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Interface Growth in FeCo-Si Multilayers with atomic resolution

Introduction

FeCo-Si multilayer systems can be used as neutron polarisers due to the matching of their scattering length densities for one spin component. To optimise their performance, the thickness of interface layers should be as small as possible. For this purpose a model system was built and characterised by several methods.
Polarized neutron reflectometry is used to characterise a model system of a monochromator with 5 bilayers of nominally 100 Å Si and 100 Å $Fe_{89}Co_{11}$ covered with a final layer of 100 Å Si to prevent oxidation of the $Fe_{89}Co_{11}$ layer. From these data it was possible to determine the thickness and composition of the interface layers.
The values of these properties depend on the sputtering parameters. Under the conditions of minimal thickness of the interface layers neutron reflectometry showed on top of the silicon layer 15 Å $(Fe_{89}Co_{11})_{0.51}Si_{0.49}$ and on top of the iron cobalt layer 18 Å $(Fe_{89}Co_{11})_{0.67}Si_{0.33}$. The errors are in the thickness ±2 Å and in the composition ±2%.
Additional measurements with in situ fast kinetic ellipsometry and x-ray scattering agree with the neutron results within the error limits.
In situ fast kinetic ellipsometry allows investigating the growth of sputtered $Fe_{89}Co_{11}$-Si multilayers, revealing that during growth the iron cobalt layer undergoes a phase transition. After the formation of the interface layer on top of the silicon layer the iron cobalt alloy starts to grow in an amorphous phase until a thickness of 25 Å is reached. Then it crystallizes down to the interface layer whereby it shrinks to 18.5 Å. The atomic density changes nearly proportionally to the imaginary part of the index of refraction.
Using all these data it was possible to describe the growth of the multilayer system with atomic resolution.

Reflected spin up neutrons and fit, λ = 4.72 Å

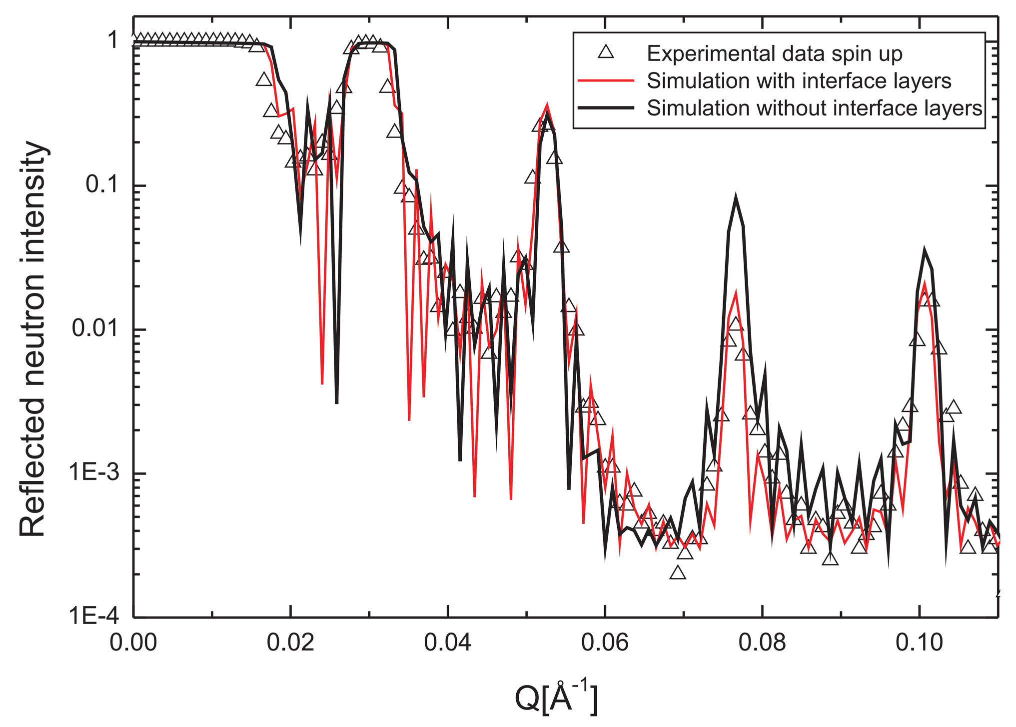

Fig. 1

Reflected spin down neutrons and fit, λ = 4.72 Å

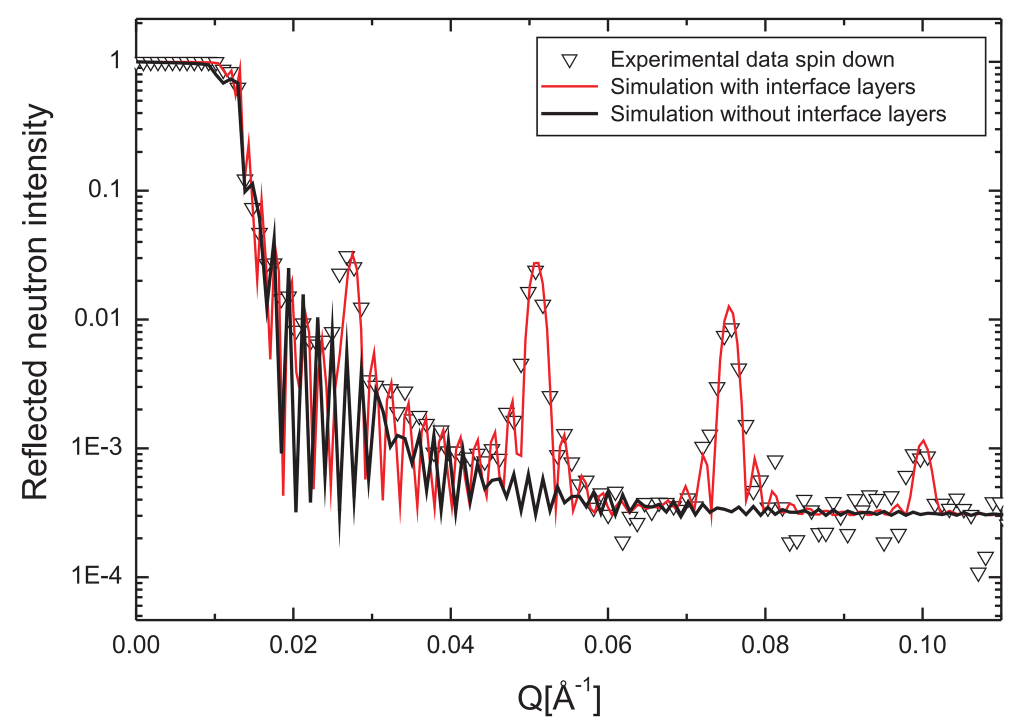

Fig. 2

Reflected x-rays and fit, λ = 1,54 Å

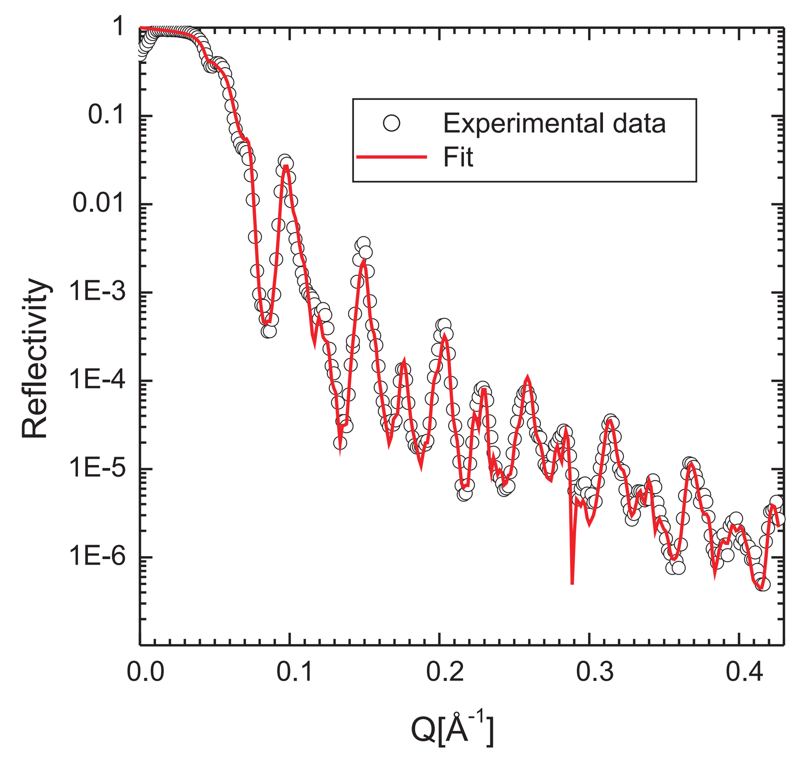

Fig. 3

Ellipsometer growth curve for the whole monochromator

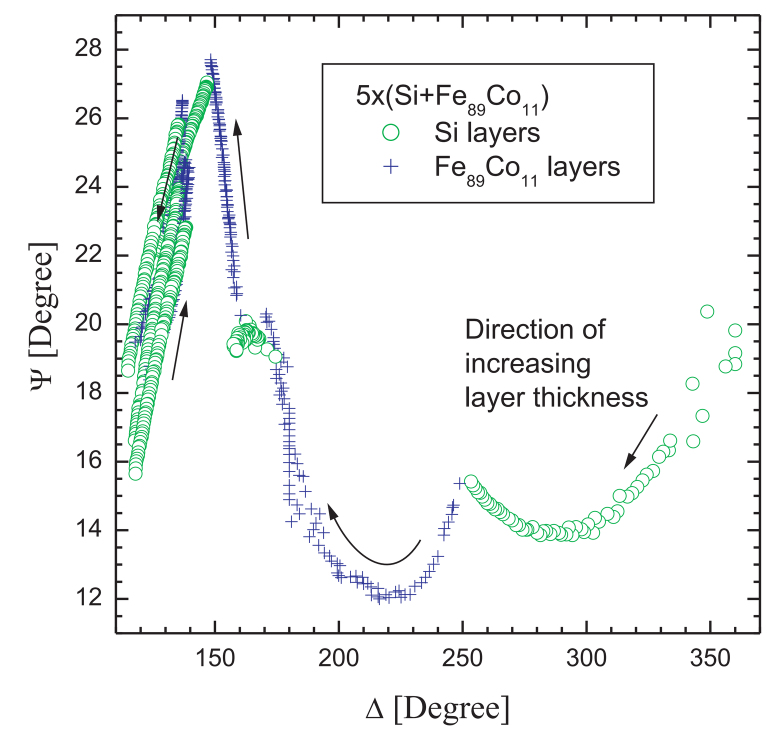

Fig. 4

Ellipsometer growth curve and fit for one interface layer

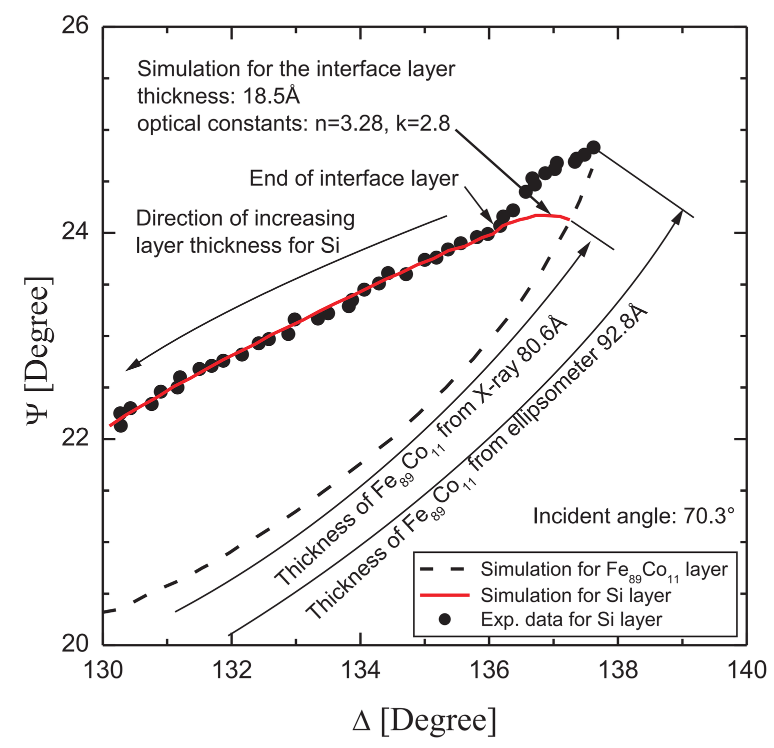

Fig. 5

Ellipsometer curves for artificially mixed layers

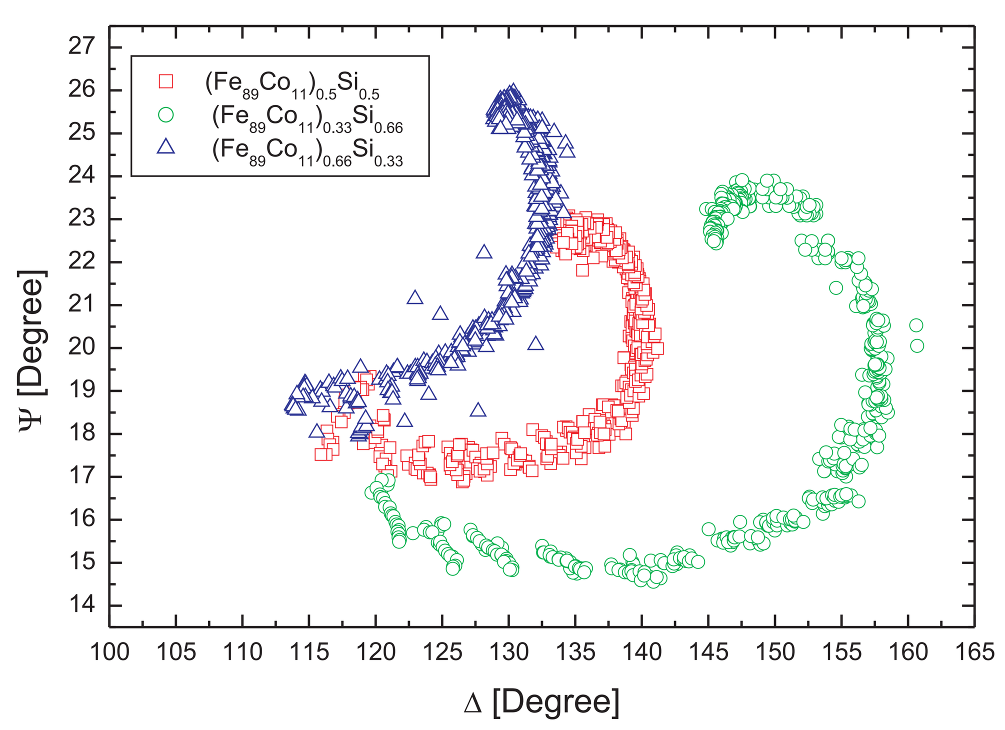

Fig. 6

Optical constants derived from Fig. 6

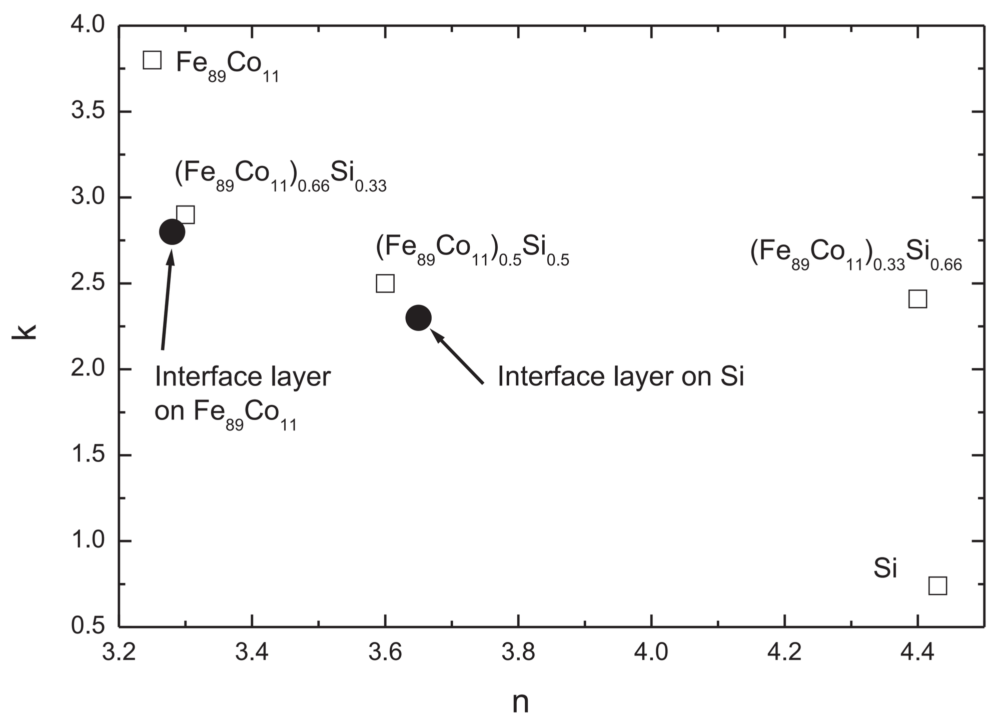

Fig. 7

Ellipsometer curve of the crystallisation of an amorphous FeCo layer

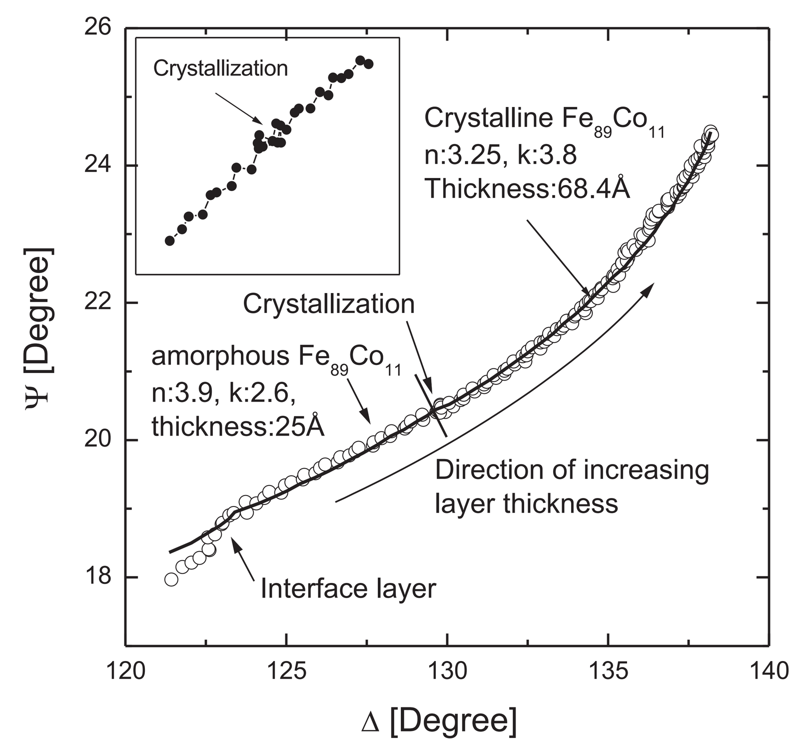

Fig. 8

Thickness and scattering length density for all layers

	t (x-ray) [Å]	t (Ellipsometer) [Å]	t (n spin up) [Å]	t (n spin down) [Å]	t_{mean} [Å]
Interface layer	18.5	17.2	14.5	14.8	16.3
$Fe_{89}Co_{11}$	80.3	80.6	78.3	83.2	80.4
Interface layer	15.3	14.5	14.2	12.3	14.1
Si	88.7	89.1	90.9	91.5	90.1
Sum	202.8	201.4	197.9	201.8	200.9
Chi^2	1.1×10^{-2}		9.1×10^{-2}	1.52×10^{-1}	

	SLD_{re} (x-ray) $[10^{-5}Å^{-2}]$	SLD_{im} (x-ray) $[10^{-6}Å^{-2}]$	SLD_{re} (n-up) $[10^{-6}Å^{-2}]$	SLD_{re} (n-down) $[10^{-6}Å^{-2}]$	SLD_{im} (n) $[10^{-10}Å^{-2}]$	n	k
Interface layer	4.99	2.36	7.81	5.11	5.4	3.28	2.8
$Fe_{89}Co_{11}$-layer	5.99	7.83	12.74	2.12	1.6	3.25	3.8
Interface layer	4.62	1.68	6.11	6.07	5.4	3.65	2.3
Si-layer	2.01	0.46	2.07	2.07	2.4	4.44	0.75

Composition of interface layers from different methods

		Interface Si ☐ FeCo		Interface FeCo ☐ Si	
Method		Si content [at.%]	FeCo content [at.%]	Si content [at.%]	FeCo content [at.%]
Ellipsometer I II		52.0 49.6	48.0 50.4	33.0 31.5	67.0 68.5
X-ray		52.3	47.7	(41.5)	(58.5)
Neutron	up	52.3	47.7	33.5 (cryst.) 37.4 (amorph.)	66.5 (cryst.) 62.6 (amorph.)
	down	51.2	48.8	34.5 (cryst.) 37.8 (amorph.)	65.5 (cryst.) 62.2 (amorph.)
Average values	Ellipsometer n, crystalline n, amorphous	50.8	49.2	32.3 34.0 37.6	67.8 66.0 62.4
	all except n, amorphous	51.48	48.52	33.1	66.9

Time sequence for the growth of an FeCo-Si bilayer

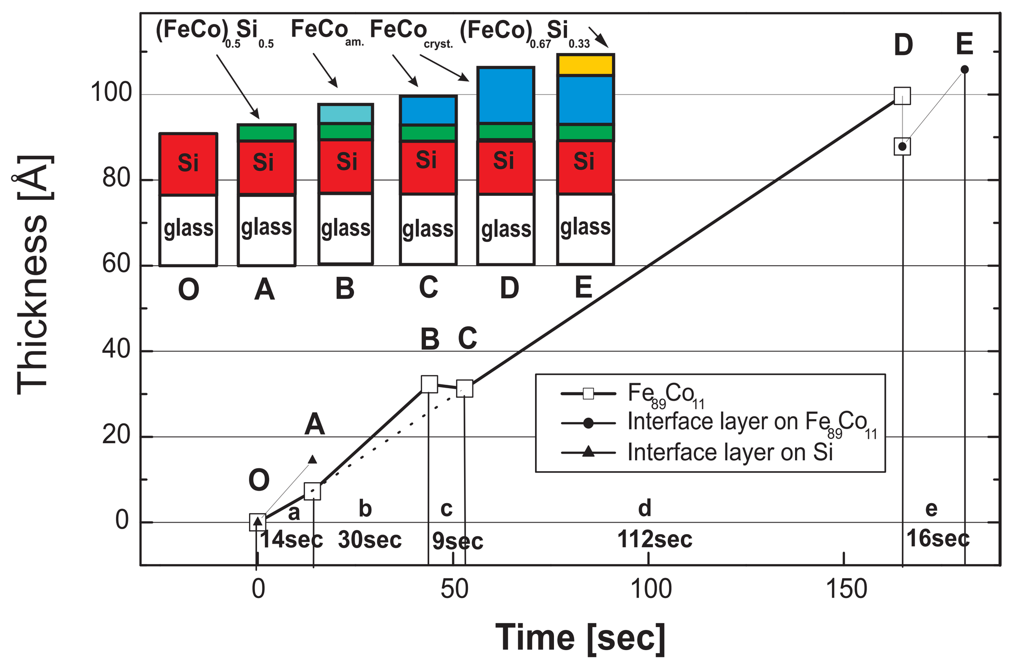

Fig. 9