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ESRF

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office using the **Electronic Report Submission Application:**

http://193.49.43.2:8080/smis/servlet/UserUtils?start

Reports supporting requests for additional beam time

Reports can now be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

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Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
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Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title:** Strain, composition and shape of lateral InAs/GaAs quantum dot molecules	**Experiment number**: SI-994
Beamline: ID01	**Date of experiment**: from: 03.03.2004 to: 09.03.2004	**Date of report**: 27.07.2004
Shifts: 18	**Local contact(s)**: Dr. Baerbel Krause	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

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Dr. Baerbel Krause*
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Report:

Lateral quantum dot molecules are groups of quantum dots placed within a short lateral distance of each other [1]. The discrete electron levels of a quantum dot can be compared with the orbitals of the hydrogen atom. Similar to the orbitals of a hydrogen molecule, the electron levels of a quantum dot molecule consisting of two identical dots form entangled states, i.e. each electron level splits into two. Structures of this type have been proposed as building blocks of quantum computers.
Ordered groups of quantum dots can be produced using standard lithography methods, but this approach is expensive and time-consuming. It has been shown that, using a combination of molecular beam epitaxy and selective etching, large areas of a GaAs substrate can be structured with InAs quantum dot molecules. The growth process consists of several steps: (1) nucleation of a conventional layer of InAs quantum dots, (2) overgrowth of the quantum dots with a 10 nm GaAs cap layer, (3) in situ etching resultion in holes at the positions of the initial quantum dots, and (4) overgrowth of the holes by InAs forming quantum dot molecules at the positions of the holes. The positions of the quantum dot molecules are arbitrary, but the number of quantum dots in each molecule is well-defined by the growth temperature. The quantum dot molecules have a narrow size distribution, and they are oriented similarly.

The aim of the experiment has been to study the strain, shape, and composition of quantum dot molecules, and to compare them to conventional quantum dots deposited at similar growth conditions. The x-ray diffraction experiments have been performed in grazing incidence geometry using a PSD detector. Several samples have been studied: a reference sample with conventional quantum dots, a quantum dot bimolecule sample, and samples at different growth stages of the quantum dot molecule including the overgrown quantum dots, the etched holes, and the filled holes. The shape and the strain of the samples has been studied using the strong (220) and (2-20) reflections, the composition has been studied by anomalous diffraction at the weak (200) reflection. The anomalous scattering has been performed at the Ga edge at 10.37 keV, in order

to enhance the GaAs contribution in the quantum dot, and at 12.34 keV, where the GaAs contribution is strongly suppressed.

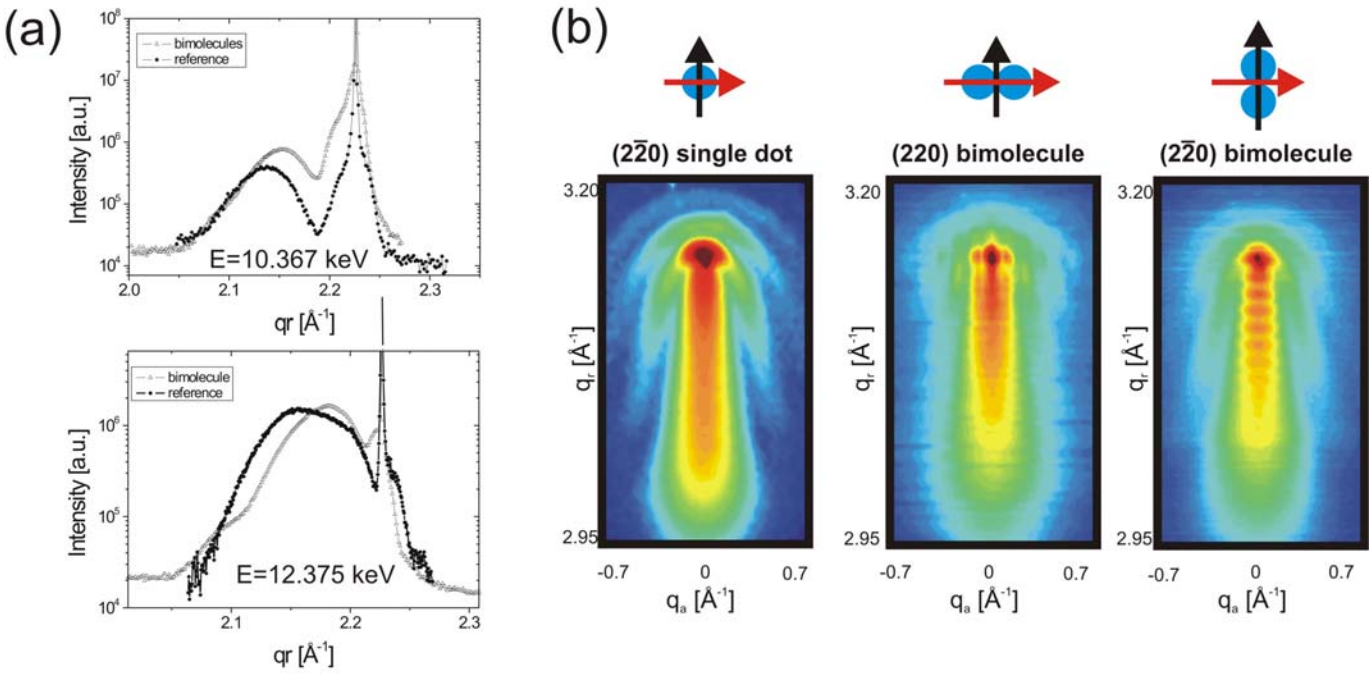

Fig.1: (a) Comparison of the (200) radial scans for the quantum dot bimolecule and the reference quantum dot sample, performed at different x-ray energies. (b) in plane maps of the (220) and (2-20) reflection.

Results

Fig. 1(a) shows the (200) radial scans of the quantum dot bimolecule and the reference sample. The intensity is distributed between q_r=2.05 Å^{-1} and q_r=2.25 Å^{-1}. The (200) position of unstrained InAs is q_r=2.074 Å^{-1}, the GaAs substrate peak is at q_r=2.224 Å^{-1}. At the Ga edge (E=10.367 keV) the intensity around the substrate Bragg peak is enhanced, while at 12.375 keV the diffuse intensity at lower q_r is dominant. The changes in the intensity distribution as a function of E show that the composition of both the bimolecules and the reference sample change with the lattice parameter, i.e. in both cases a lattice parameter gradient is accompanied by a composition gradient.

From the evaluation of the q_r/q_a maps (Fig. 1(b)), we reveal the following model: both the conventional quantum dot and the quantum dot bimolecules, grown on top of a hole, have a similar shape. The quantum dot bimolecules have a diameter of 50 nm and a height of about 17nm, the reference dots have a slightly smaller diameter of about 40 nm and a height of 4 nm. The size distribution of the dots is about 7%, the size distribution of the bimolecules is slightly larger. All bimolecules are well-aligned in (1-10) direction, as can be seen by intensity oscillations in the radial scan of the (2-20) reflection.

It turned out that the scattering of the bimolecule is very similar to the scattering of the reference sample. In first approximation, the influence of the filled hole underneath the bimolecule seems to be negligible. This indicates that the isostrain method [2], a well-established method to analyse the strain and the shape of freestanding quantum dots, might be valid also for the quantum dot bimolecules. Using the isostrain model, the following has been found: both the quantum dot bimolecules and the conventional quantum dots have a high InAs content at the top, and a low InAs content at the bottom. Towards the top, they are nearly completely relaxed. The filled hole below the bimolecule does not seem to influence much the strain and the composition of the dots. This is consistent with the observation that the photoluminescence of InAs bimolecules is very similar to the photoluminescence of conventional quantum dots [1].

References

[1] R. Songmuang, S. Kiravittaya, and O. G. Schmidt, APL **82** (17), 2892 (2003)

[2] I. Kegel et al, PRB **63**, 35318 (2001)