Two-wave X-ray optical diagnostics of Ge_xSi_{1-x}/Si modulation-doped heterostructures

A.G. Touryanski[a], I.V. Pirshin[a], M. M. Rzaev[a],
F. Schäffler[b], M. Mühlberger[b],

[a] P.N.Lebedev Phisical Insitute, 53 Leninsky pr., 117924, Moscow, Russia
[b] Insitut für Halbleiter- und Festkörperphysik, Johannes Kepler Universität Linz,
Altenbergerstraße, A-4040 Linz, Austria

New X-ray optical methods – two-wave reflecto- and refractometry - have been used for the first time for determination of Ge_xSi_{1-x}/Si composition and exact measurements layer thickness in multilayer heterostructure. Both techniques are based on simultaneous measurements of two intense characteristic X-ray lines, separated from the polychromatic X-ray probe by semitransparent monochromators. Two-wave reflectometry study allows to realize unique opportunity to measure the ratio of reflected intensities for two X-ray lines providing almost complete elimination of the X-ray beam instability and geometrical errors at small grazing angles.

Samples used in this study were grown by molecular beam epitaxy in a Riber SIVA-45 system. After a standard RCA cleaning a modulation-doped heterostructure consisting of a HT(750°C) 100 nm undoped Si buffer, a LT (250°C) 50 nm $Si_{0.7}Ge_{0.3}$ buffer, a HT(500°C) 150 nm $Si_{0.7}Ge_{0.3}$ buffer, a 10 nm $Si_{0.7}Ge_{0.3}$ channel, a undoped 10 nm $Si_{0.7}Ge_{0.3}$ spacer, a 2 nm B-doped supply layer ($1\times10^{19}cm^{-3}$), a 50nm $Si_{0.7}Ge_{0.3}$ and 10 nm Si cap layers were grown on an 5" Si (001) n-type(3,5-40 Ω cm) substrate.

The ratio reflectogram with CuK_α and CuK_β lines for Ge_xSi_{1-x}/Si heterostructure is shown in Fig.1. The maximum thickness deviation of measured from a technologically predetermined value was 10% for thick 45-50 nm Ge_xSi_{1-x} layers.

The major advantage of newly developed refractometry metrology [1] lays in its insensitivity to high defect concentration and in the detector scan mode to mechanical strains in heterostructures. However, in the sample scan mode surface curvature and respectively non-relaxed strains may be easily identified. In this work we received for the first time clearly resolved refraction peaks from the Si substrate and the Ge_xSi_{1-x} layer under the Si cap-layer (Fig. 2). Composition calculations from of Ge_xSi_{1-x} refraction index for two characteristic lines gave x=0.32 as compared with technologically pre-assigned x=0.30 and x=0.29 from XRD measurements.

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References
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Corresponding author: Alexander G. Touryanski, P.N.Lebedev Phisical Insitute,
53 Leninsky pr., 117924, Moscow, Russia, phone: (095)-132-62-68, Fax: 7(095)-135-10-59.
E-mail address: tour@mail1.lebedev.ru

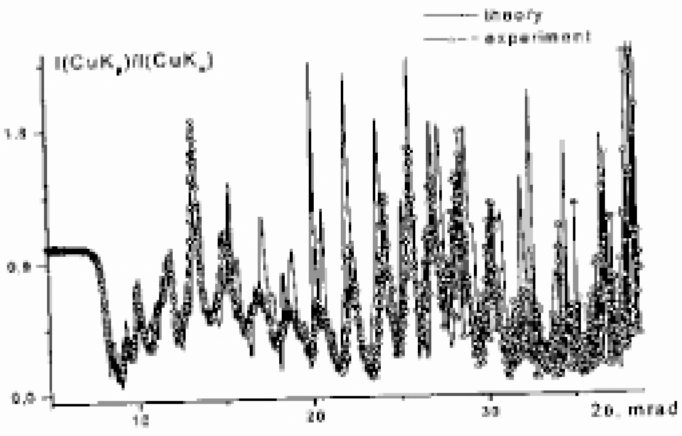

Fig.1. Ratio of reflected intensities $I(CuK_\alpha)/I(CuK_\beta)$ from θ-2θ scan for Ge_xSi_{1-x}/Si heterostructure.

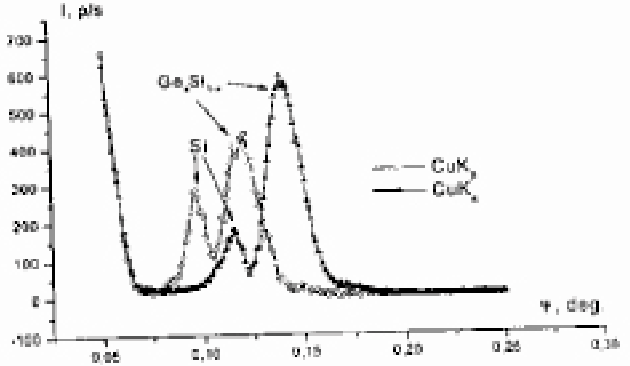

Fig. 2. Refracted intensity I versus deviation angle Ψ for Ge_xSi_{1-x}/Si heterostructure.