QD is shown in Fig. 1. Little material contrast is evident; however, careful examination shows the presence of some dislocations, marked here by arrows. Strain analysis using the peak pairs algorithm [2] allows both the QD and the dislocations to be seen more clearly, shown on the right. The QD is visible as a diffuse region with strain along the growth direction ε_{yy} of around 5%, consistent with the lattice mismatch. The dislocations can be seen to be formed in pairs with opposite Burgers vectors, marked A-A and B-B in Fig. 1, each pair lying on the same {111} plane, i.e. consistent with glissile ½<101> dislocation loops which relax the QD through shear of a {111} plane, producing 60° dislocations at the upper and lower interfaces of the QD, as shown schematically in Fig. 2 (left). Interestingly, the upper 60° dislocation of the dislocation loop A is adjacent to that of loop B, implying some coordination in the relaxation process between the two distinct loops. The small apparent separation between the upper dislocations may be due to a difference in the Burgers vector component parallel to the electron beam, preventing their recombination into a sessile ½ [110] edge dislocation at the upper interface.

Observation of several QDs indicated that this process can repeat multiple times to give a chain of loops along the QD, depending upon its lateral dimensions. Fig. 2 (right) shows a QD in which a third dislocation loop has nucleated to produce a /\/ structure; other QDs were also seen with longer chains, forming W or /\/\/\ structures. Although invisible in the HRTEM images examined here, we suspect that a similar set of dislocations exists along the perpendicular <110> direction, I.e. perpendicular to the electron beam.

This structure is quite distinct to that seen in InAs/GaAs QDs, which tend to relax in a much less regular manner often with a single pair of stacking faults above the dot [3] even though the misfit strain is similar in magnitude and sign. We speculate that this is related to the difference in stacking fault energy for InAs and InSb [4].

References

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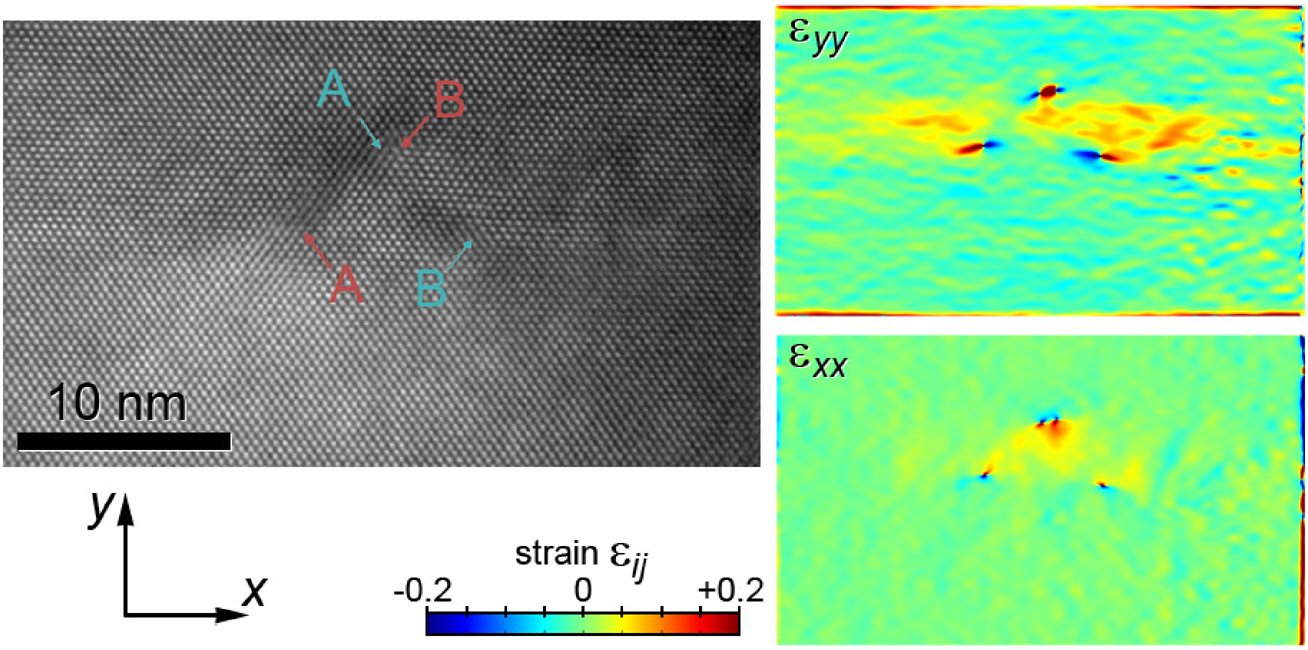

Figure 1. *Left: HRTEM image of an InSb QD in a GaSb matrix. Pairs of 60° dislocations which form opposite sides of a glissile loop are marked A and B respectively. Right: peak-pairs analysis showing the strain components* ε_{yy} *and* ε_{xx}*. This allows the strain in the QD and the dislocations to be seen more clearly.*

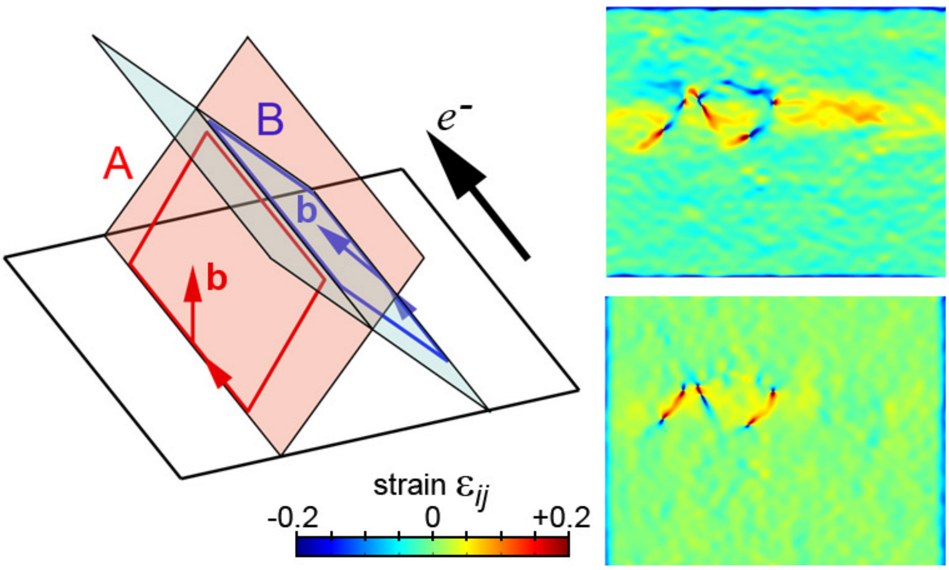

Figure 2. *Left: Schematic interpretation of the dislocation geometry observed in Fig. 1. Loops A and B lie on different {111} planes and have Burgers vector ½ <101>, with the dislocations in 60° orientation where they lie parallel to the electron beam. The inclined segments either lie out of the plane of the thin TEM specimen or are invisible in the HRTEM image of Fig.1 since they lie perpendicular to the electron beam* e^-*. The Burgers vectors* **b** *shown here would be favorable for a reaction between the dislocations to produce a sessile 90° at the intersection of the two {111} planes. Right: a longer chain of loops, giving a /\/ structure.*