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Kossel interferences of proton-induced X-ray emission lines to study the interfaces of thin film waveguides

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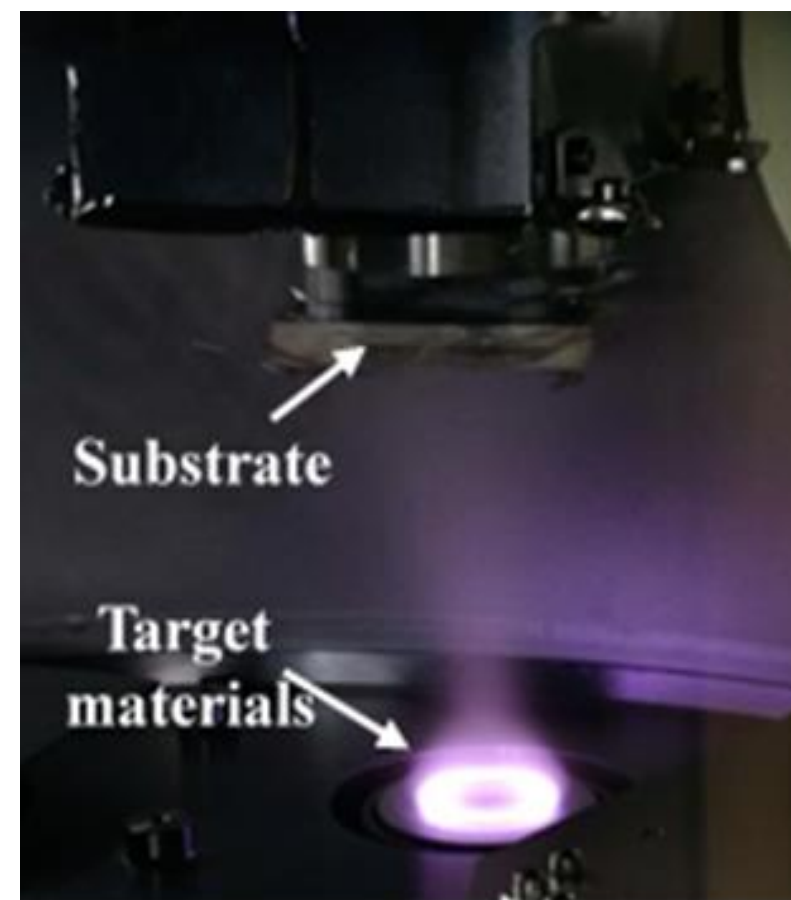
Introduction

While waveguide optic is ubiquitous in the visible and infrared spectral range, it is still much less developed in the X-ray regime. The X-ray waveguide can be used as spatial and coherence filters for X-ray coherent imaging [1-2]. It is usually designed and fabricated with a low density guiding layer embedded in high density cladding layers. The interfaces of the thin film waveguides play a crucial role in their service reliabilities. In this study, X-ray thin film waveguide are prepared by magnetron sputtering. The Kossel interferences of proton-induced X-ray emission lines, as a novel non-destructive way [3], is used to analyze the interfacial environment of the nanoscale thin films.

Experimental

Sample Preparation

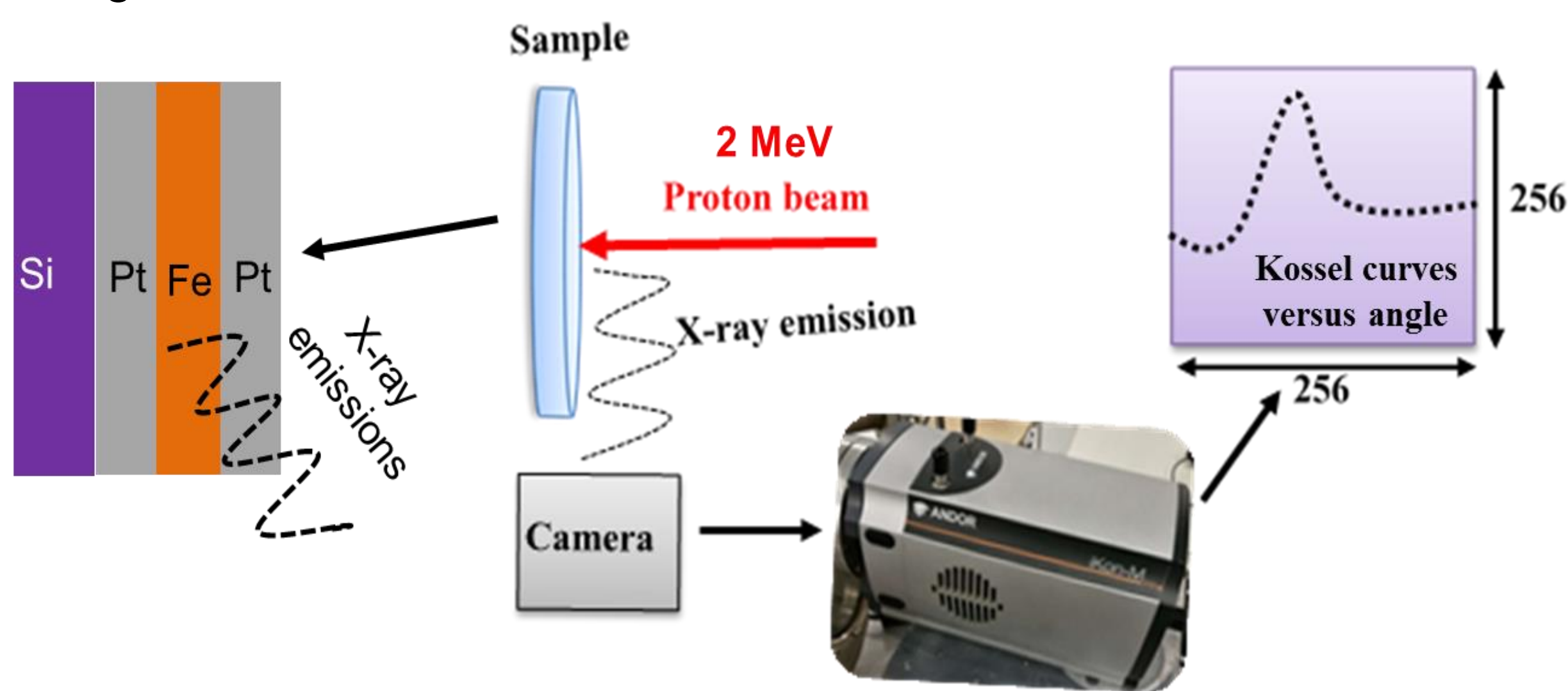
We first made simulations to obtain the optimized parameters (include elements and thickness) for the thin film waveguides by using the IMD software. No interfacial roughness of thin film as well as of the Si substrate was taken into account. A series thin films waveguides were designed and prepared by magnetron sputtering, as follow



Sample	Structure
RD1	Pt (4 nm)/Fe(8 nm)/Pt(10 nm)
RD2	Pt(4 nm)/Fe(6 nm)/Pt (10 nm)

Proton-induced X-ray emission (PIXE)

The proton beam with energy of 1.6 MeV with ≈ 100 nA current generated by the Van de Graaff accelerator is used to irradiate the sample. The angle between the proton beam and the sample is 90° . With the help of energy dispersive CCD camera ANDOR iKon-M (equipped with a 1024×1024 sensor array with $13 \times 13 \mu\text{m}$ pixels), the generated X-ray fluorescence signal is recorded.



X-ray reflectivity (XRR)

To know the actual thickness and roughness of the deposited thin films, XRR is conducted. The XRR measurements were performed at the 0.154 nm wavelength on the Rigaku five-circle diffractometer.

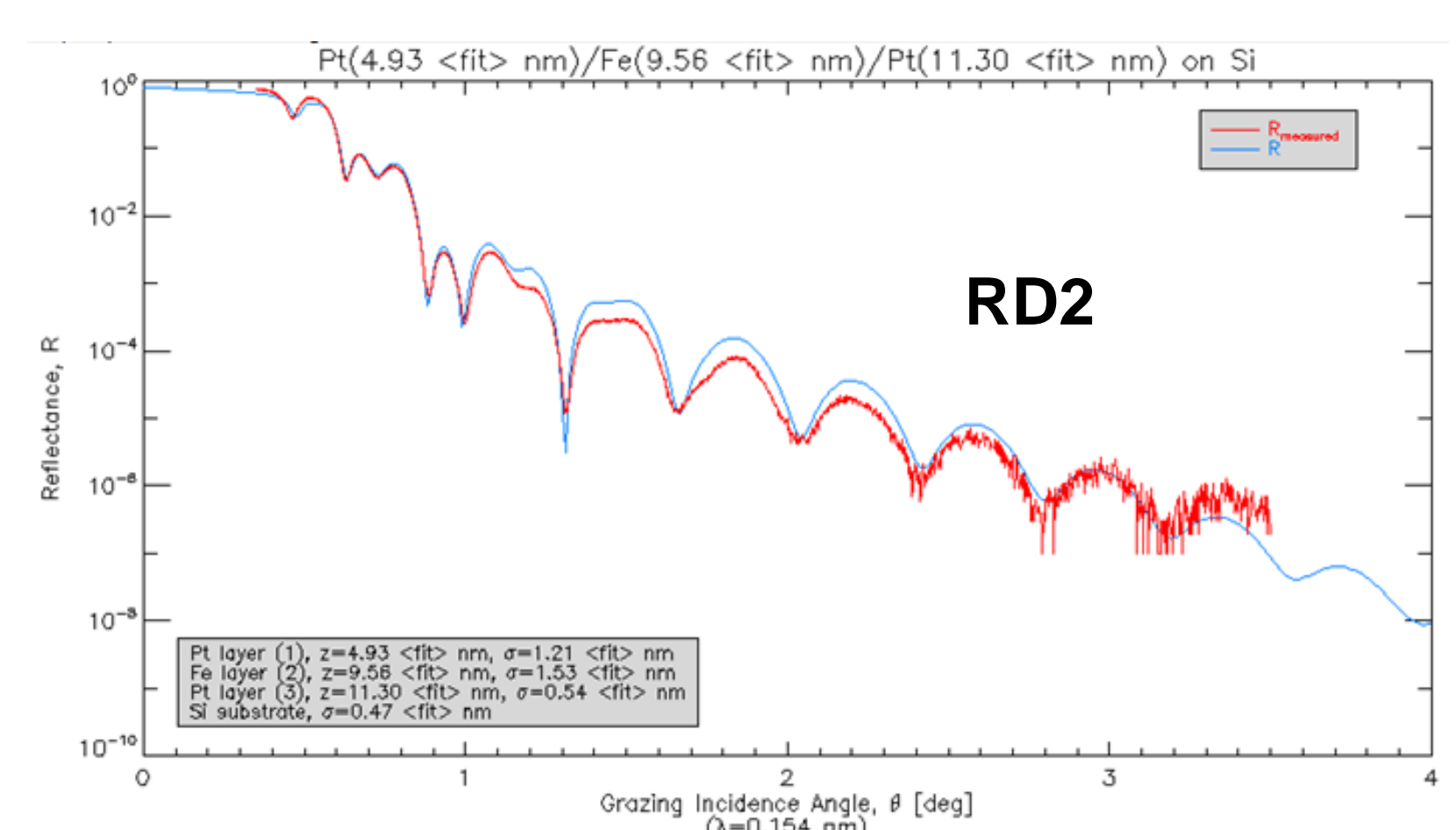
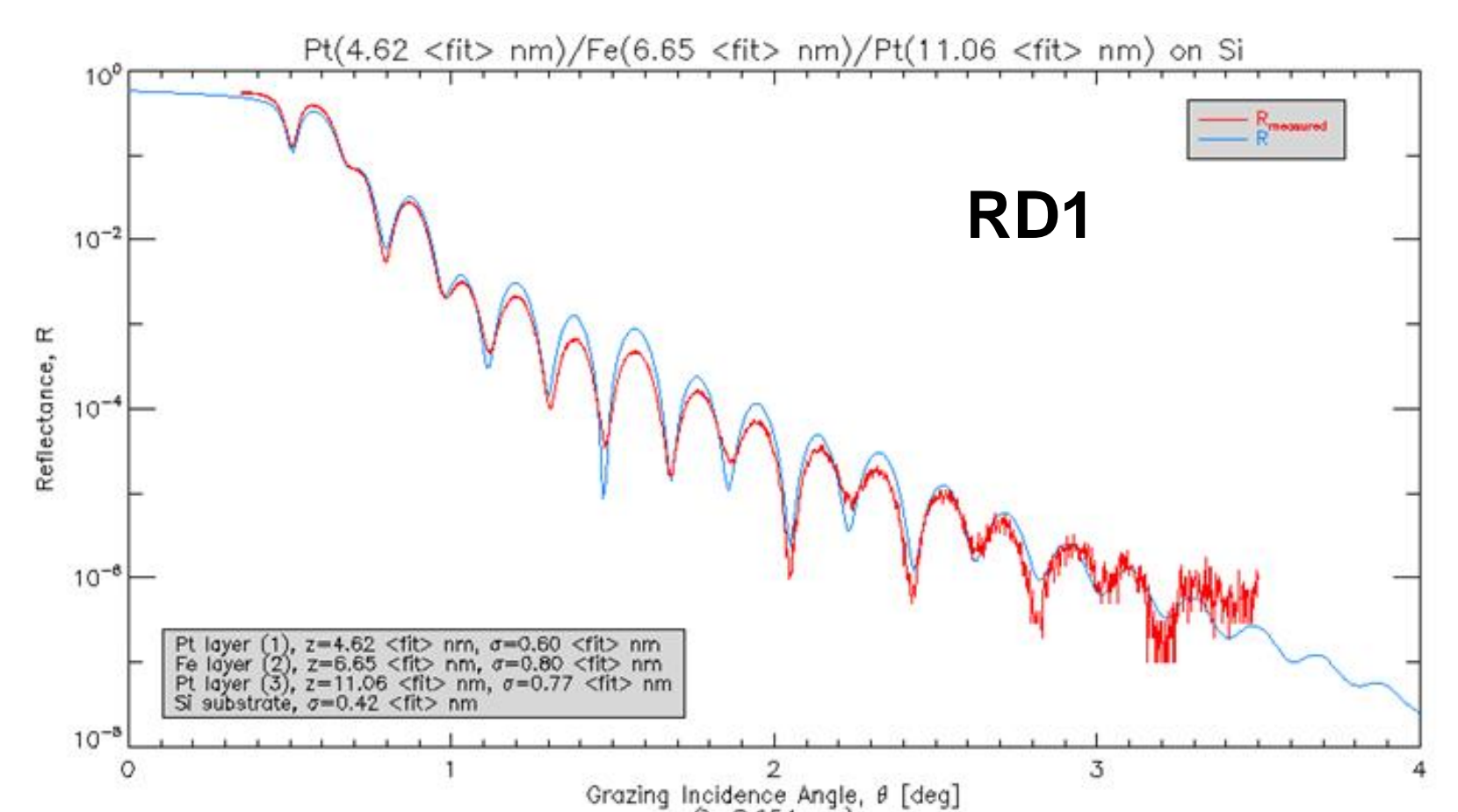


XRR and fitting results

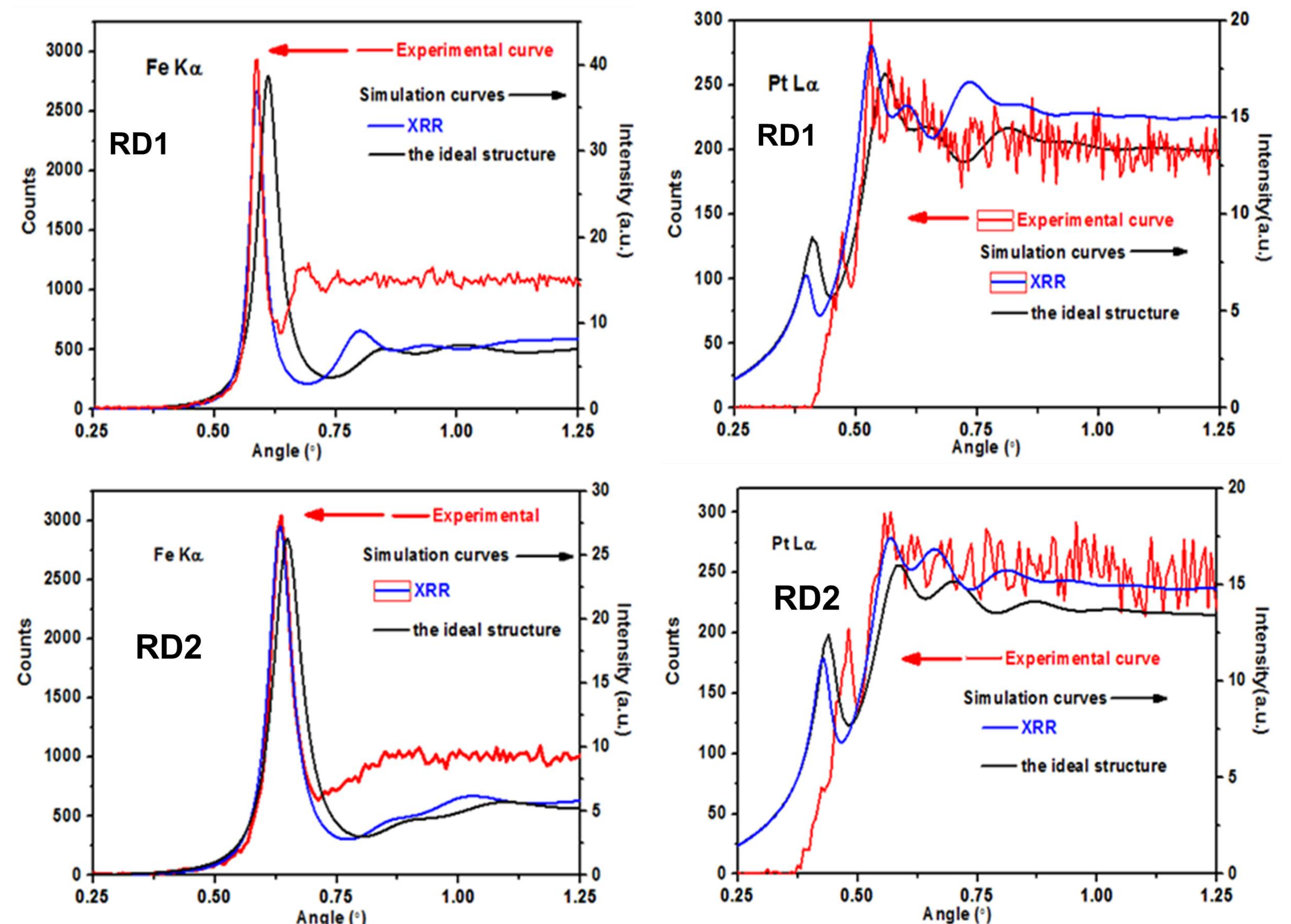
Compared with the ideal structures, it is seen that the deposited thickness of Pt and Fe layers is larger by about 10-20%. But the density of the bulk was chosen for the different films. If we consider that the layers have in fact a density of 90% of the bulk one, then the discrepancy could be explained. The roughness difference of Pt and Fe layers, indicating the Pt-on-Fe and Fe-on-Pt interfaces are asymmetrical.

RD1	Thickness (nm)	Roughness (nm)
Pt (top layer)	4.93	1.21
Fe (second layer)	9.56	1.53
Pt (bottom layer)	11.30	0.54
Si substrate		0.47

RD2	Thickness (nm)	Roughness (nm)
Pt (top layer)	4.62	0.60
Fe (second layer)	6.65	0.80
Pt (bottom layer)	11.06	0.77
Si substrate		0.42



PIXE-Kossel lines to study the interfaces



The main features of the simulated curves are almost reproduced by the experimental ones.

REFERENCES

- [1] Osterhoff, Markus, and Tim Salditt. "Real structure effects in x-ray waveguide optics: The influence of interfacial roughness and refractive index profile on the near-field and far-field distribution." *Optics Communications* 282.16 (2009): 3250-3256.
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CONCLUSION AND PERSPECTIVES

1. The main features of the simulated curves are reproduced by the experimental ones. But the relative intensities of the main peaks still have obvious differences.
2. We need to refine the description of the stack so as to find a combination of thicknesses and roughnesses that satisfies both XRR and PIXE-Kossel measurements.