Analysis of semiconductor interfaces and surface segregation using the Composition Evaluation by Lattice Fringe Analysis (CELFA) method

M. Schowalter, T. Mehrtens, K. Frank, K. Müller, A. Rosenauer
Institut für Festkörperphysik, Universität Bremen, Germany

Modern growth techniques such as molecular beam epitaxy (MBE) and metal organic vapor phase epitaxy (MOVPE) are used for growing structures in the development of new devices such as vertical cavity surface emitting lasers (VCSELs) or single photon emitters based on quantum dot structures. For such applications it is important to analyse the composition distribution within the layers and at their interfaces on an atomic scale.

With the composition evaluation by lattice fringe analysis (CELFA) method it is possible to extract the composition distribution on a lateral atomic scale. CELFA exploits the chemically sensitive 002 reflection in sphalerite materials. In InGaAs the amplitude of the normalized 002 reflection nearly linearly depends on the concentration, but is almost independent of the specimen thickness in a wide range of thicknesses. Using the objective aperture the 000 reflection and the 002 reflection are chosen and the resulting lattice fringe image is recorded. The image is then subdivided into primitive unit cells and the contrast is measured within each unit cell. The contrast then is compared with Bloch wave simulations yielding a concentration for each unit cell. From such concentration maps the lateral interface roughness and islands with enriched In concentration can be studied. Averaging the concentration along the fringes allows to study processes, such as surface segregation and diffusion occuring during the growth of the heterostructures.

In this contribution we will focus on our studies on surface segregation. This effect describes the tendency of a certain atomic species to float on the surface during growth. E.g. In floats on top of growing InGaAs. This tendency results in an asymmetrical broadening of the interfaces of an InGaAs layer sandwiched between a GaAs substrate and a GaAs cap layer. At the lower interface the incorporation of the In atoms into the layer is delayed, whereas at the upper interface In atoms are still incorporated after the In flux has been stopped. The strength of segregation is usually quantified by the segregation efficieny R, that is the probability of the In atoms not being incorporated into the crystal during the growth of an atomic layer.

We investigated the dependence of the segregation efficiency on growth parameters such as growth temperature and V/III ratio for MBE grown InGaAs/GaAs heterostructures. The segregation efficiency increases with temperature up to a critical temperature, over which the physisorbed In atoms desorb from the growth surface. The segregation efficiency decreases with increasing V/III ratio. The investigation of other material systems such as InAlAs/GaAs, GaSbAs/GaAs and ZnSSe/ZnSe showed that segregation efficiencies are comparable to the segregation efficiencies of In in InGaAs. All these material systems exhibit a lattice mismatch of about 7%. In contrast, the segregation efficiency of in AlGaAs/GaAs with a lattice mismatch of 0% is significantly smaller than in the other material systems indicating a strong dependence of the segregation efficiency on the lattice mismatch. We also investigated MOVPE grown InGaAs/GaAs samples and found much smaller segregation efficiencies as for MBE grown specimen.