Influence of X-ray optical systems and sample characteristics on the angular resolution of X-ray reflectometry measurements with Cu Kα radiation

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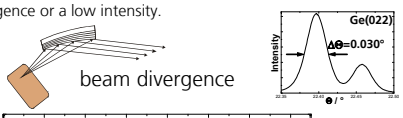
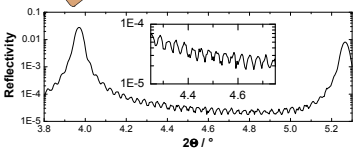
Motivation

The determination of film thicknesses from thickness oscillations (Kiessig fringes) with specular X-ray reflectometry (XRR) is limited by (i) the absorption of X-rays in the film, (ii) the divergence and (iii) the monochromacy of the incident beam in case of ideal lateral thickness homogeneity. A prerequisite for the resolution of thickness oscillations of films thicker than 250 nm with Cu $K\alpha$ is a small beam divergence and a high beam intensity. In commercial XRR systems and in literature, various solutions have been given comprising (1) direct beam optics, (2) Göbel mirror optics, (3) channel cut monochromators and (4) secondary monochromators. These beam optics, however, suffer either from a large divergence or a low intensity.

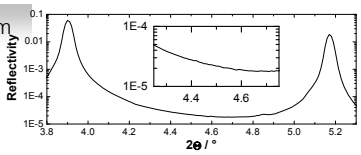


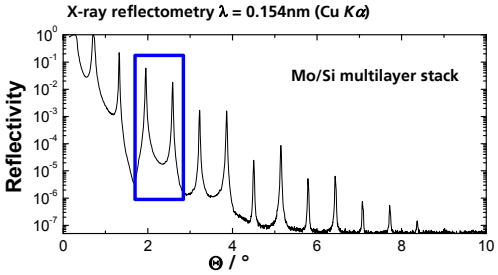


N*d = 270 nm

Göbel Mirror (GM) limits in layer thickness determination

N*d = 414 nm



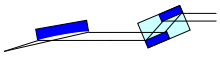


Advanced solution

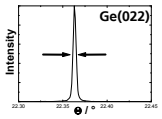
The concept presented here overcomes the shortcomings of conventional systems. By coupling a parallel beam multilayer mirror to a channel cut monochromator, a significantly lower beam divergence at a still high beam intensity can be achieved.

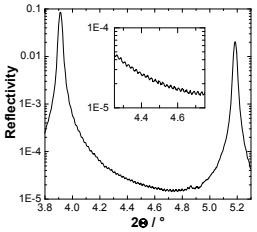
Result:

GM + symmetric CC



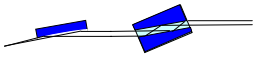
FWHM
Δθ = 15″



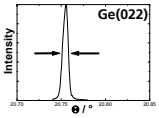


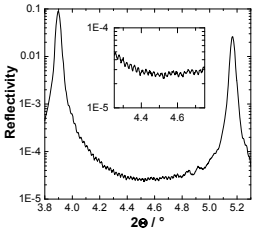
N*d = 414 nm

GM + asymmetric CC



FWHM
Δθ = 26″

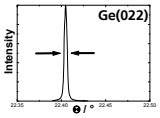


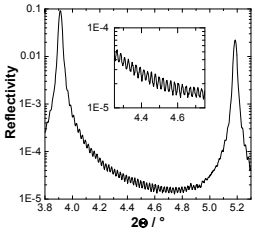


N*d = 415 nm

GM + EXP VC

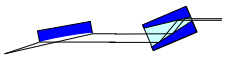
FWHM
Δθ = 14″



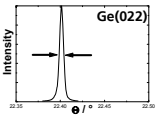


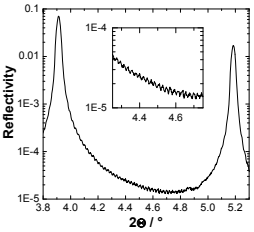
N*d = 414 nm

GM + COMP VC

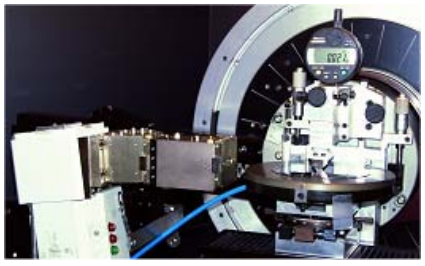


FWHM
Δθ = 20″





N*d = 414 nm



	GM	sym.CC	asym.CC	EXP VC	COMP VC
intensity after primary beam optics [cps]	$3 * 10^9$	$1.3 * 10^8$	$1.5 * 10^8$	$1.7 * 10^8$	$3.9 * 10^7$
beam width [mm]	0.8	0.55	0.55	2.2	0.15
intensity after sample reflection (Ge022) [cps]	$2.1 * 10^8$	$1.0 * 10^8$	$6.4 * 10^7$	$1.4 * 10^8$	$2.2 * 10^7$
divergence Ge(022)*	0.030°	0.0037°	0.0070°	0.0035°	0.0052°

GM Göbel mirror
CC channel-cut monochromator
VC V-cut monochromator
EXP beam expander
COMP beam compressor

* We estimated the divergence from the measured FWHM by using a 12″ Darwin width of Ge(220) symmetrical Bragg reflection.

Summary

The resulting beam properties have been characterized by rocking curves on a Ge(022) reflection from a perfect single-crystalline germanium sample and Θ-2Θ scans on multilayer samples of various layer stack thicknesses.
Compressing and expanding V-cut Ge(022) crystal monochromators (VC) are compared with standard symmetric and asymmetric channel cut monochromators (CC). The results on the beam width, divergence and intensity are summarized in the table above.

Beam width and angular resolution can be tuned by the beam optics. Layer stack thicknesses of more than 400 nm can be analyzed with a combination of a parallel beam Göbel mirror and a CC/VC [1, 2]. The resolution of Kiessig fringes is best for the expander VC yielding a divergence of 0.0035° at a gross beam intensity of 140 Mio. cps using a long fine focus Cu tube (2.2 kW) at 40 kV / 40 mA.

The ideal lateral homogeneity better than Δd/d = 0.1% and the accurate periodicity of the layer stack do not obliterate oscillations and therefore meet the requirements of high resolution X-ray reflectometry.

References:
[1] DPG Spring Meeting 2004, Regensburg, 08-11.03.2004
[2] D. Korytar, priv. communication and providing CC monochromators.

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