Determination of Composition Amplitude in a Spontaneously Organized Lateral Structure

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Introduction: Spontaneous lateral composition modulation (LCM) in III-V semiconductor alloy films have been confirmed by many structural characterization techniques (XRD, TEM, AFM etc.). However, none of them can determine the amplitude of LCM. This work demonstrates a simple method for this purpose.

Methods and Materials: The sample we studied is a $(InAs)_{1.99}/(AlAs)_{1.43}$ short-period superlattice (SPS) grown on InP (001) miscut towards the [100] direction by ~2°. A single modulation variant along roughly [100] was formed. To improve the sensitivity of x-ray scattering to the LCM, we have chosen 402 and 602 reflections that have the largest accessible components of the diffraction vector, **h,** parallel to the modulation direction, given our experimental conditions. These reflections, however, are not accessible in a coplanar geometry. Therefore, an inclined geometry was introduced by using the χ-angle in a four-circle diffractometer.

Results: Figure 1a shows the measured 602 reciprocal space map around the zero-order superlattice peak in the (010) reciprocal lattice plane. Six lateral satellites were observed. This highlights the importance of strain in the diffraction, since the atomic displacement, **u**, due to strain contributes to the diffraction in form of $\mathbf{h}\cdot\mathbf{u}$. The separation of the lateral satellites gives a LCM wavelength of L=328±5 Å.

To determine the LCM amplitude, we need to calculate the intensity distribution in reciprocal space. Since we have considered only the zero-order SPS satellite, the actually SPS structure can be simplified by a vertically homogeneous layer $In_pAl_{1-p}As$, where p is a function of lateral x-coordinate in the modulation direction, and is given as:

$$p(x) = p_0 + A\cos(Gx), \qquad G = 2\pi / L. \tag{1}$$

Where p_0 is the average In concentration, A is the composition amplitude, and G is the distance of the lateral satellites in reciprocal space. This modulation gives rise to a periodic intrinsic mismatch with respect to the InP substrate,

$$\delta(x) = \frac{p_0 a_{InAs} + (1-p_0)a_{GaAs}}{a_{InP}} - 1 + A\cos(Gx)\frac{a_{InAs} - a_{GaAs}}{a_{InP}}, \tag{2}$$

and a periodic modulation of x-ray scattering amplitude, or susceptibility, $\chi_{\mathbf{h}}(x)$,

$$\chi_h(x) = p_0\chi_{\mathbf{h},InAs} + (1-p_0)\chi_{\mathbf{h},AlAs} + A\cos(Gx)(\chi_{\mathbf{h},InAs} - \chi_{\mathbf{h},AlAs}). \tag{3}$$

The x-ray scattering intensity is calculated by

$$I(q_x, q_z) = \left| \int_{-\infty}^{\infty} dx \int_{-T}^{0} dz \chi_{\mathbf{h}}(x) e^{-i(q_x x + q_z z)} e^{-i\mathbf{h}\cdot\mathbf{u}(\mathbf{x},\mathbf{z})} \right|^2, \tag{4}$$

where T is the total layer thickness, **q** is the deviation from the fundamental Bragg point. **u**(x,z) can be calculated by elastic Green function,[1]

$$\int_{-\infty}^{\infty} dx' \int_{-T}^{0} dz' \delta(x') g_j(x - x', z, z'), \qquad j = x, z \tag{5}$$

where g_j is the elastic Green function defined in Ref.1.

The integrated intensities of the satellites were calculated based on the above equations. We found that the intensity profile is quite sensitive to the composition amplitude. In figure1b, a comparison between the measured and calculated integrated intensities of the satellites about the 602 diffraction were plotted, which yields a composition amplitude of ~ 0.12±0.05 in our particular sample.

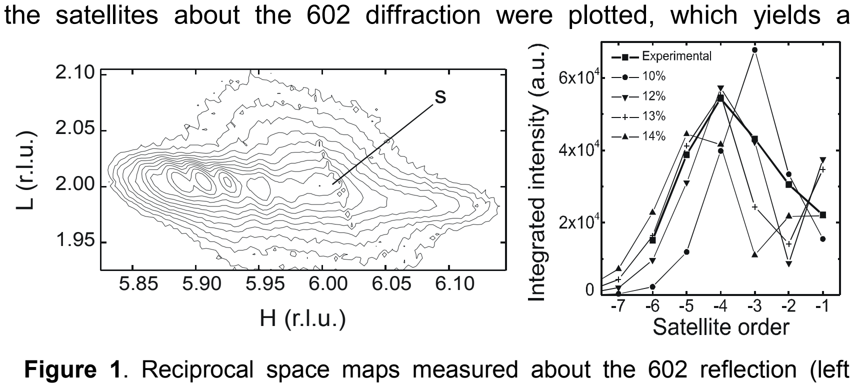

Figure 1. Reciprocal space maps measured about the 602 reflection (left panel). (b) Comparison of the measured and calculated integrated intensities of the satellites (right panel).

Conclusions: By applying an inclined x-ray diffraction geometry and a structural model, we have determined the composition amplitude of spontaneous lateral modulation in an $(InAs)_n/(AlAs)_m$ short-period superlattice.

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References: 1. S.M. Hu, J. Appl. Phys. 66, 2741 (1989).