

Structure Analysis of Gate Dielectric Films by X-Ray Reflectivity Measurement

~ interface structure of CeO₂/Si ~

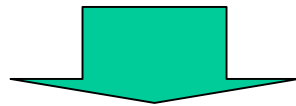
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- 1 . About CeO_2**
- 2 . Objectives**
- 3 . Sample**
- 4 . Experimental Method**
- 5 . Result**
- 6 . Summary**

CeO₂

- CaF₂ structure
- excellent lattice match with Si(111) ~0.35%
epitaxial growth (further reduction of EOT)
- high dielectric constant ~26 (high-k)
- high-melting point ~2600
- chemically stable



high-k gate oxide in the 30nm CMOS technology

Objectives

- CeO_2 / Si interface : a-Ce and/or SiO_2 !?
- Interface structure electric property

Clarification of interface structure

Sample

[Sample Structure]

CeO₂ /Si(111) sub.

[Film Deposition]

**MBE using metal Ce and O₂
(650 × 30min.)**

Experiment

X-ray Reflectivity Measurement

BL16XU (undulator)

=1.5406

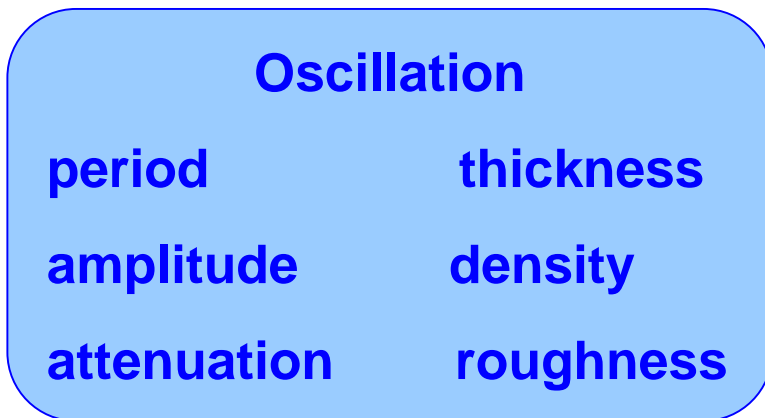
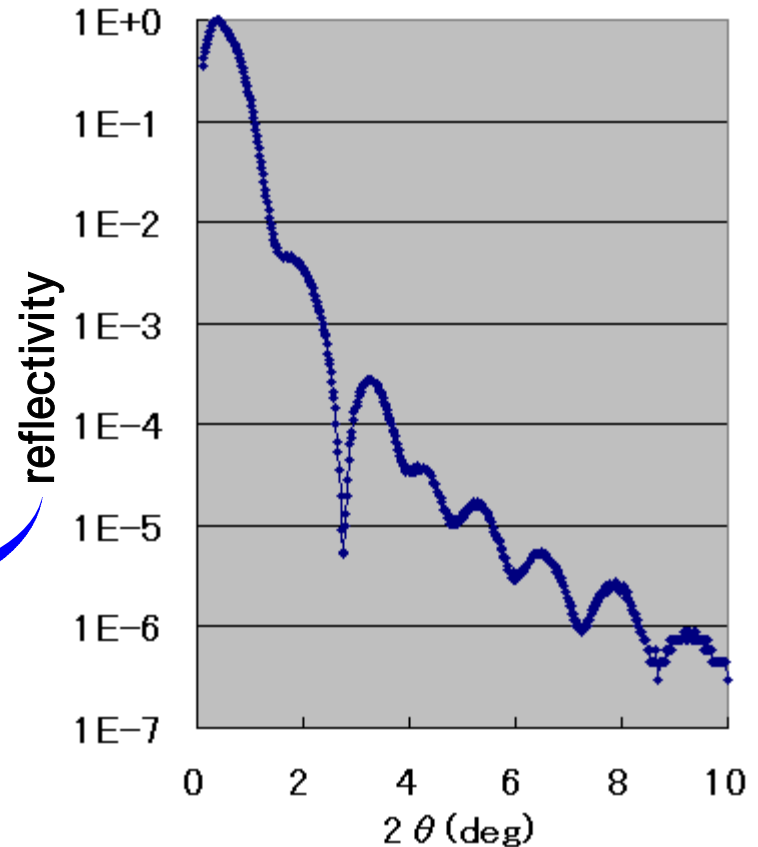
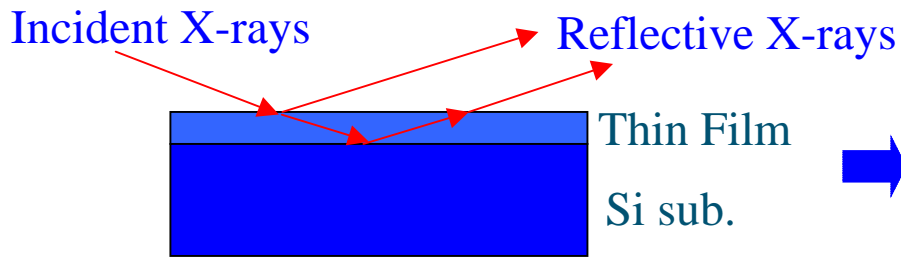
TEM

Cross-sectional image

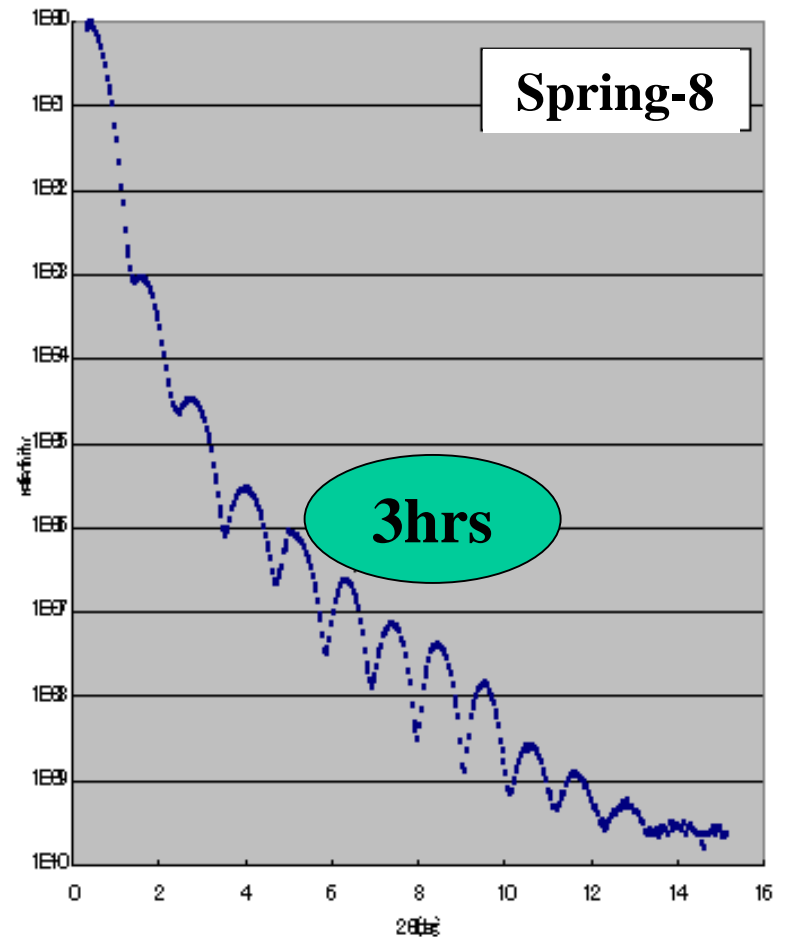
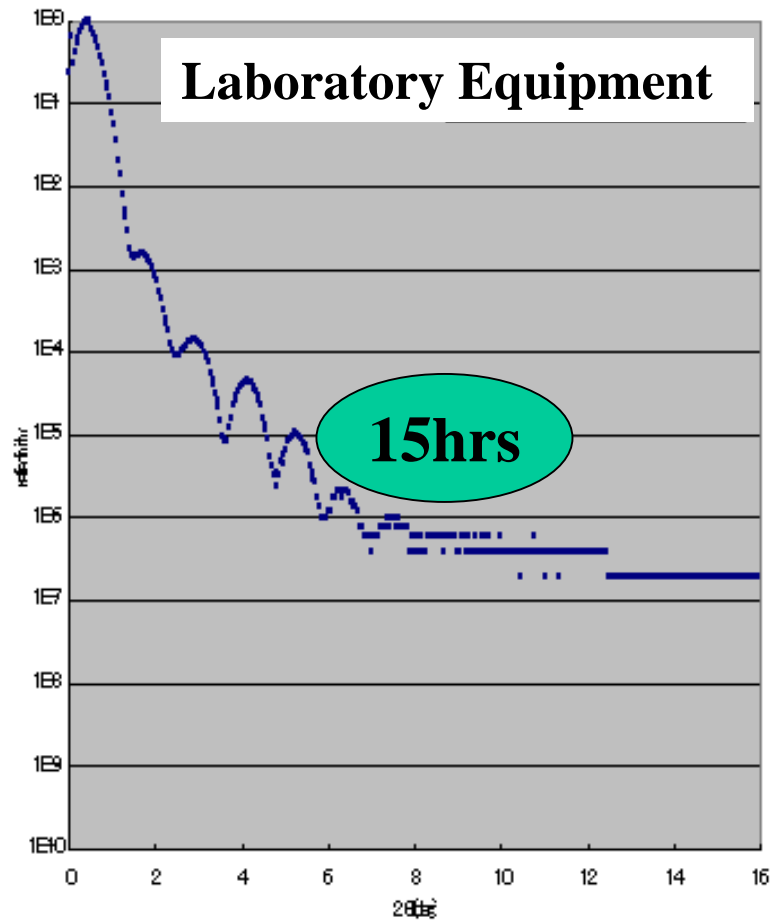
HR-RBS

Depth profile of Ce, Si, and O

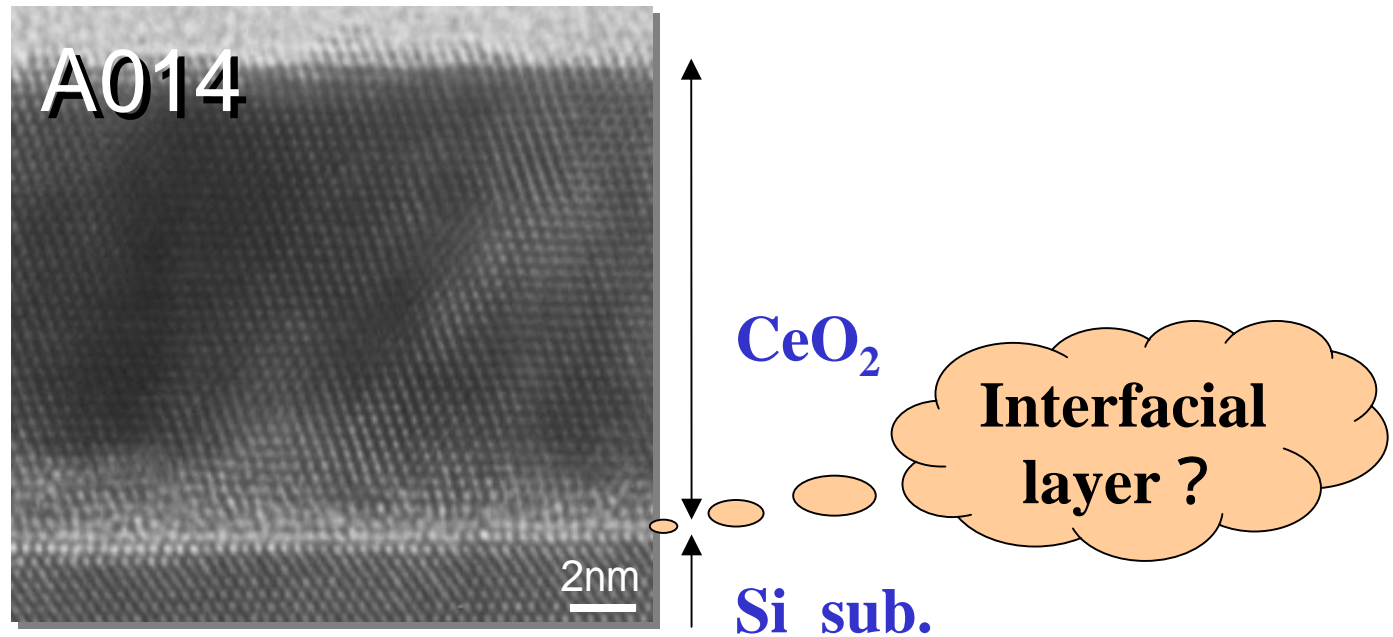
X-ray Reflectivity Measurement



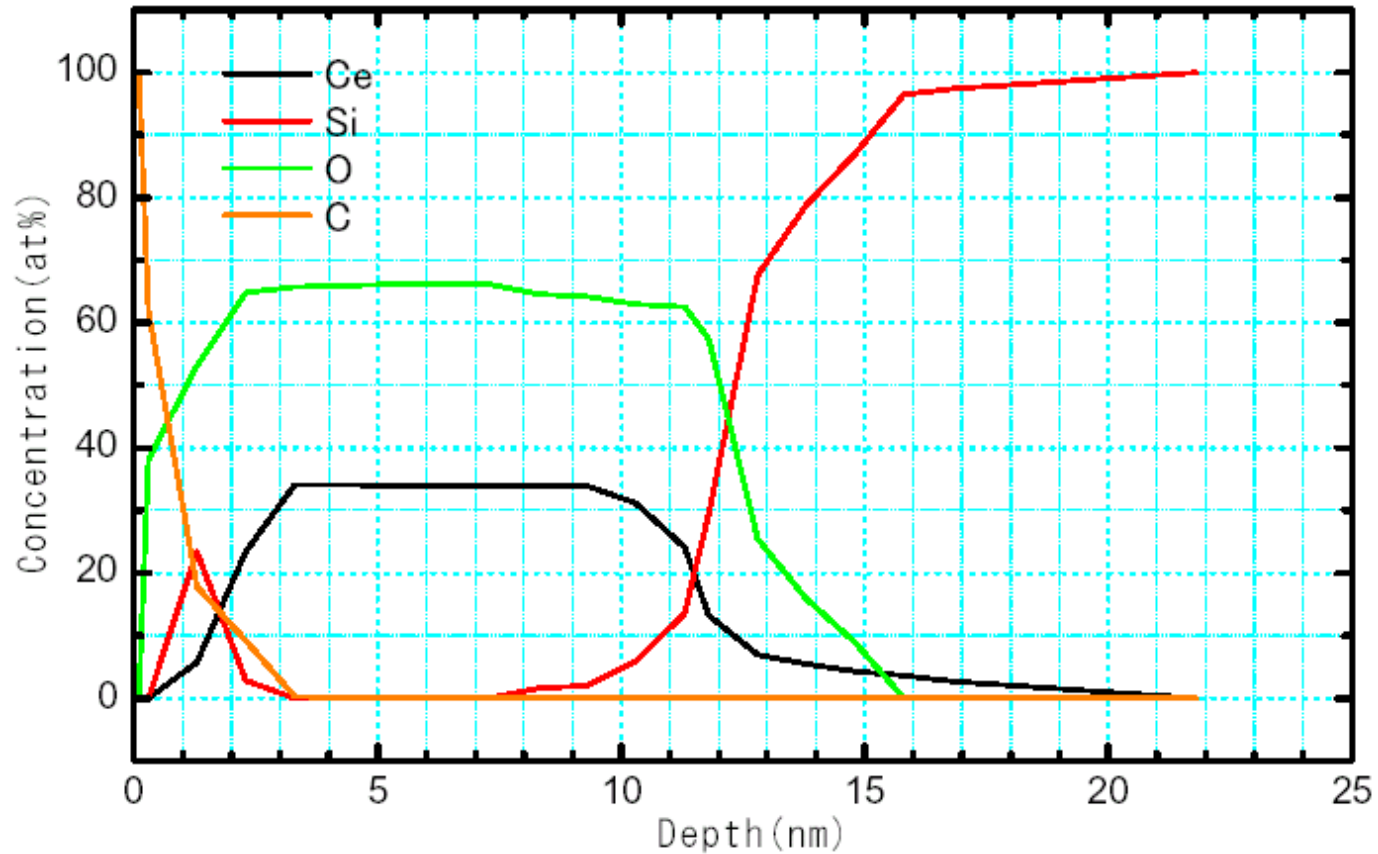
Potency of SPring-8



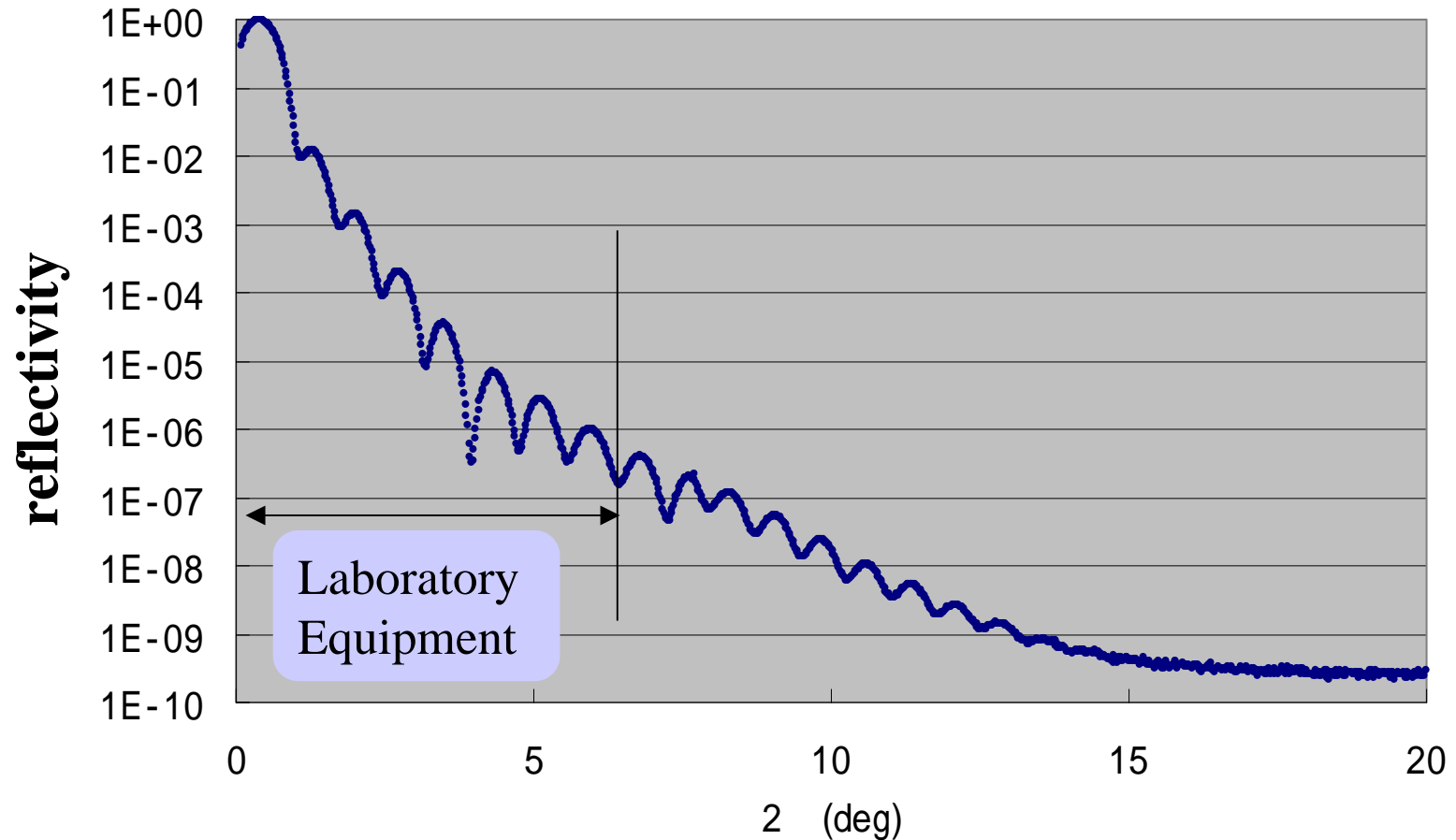
Cross Sectional TEM Image



Depth Profiling by HR-RBS



X-Ray Reflectivity Curve

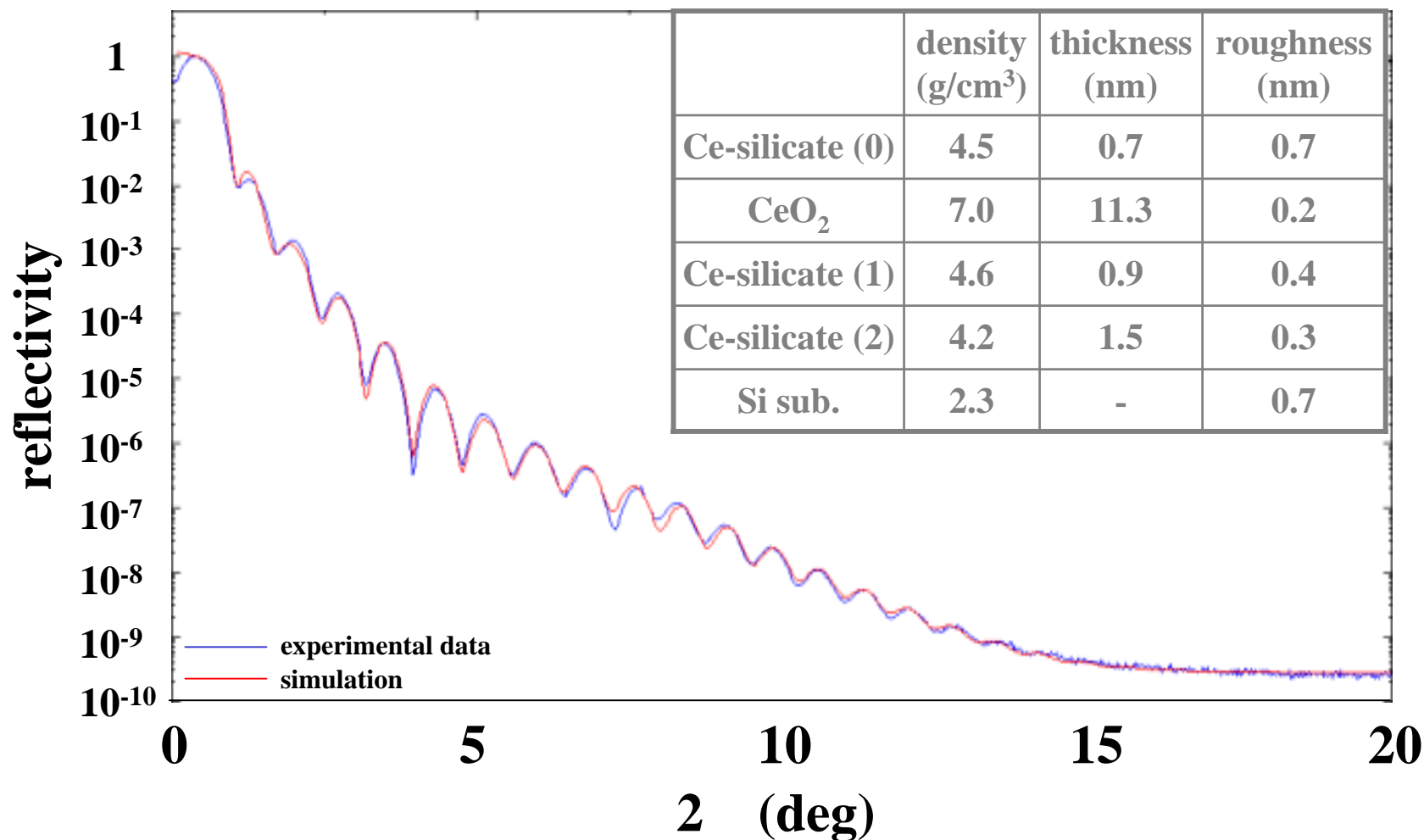


Analysis (Fitting) Procedure

- **Reflectivity Curve Oscillation**
TFT Film Thickness
- **Layer Model (from TFT, TEM & HR-RBS) Fitting**
- **Change Model Fitting : Repeat**

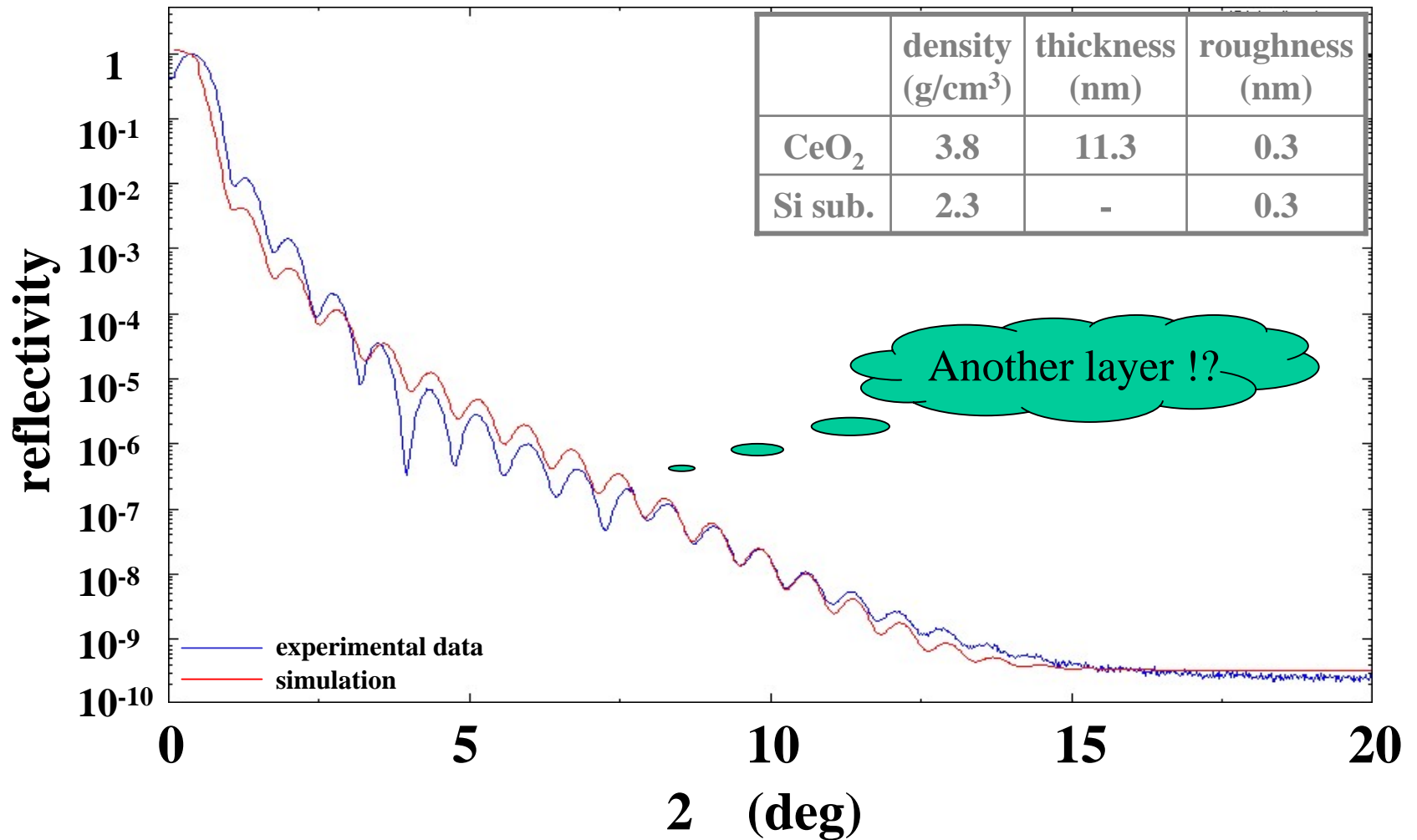
fitting

Ce-silicate / CeO₂ / Ce-silicate / Si

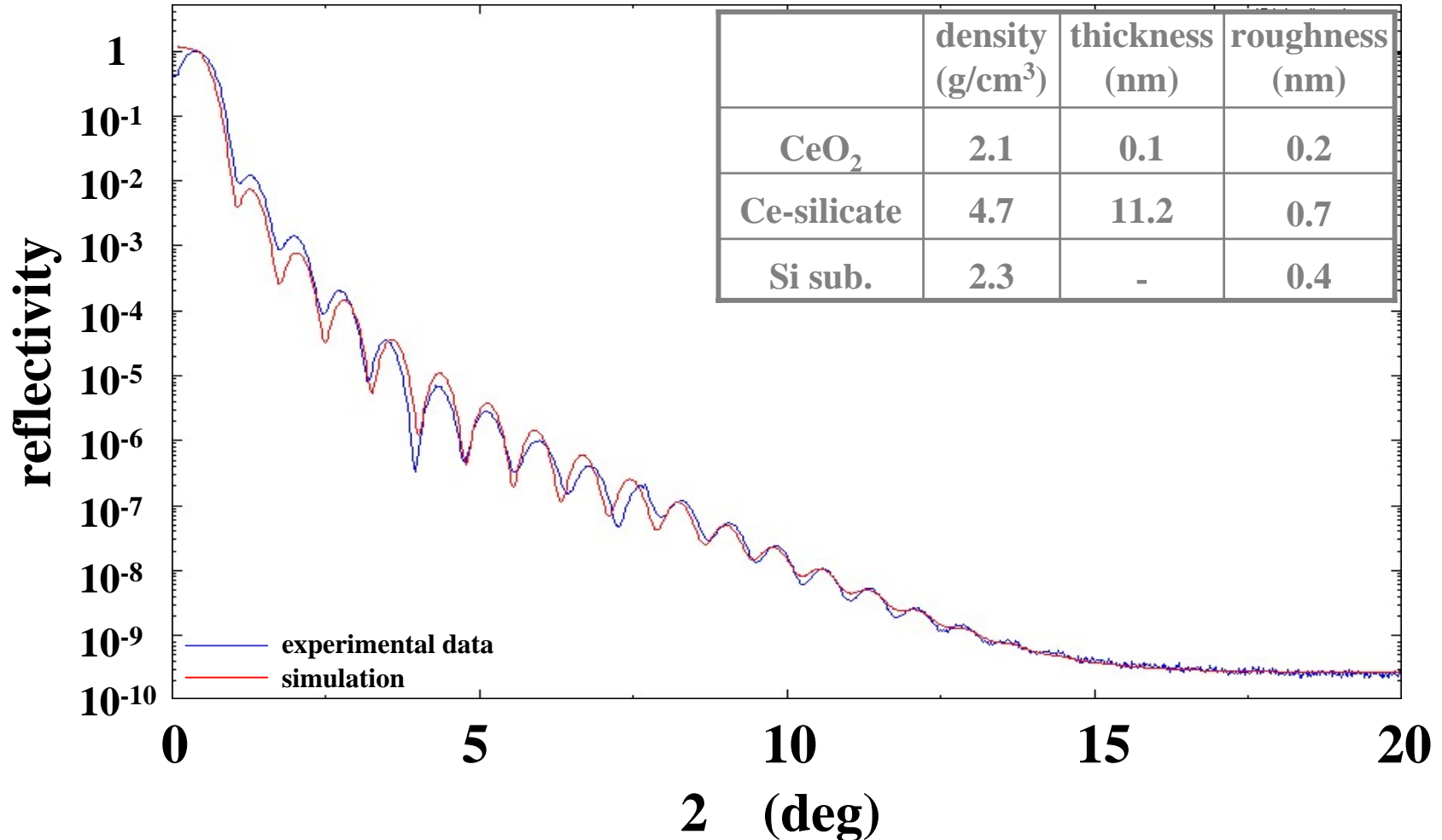


CeO₂ / Si

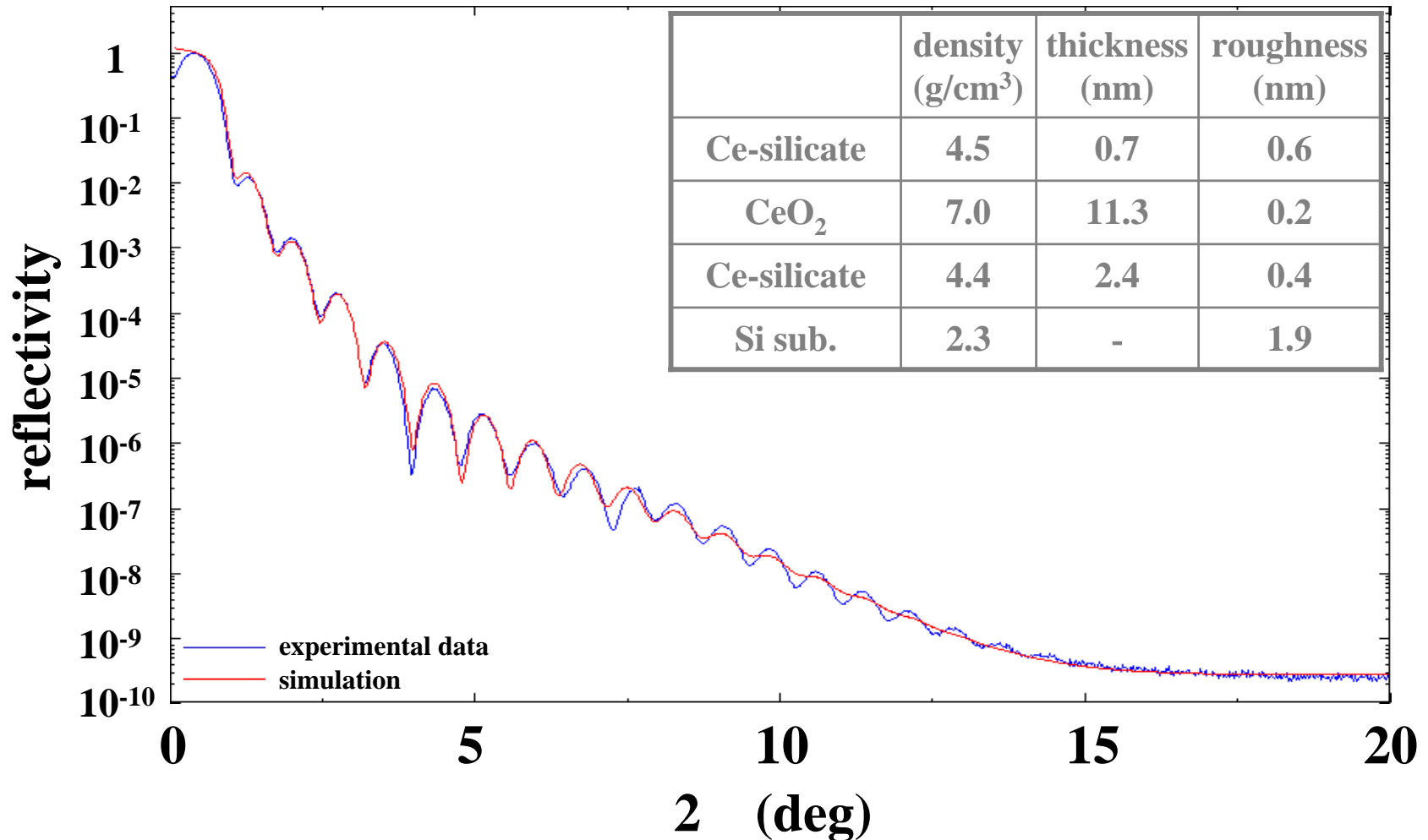
	density (g/cm ³)	thickness (nm)	roughness (nm)
CeO ₂	3.8	11.3	0.3
Si sub.	2.3	-	0.3



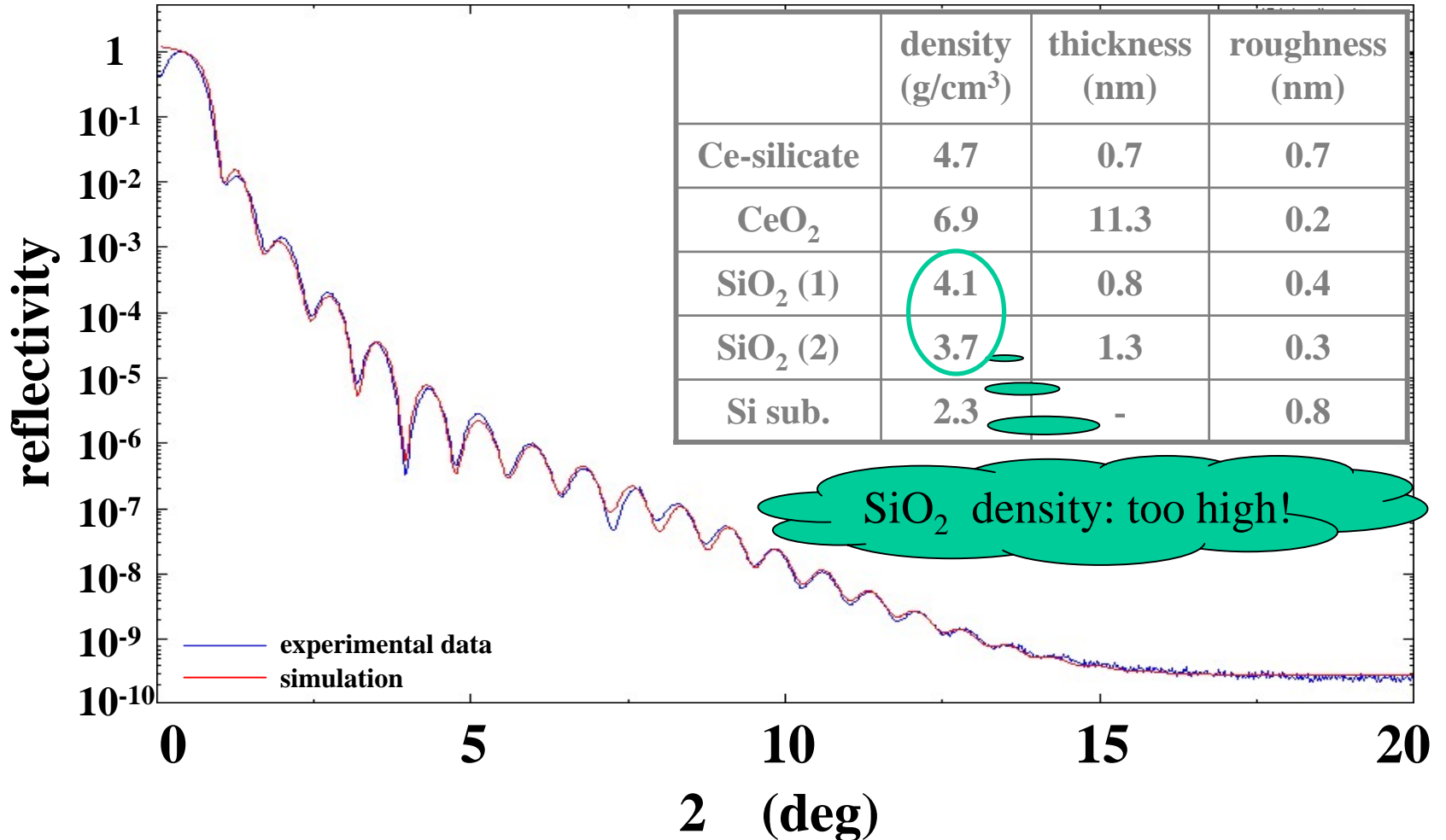
CeO₂ / Ce-silicate / Si (no density distribution)



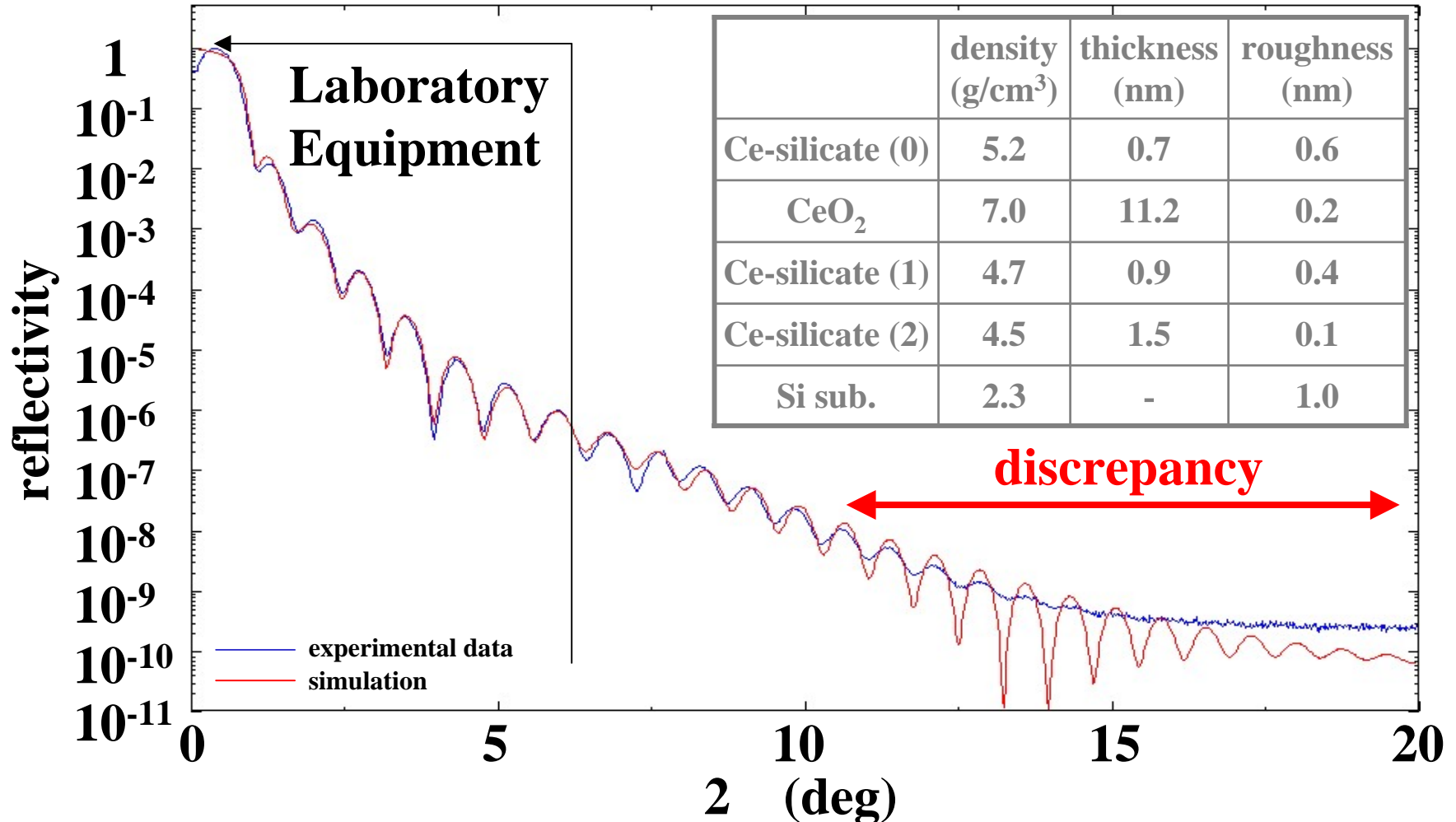
Ce-silicate / CeO₂ / Ce-silicate / Si (no density distribution)



Ce-silicate / CeO₂ / SiO₂ / Si



Fitting : Laboratory Equipment Data



Comparison

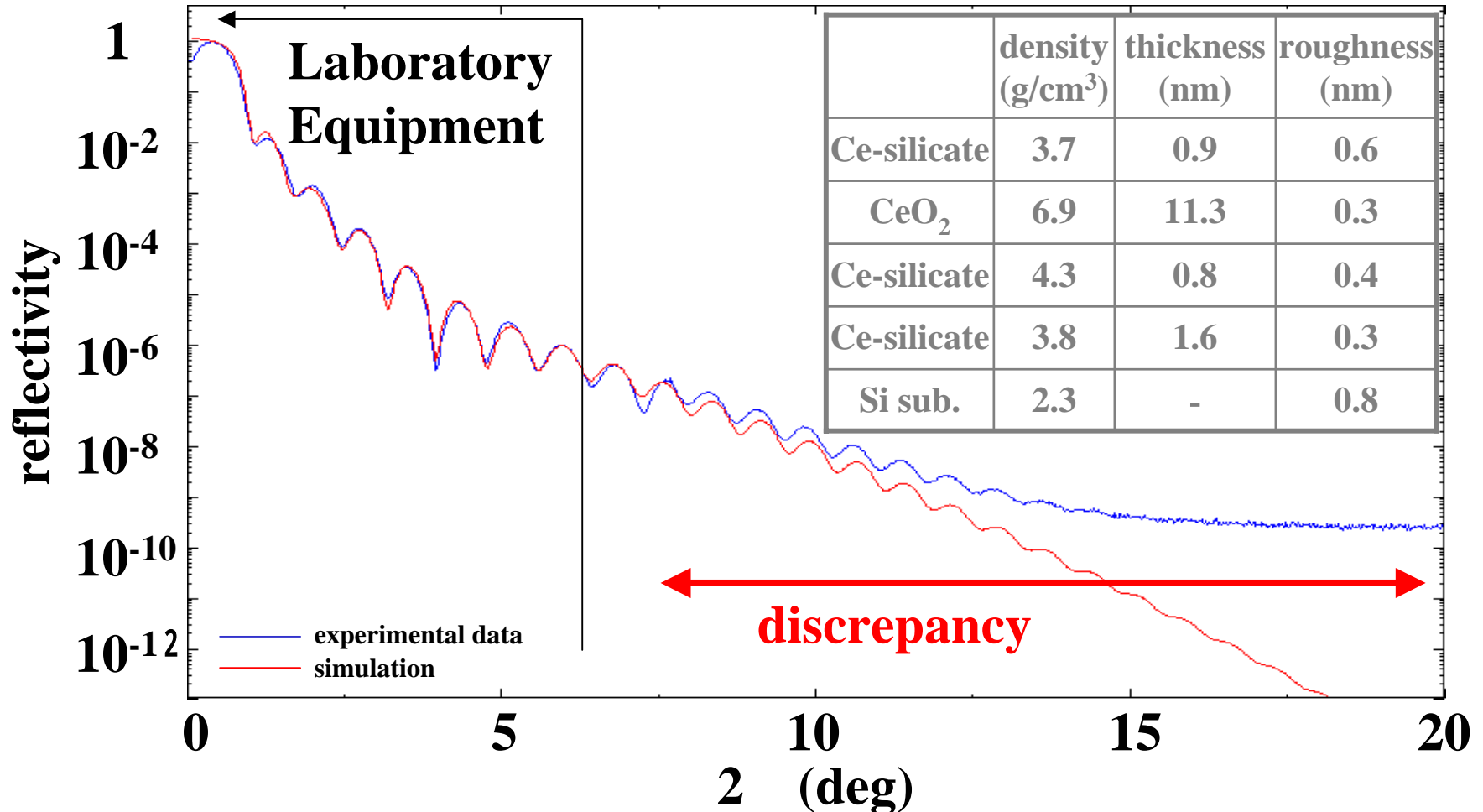
Spring-8

	density (g/cm ³)	thickness (nm)	roughness (nm)
Ce-silicate (0)	4.5	0.7	0.7
CeO ₂	7.0	11.3	0.2
Ce-silicate (1)	4.6	0.9	0.4
Ce-silicate (2)	4.2	1.5	0.3
Si sub.	2.3	-	0.7

Laboratory
Equipment

	density (g/cm ³)	thickness (nm)	roughness (nm)
Ce-silicate (0)	5.2	0.7	0.6
CeO ₂	7.0	11.2	0.2
Ce-silicate (1)	4.7	0.9	0.4
Ce-silicate (2)	4.5	1.5	0.1
Si sub.	2.3	-	1.0

Fitting : Laboratory Equipment Data



Comparison

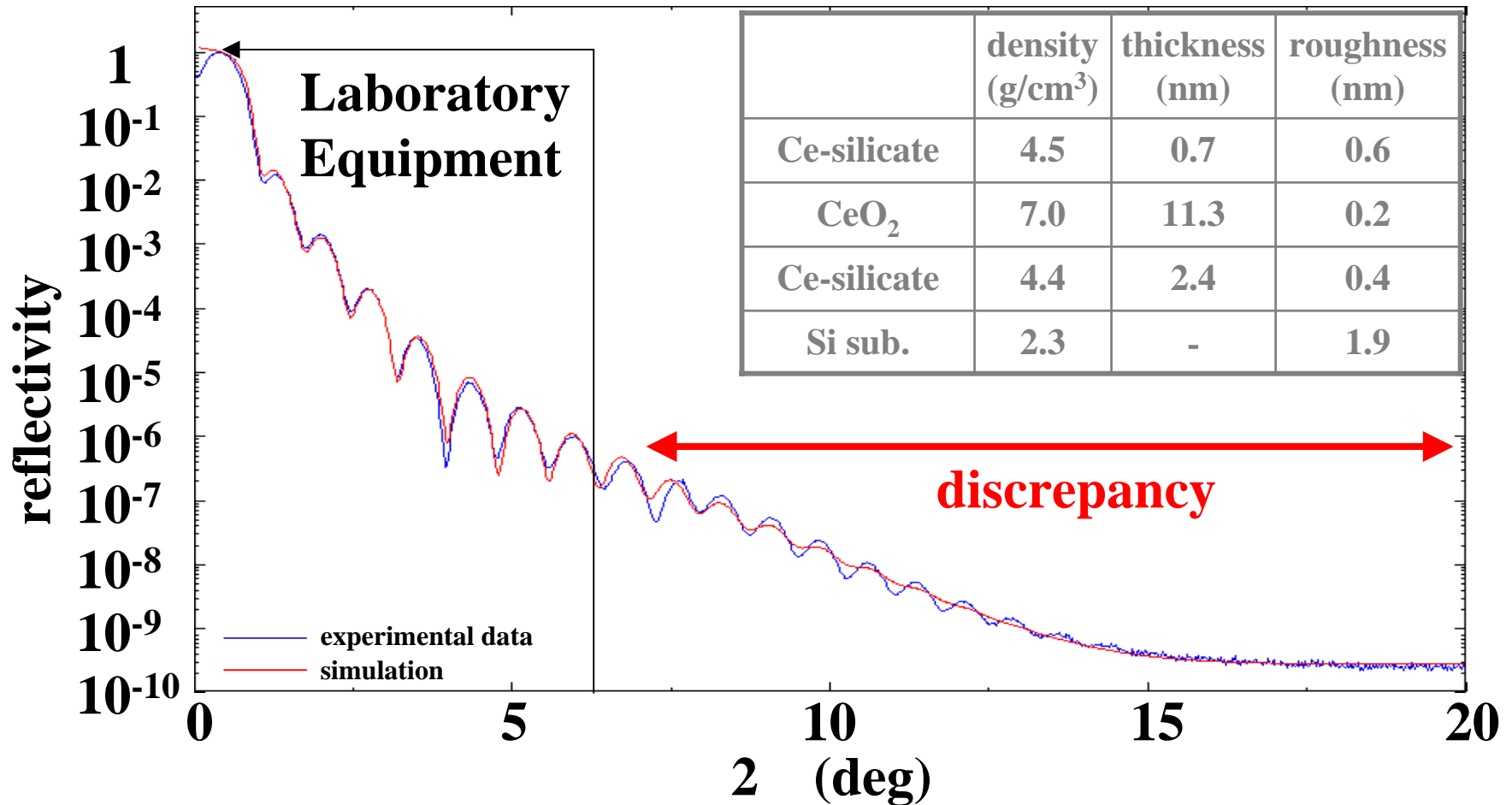
Spring-8

	density (g/cm ³)	thickness (nm)	roughness (nm)
Ce-silicate (0)	4.5	0.7	0.7
CeO ₂	7.0	11.3	0.2
Ce-silicate (1)	4.6	0.9	0.4
Ce-silicate (2)	4.2	1.5	0.3
Si sub.	2.3	-	0.7

Laboratory
Equipment

	density (g/cm ³)	thickness (nm)	roughness (nm)
Ce-silicate (0)	3.7	0.9	0.6
CeO ₂	6.9	11.3	0.3
Ce-silicate (1)	4.3	0.8	0.4
Ce-silicate (2)	3.8	1.6	0.3
Si sub.	2.3	-	0.8

Fitting : Laboratory Equipment Data



Comparison

Spring-8

	density (g/cm ³)	thickness (nm)	roughness (nm)
Ce-silicate (0)	4.5	0.7	0.7
CeO ₂	7.0	11.3	0.2
Ce-silicate (1)	4.6	0.9	0.4
Ce-silicate (2)	4.2	1.5	0.3
Si sub.	2.3	-	0.7

Laboratory
Equipment

	density (g/cm ³)	thickness (nm)	roughness (nm)
Ce-silicate (0)	4.5	0.7	0.6
CeO ₂	7.0	11.3	0.2
Ce-silicate (1)	4.4	2.4	0.4
Si sub.	2.3	-	1.9

Result

	density (g/cm ³)	thickness (nm)	roughness (nm)
Ce-silicate (0)	4.5	0.7	0.7
CeO ₂	7.0	11.3	0.2
Ce-silicate (1)	4.6	0.9	0.4
Ce-silicate (2)	4.2	1.5	0.3
Si sub.	2.3		0.7

Interfacial
Layer

Density
Distribution

Summary

- **Interfacial layer (between CeO₂ and Si substrate) was Ce-silicate**
- **The silicate layer has density distribution across the thickness (upper side > lower side)**
- **Layer with lower density existed on the CeO₂ layer Ce-silicate**