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X-ray intensity oscillations occurring during growth of Ge on Ge(111)—a comparison with RHEED

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Abstract. The growth of Ge on Ge(111) has been studied *in situ* by x-ray diffraction and reflectivity. For well defined geometries the scattered x-ray intensity is extremely sensitive to atomic-scale surface morphology. For substrate temperatures up to 200 °C oscillations in the reflected and diffracted yields are observed, which are indicative for two-dimensional nucleation. Curves showing reflectivity versus perpendicular momentum transfer Q_z yield the height distribution of the islands. The use of x-rays allows for a straightforward 'single-scattering' interpretation of the intensities, as opposed to the use of reflection high-energy electron diffraction where multiple-scattering effects have to be taken into account.

The Ge(111) crystal consists of bilayers (containing 1.4×10^{15} atoms cm^{-2}) separated by a distance of 3.27 Å. A maximum sensitivity to the growth of islands is obtained if

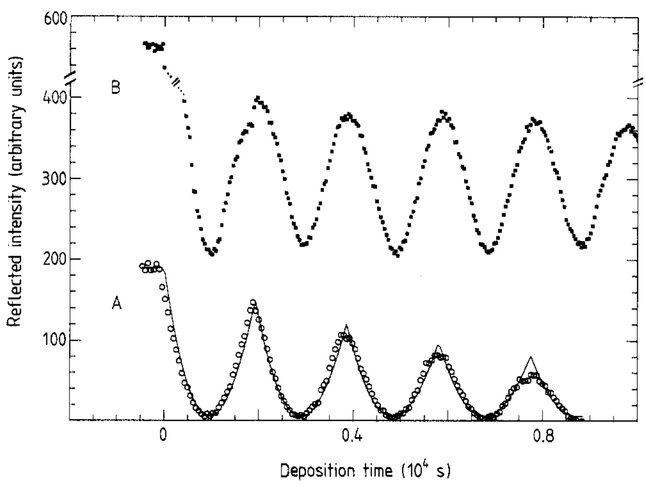

Figure 1. The reflected signal from Ge(111) during Ge deposition. Curve A shows the result from the x-ray experiment (the full curve shows the fit made to the data using a multilevel model). Curve B was given a fixed offset of 200 and shows the result of the RHEED experiment.

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there is a destructive interference between x-rays scattered from an island and those scattered from the terrace below. For the 1.13 Å wavelength used, this situation is obtained for an angle of incidence of 5°. The reflected intensity at this relatively high angle is, however, a factor 10^7 lower than that of the incident beam. This necessitates the use of a very intense x-ray source. The experiment described was performed at the wiggler line 9.4 of the Daresbury Synchrotron Radiation Source.

Prior to growth, the Ge(111) substrate was sputtered and annealed. A reflectivity scan as Q_z is varied shows an almost perfectly flat surface. The reflected intensity under destructive interference conditions was measured during deposition using a Knudsen effusion cell. The substrate temperature was held at 200 °C (figure 1, curve A). The period of the oscillation corresponds to the growth of a single bilayer. The general features can be understood if one assumes, for each period, nearly perfect two-dimensional nucleation followed by coalescence of islands. A detailed analysis [1] of the scattered intensity for a two-level surface reveals a parabolic dependence with the deposited amount up to one bilayer, which is consistent with the experimental observation. Intensity oscillations are well known in reflection high-energy electron diffraction (RHEED) [2]. For comparison with our x-ray results the deposition was repeated with RHEED under the same out-of-phase conditions, but at an angle of incidence of 0.5° which was chosen to match the smaller wavelength of the electrons ($\lambda_e = 0.11$ Å). The beam was incident $\simeq 4°$ off the $\langle 11\bar{2} \rangle$ azimuth. The result is shown as figure 1, curve B.

The damping of the x-ray intensity oscillations can only be explained by a model including more than two levels [3, 4]. The fit shown in figure 1 as curve A is generated by a multi-level model where every island covers a certain fraction of the level below. In the fit this fraction is allowed to increase with the total amount deposited, as described in [4]. After four periods we find best-fit top-level occupancies of 0.80, 0.16 and 0.03. The model gives a reasonably good overall description of the observed intensity changes and describes the dependence of the intensity oscillation for different angles of incidence also. The RHEED intensity oscillations, however, show a different behaviour: no parabolic shape and almost no damping of the oscillations is observed. This suggests that multiple-scattering effects are important in RHEED [5] and that a dynamical scattering theory has to be used for a proper description of the growth process.

References

[1] Lent C S and Cohen P I 1984 *Surf. Sci.* **139** 121
[2] Aarts J and Larsen P K 1987 *Surf. Sci.* **188** 391
[3] Robinson I K 1986 *Phys. Rev.* B **33** 3830
[4] Vlieg E, Denier van der Gon A W, van der Veen J F, Macdonald J E and Norris C 1988 *Phys. Rev. Lett.* **61** 2241
[5] Dobson P J, Joyce B A, Neave J H and Zhang J 1987 *J. Cryst. Growth* **81** 1