Crystallographic Characterization of Poly-Si Thin Films

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Poly-Si has been used as a gate electrode material for many years on CMOS LSIs. As smaller and smaller LSIs continue to be designed, even a minor difference in the crystal structure affects the electric property of MOS transistor. The typical thickness of gate poly-Si films is about 200nm in 0.18μm rule LSIs. Normally, the poly-Si grains are around the same order of thickness, and there are cases where a grain becomes a single crystal from the bottom to the top of film. In this case, the Boron penetration effect, which is a serious problem in making LSIs, can easily occur due to ion channeling during ion implantation. To avoid this effect, gate poly-Si films are made of double poly-Si layers. It is necessary to analyze the crystal structure of each layer of the double poly-Si layer. In this experiment, to evaluate the characteristics of the crystal structure near the surface, we examined a test sample of an amorphous-Si/poly-Si double layer film on Si wafer. The in-plane X-ray diffraction was applied. The incident X-ray energy was 10.0keV. Figure 1 shows the in-plane diffraction patterns of the amorphous-Si/poly-Si double layer film. The thickness of each layer was the same as 100nm of amorphous-Si and poly-Si. In the ω =0.180 degree case, the diffraction pattern has only an amorphous-Si structure. In the ω=0.190degree case, the diffraction pattern has mainly a poly-Si structure. From these results, it has been shown that it is possible to evaluate crystal structures of poly-Si thin films in the depth direction by precise control in incident angle.

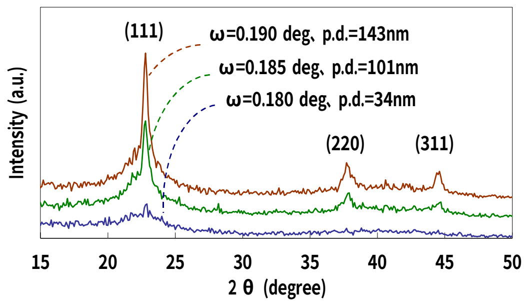

Fig. 1 In-plane XD spectra for amorphous-Si/ Poly-Si double layer film with various incident angles.

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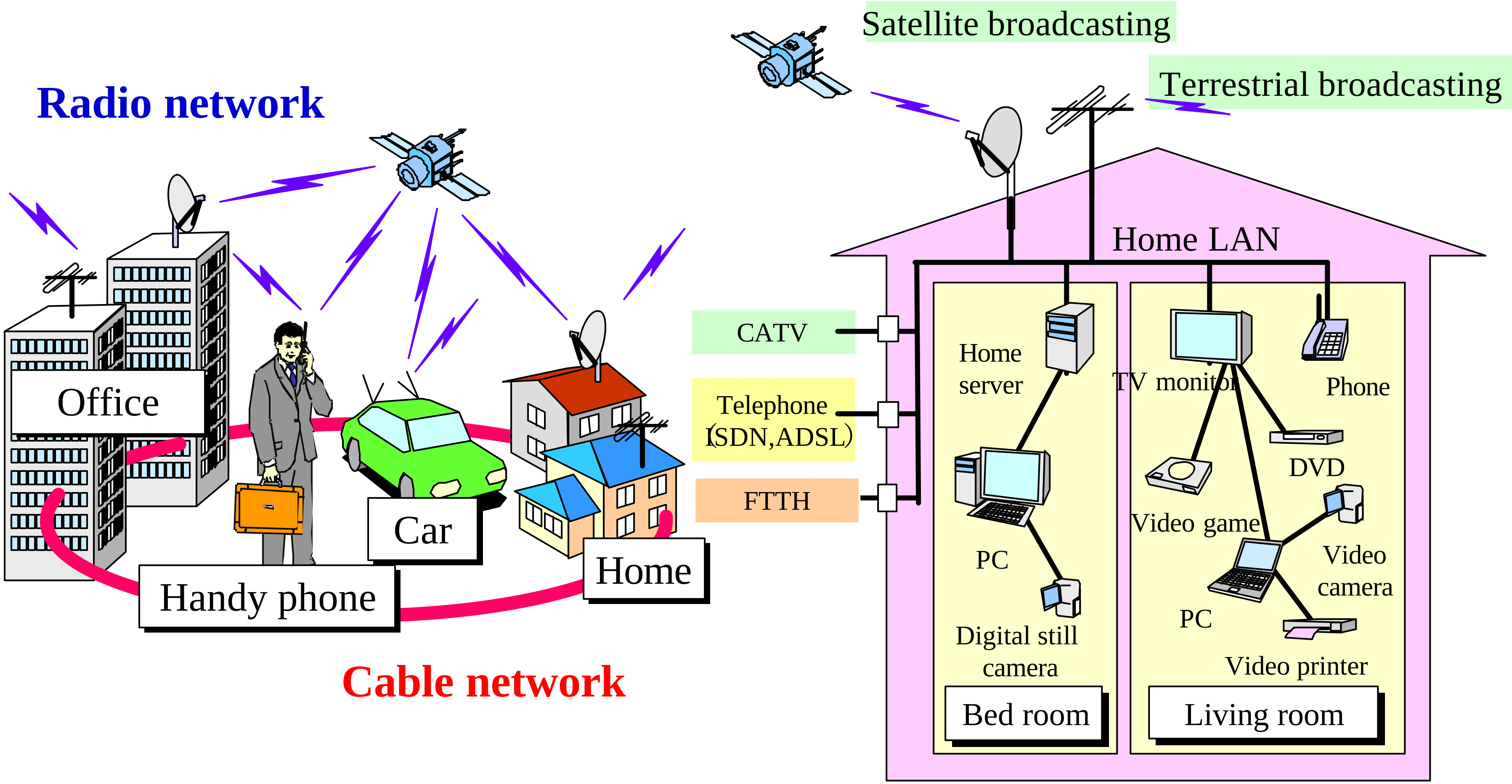
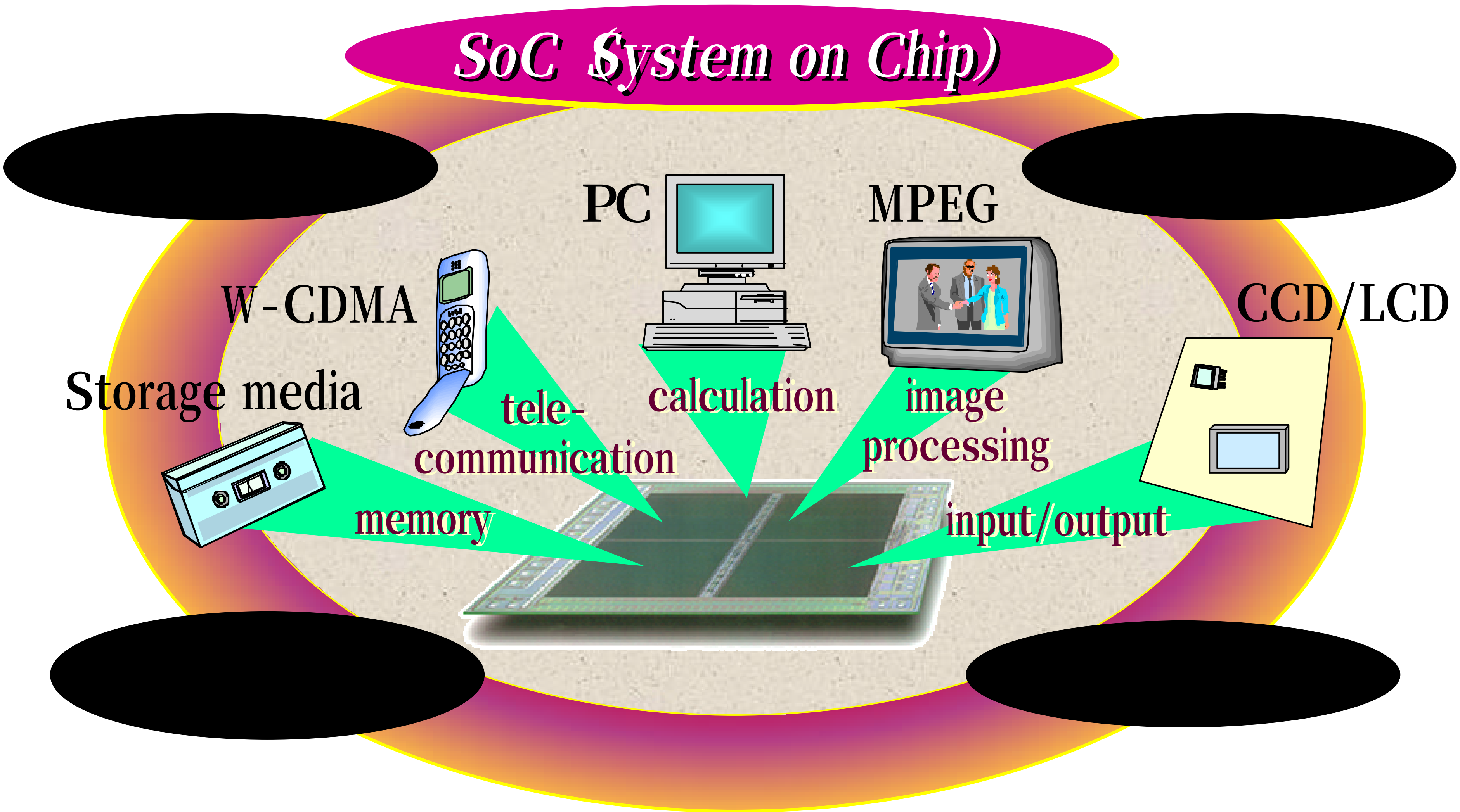
Digital network world



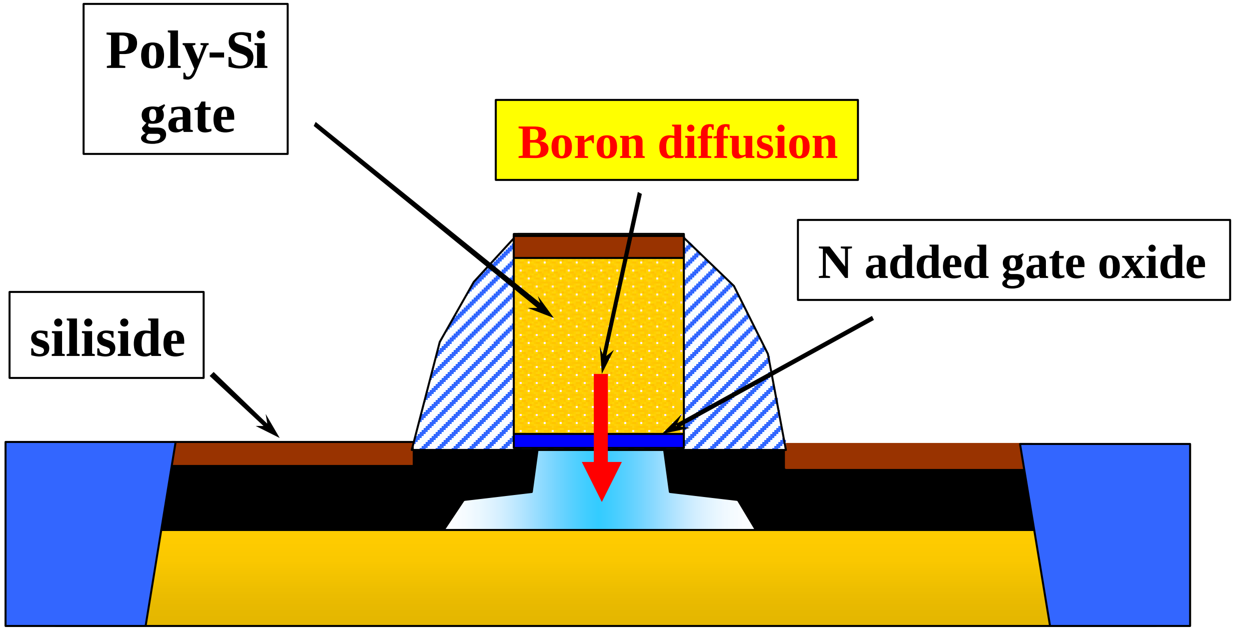
Key technology for system LSI



Requirement for LSI analysis

ITRS2002 road map

Year of production	2001	2004	2007	2010	2013	2016
DRAM 1/2 pitch(nm)	130	90	65	45	32	22
Critical perticle size(nm)	43	24	17	12	9	6
Junction depth(nm)	27	15	10	7	5	4
Void size in Cu lines(nm)	32.5	22.5	16.25	11.25	8	5.5



Analytical technique for LSI development

View	SEM, TEM, AFM
Element	**XRF**, SIMS, EPMA, AES
Structure	**XRD**, **XAFS**
Thickness	**XRR** , Ellipsometory

Make precise analytical technique using SR

Crystallographic characterization of thin films

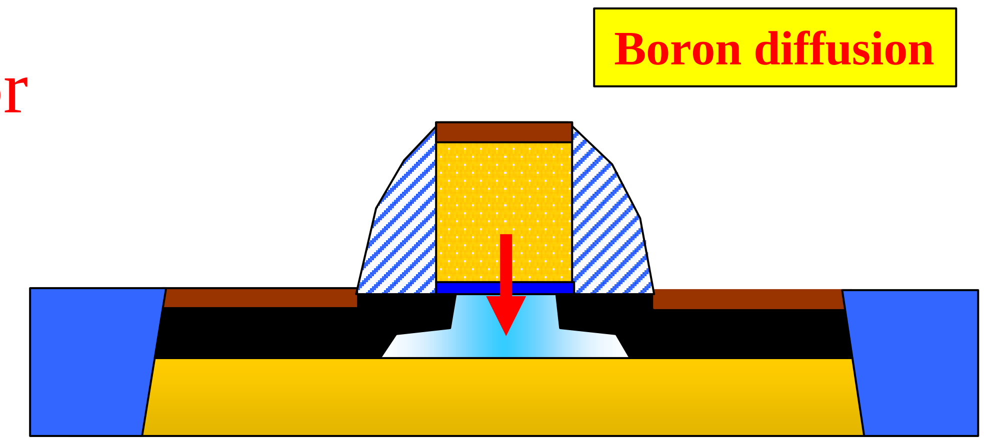
Shrinkage of MOS-Tr ⇒ Boron diffusion problem

Prevent Boron diffusion ⇒ Double Poly-Si layer

Analyze crystallographic structure of thin Poly-Si films along depth direction

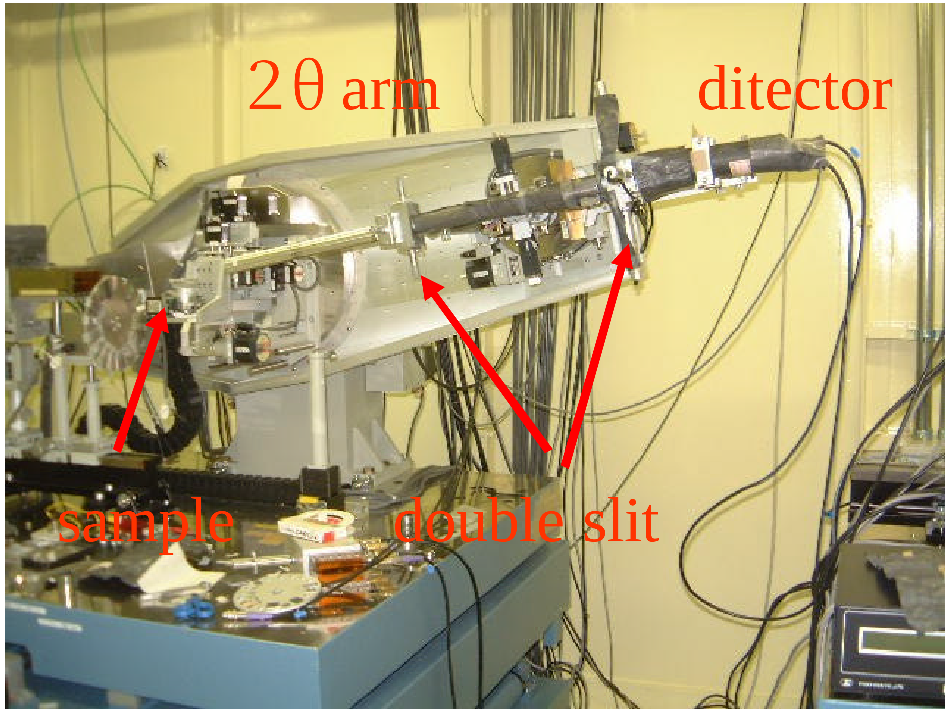
⇒ use X-ray diffractmetor

of BL16XU

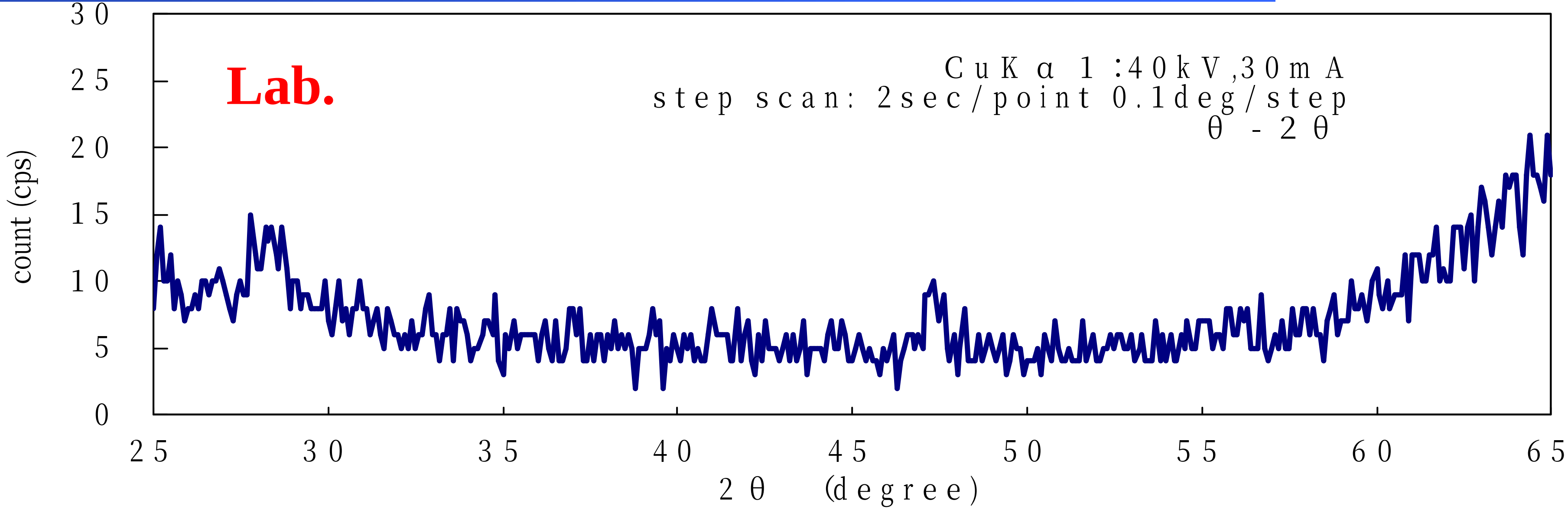


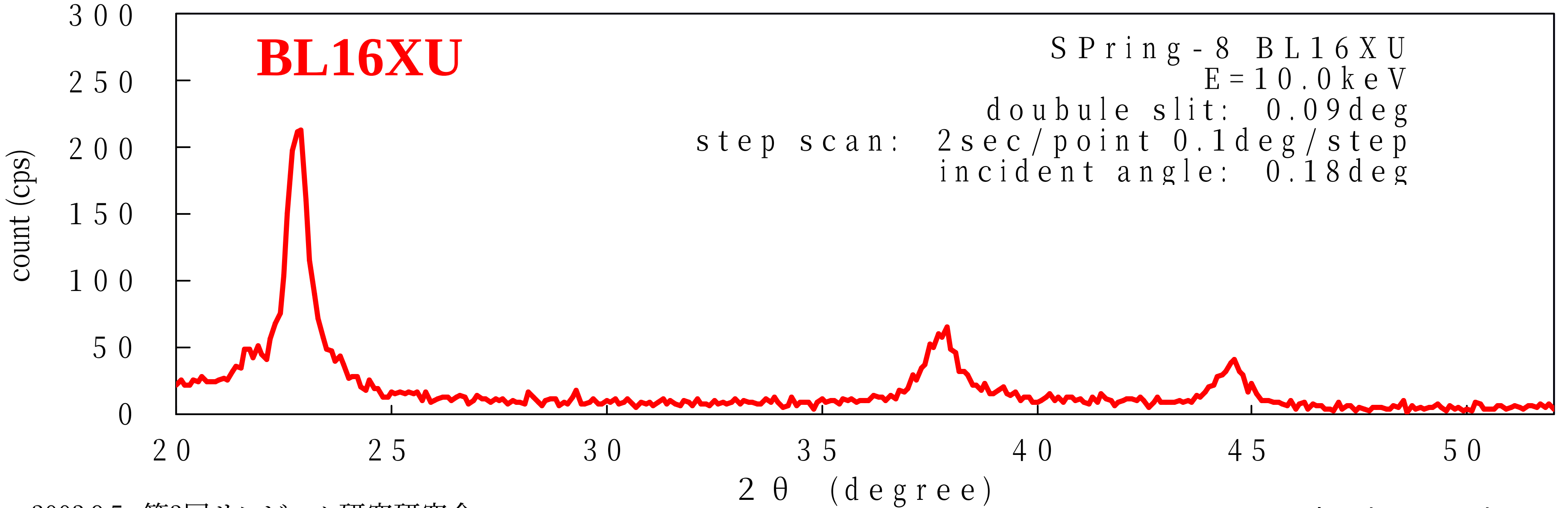
BL16XU XRD

- Parallel beam
- Small size in incident beam：**<0.2mm□**
- Energy of incident X-ray：**tunable**
- Intensity：**strong 3 order than rotation source**
- θ-2θ, thin film, in-plane

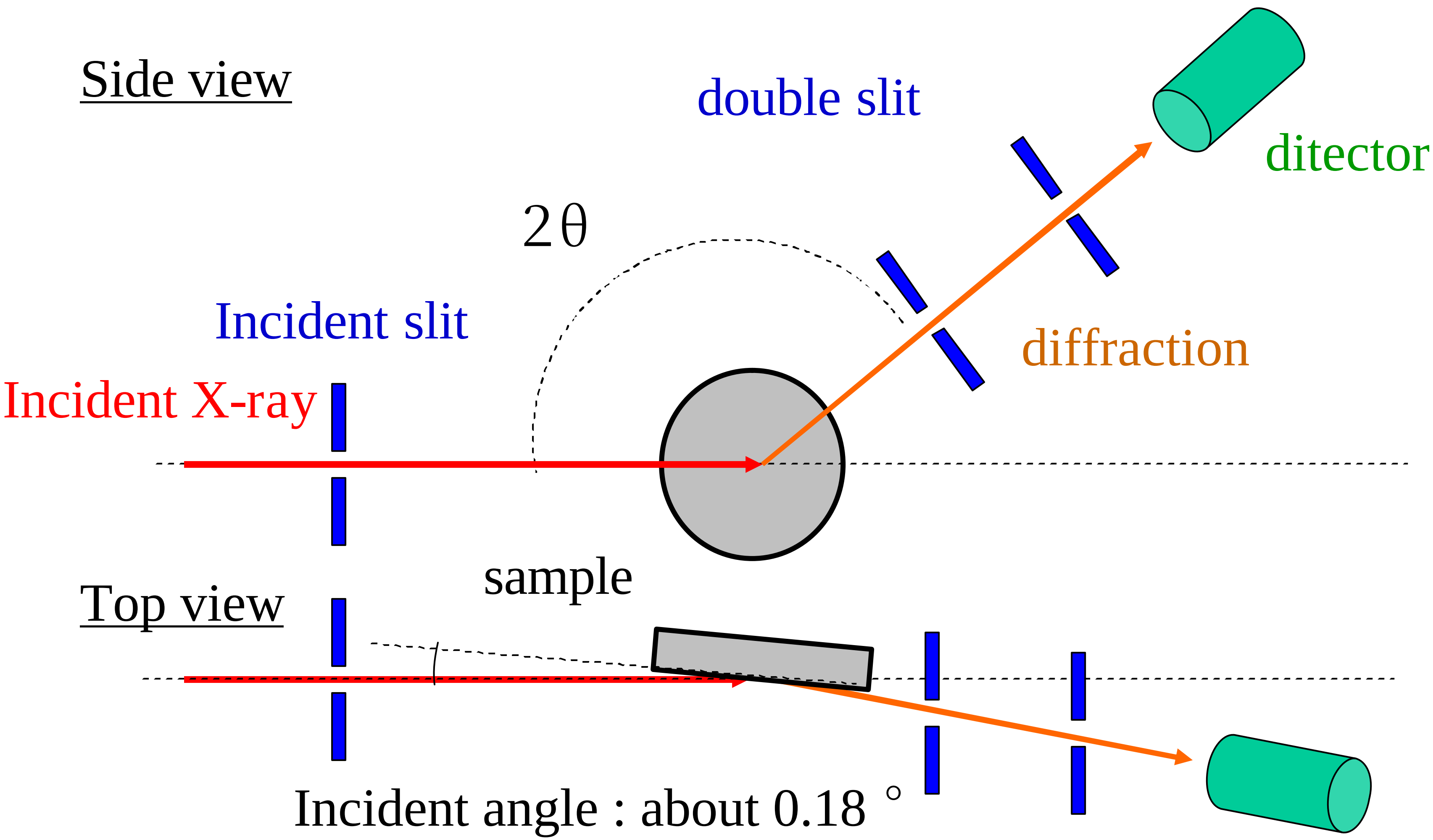


Poly-Si（50nm）diffraction





Layout of in-plane diffraction



Measurement condition

Incident X-ray

- Energy　　10.0KeV
- Beam size　　0.1mmW×0.2mmH

Sample setting

- Incident angle　　0.170～0.200 degree
  (precise angle control by tangent goniometer)
- sample sticking to stage by oil

Detection

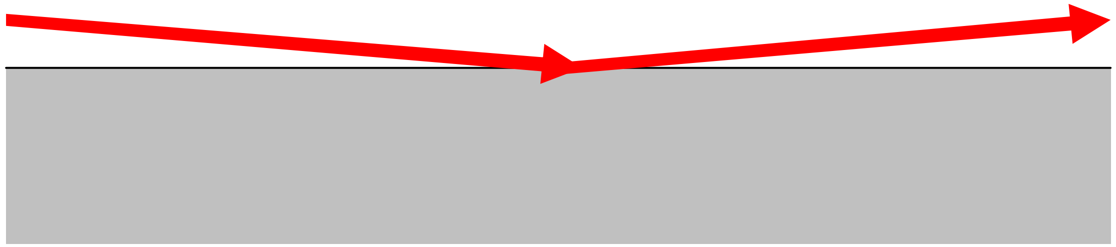
- Detector：　　Scintillation counter
- double slit　　1.0mm + 1.0mm　0.29°

Measurement mode

- 2θ scan　(θ fixed)

Total reflection on Si surface

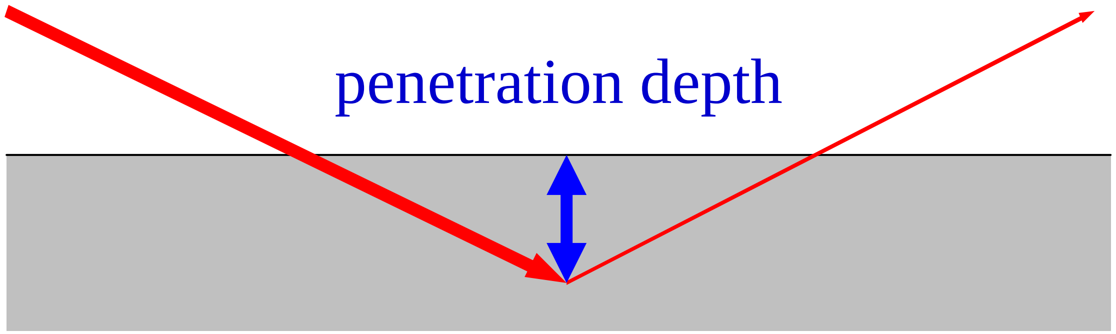
under critical angle



almost reflected by sample surface

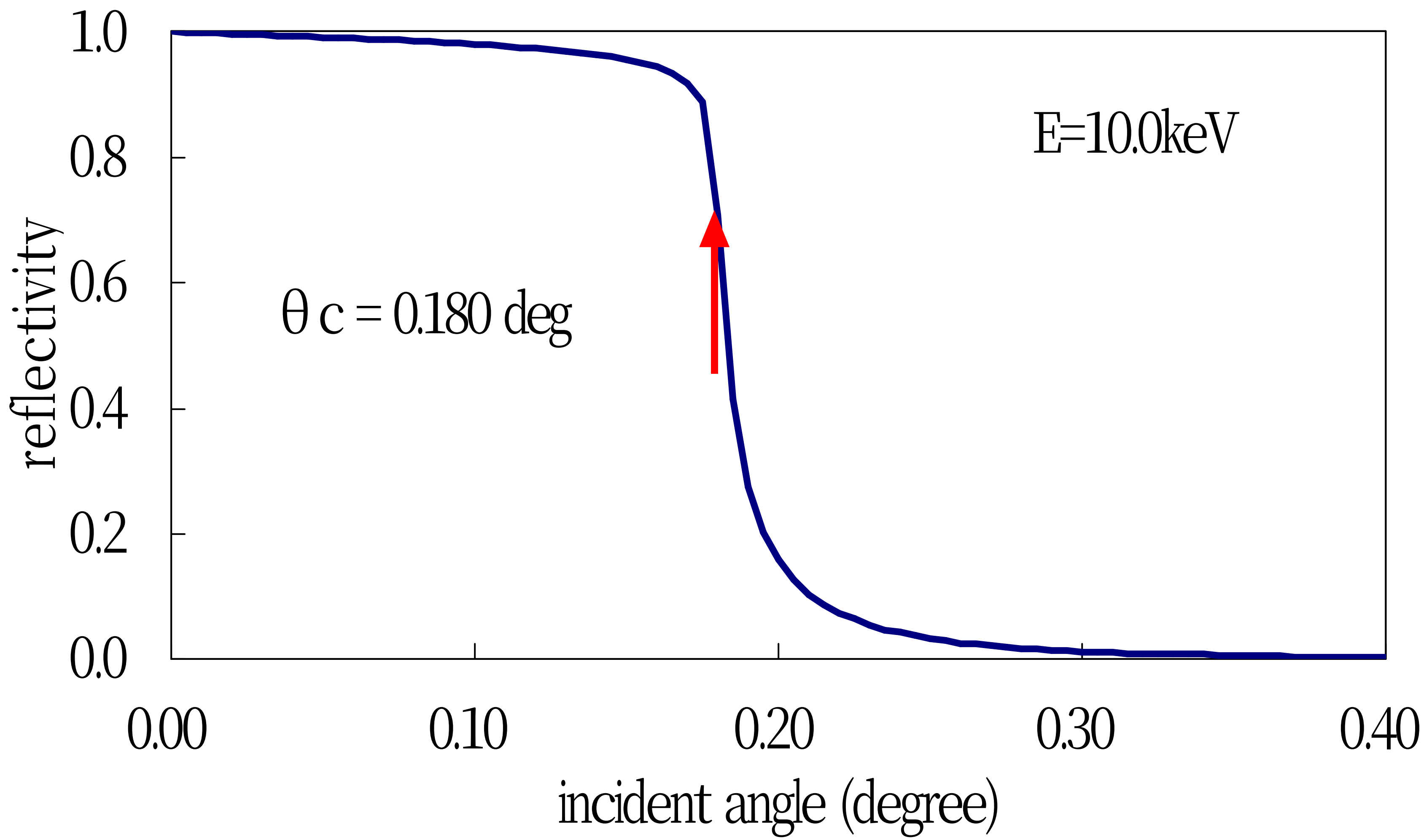
Need precise incident angle control
⇒ under 0.001 °

over critical angle

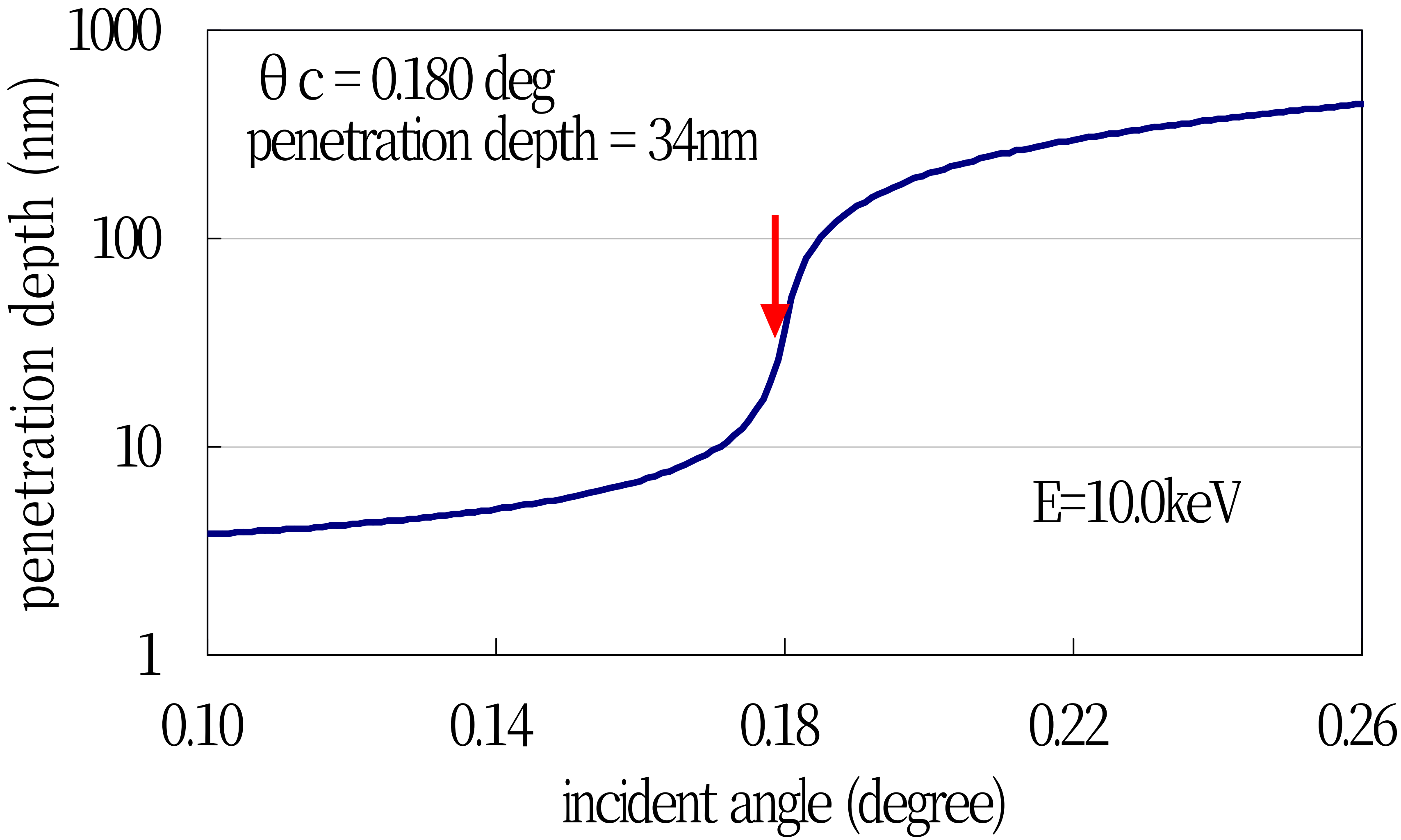


Penetrate into sample

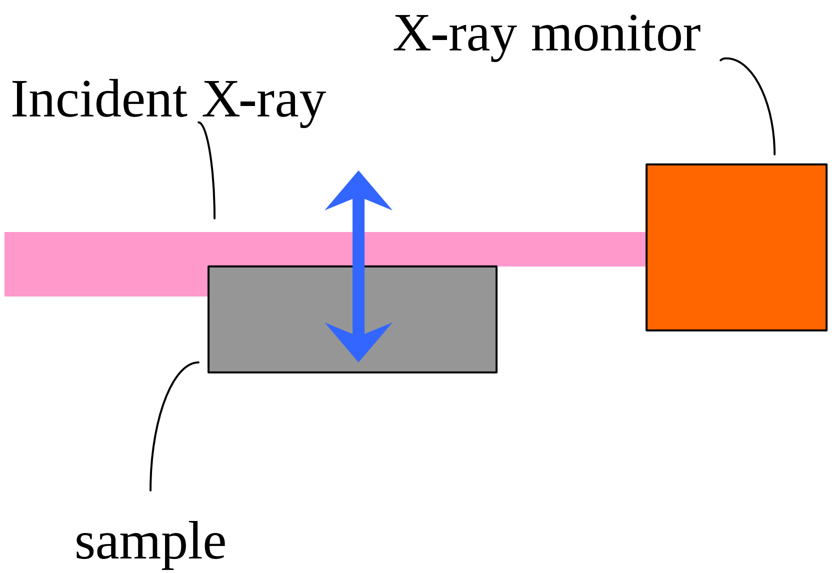
X-ray reflectivity of Si surface

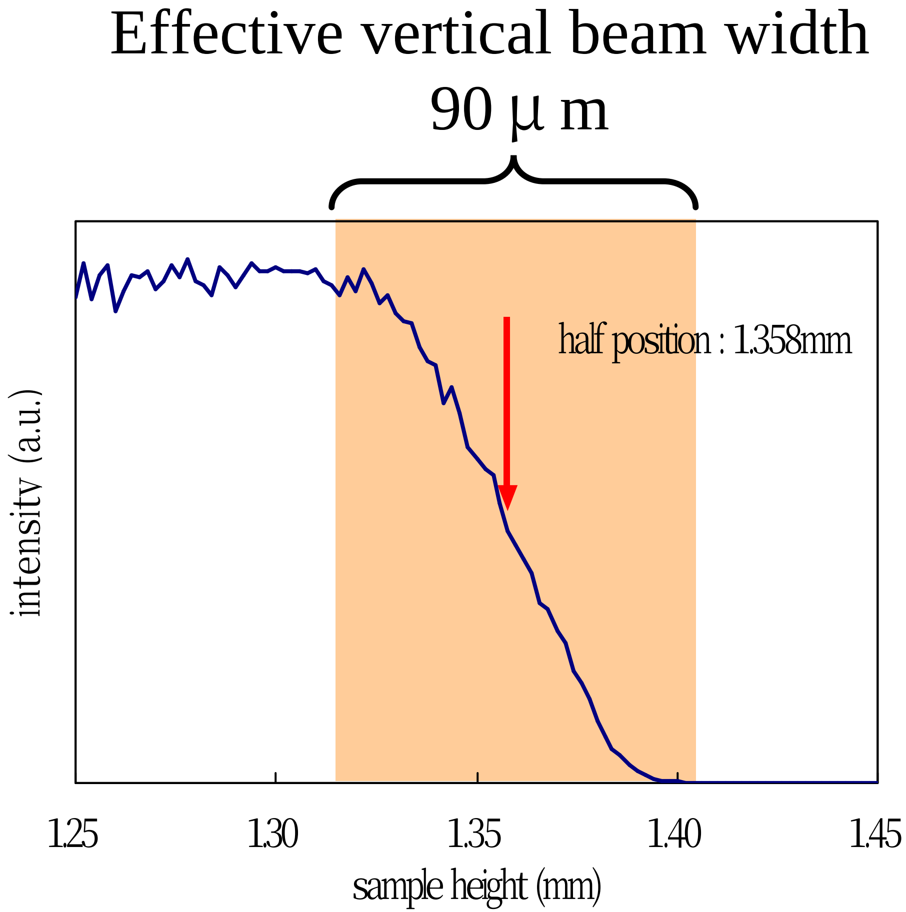


X-ray penetration depth into Si



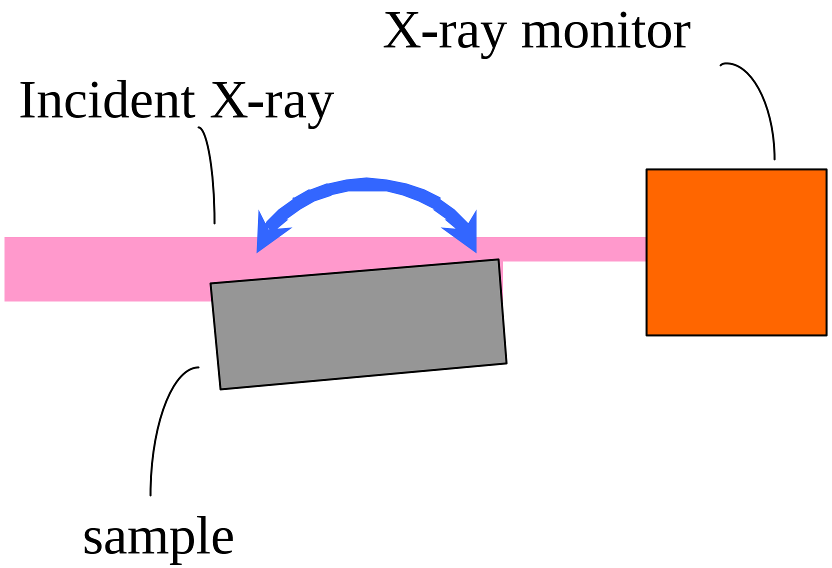
Sample setting accuracy (sample height)

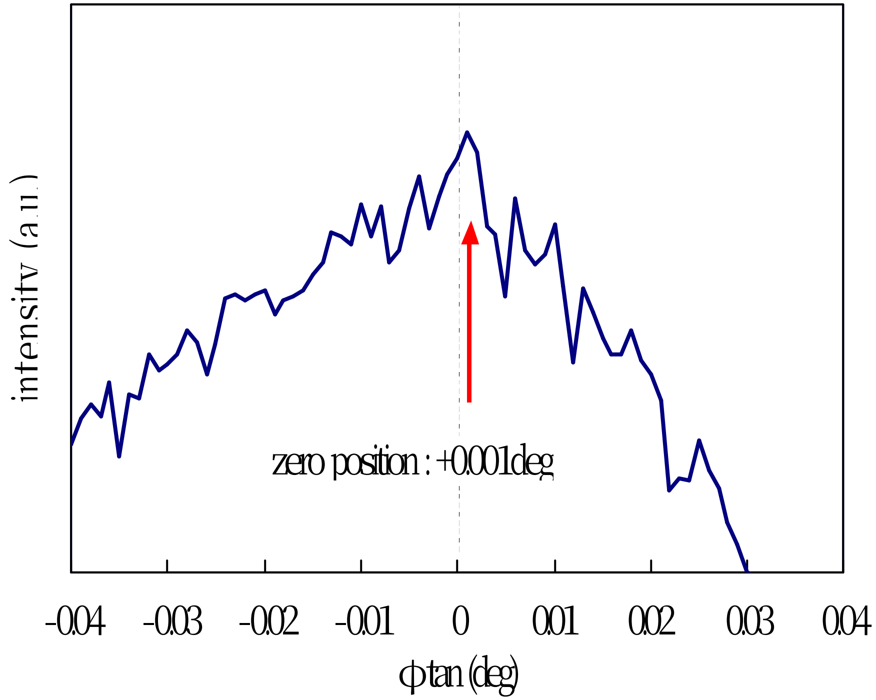




height accuracy : 1 μ m

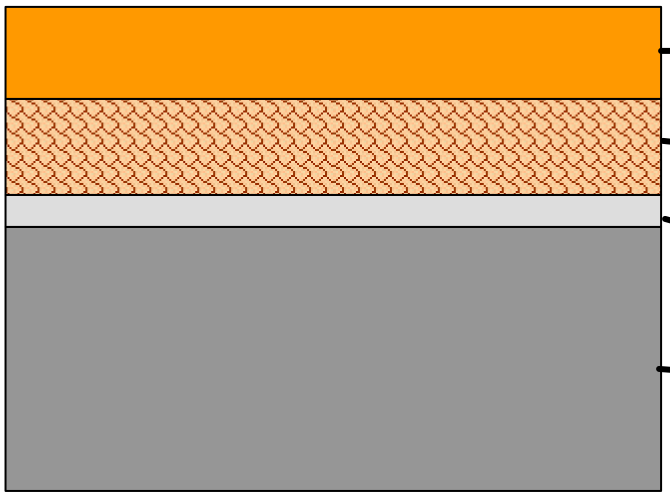
Sample setting accuracy (zero angle)



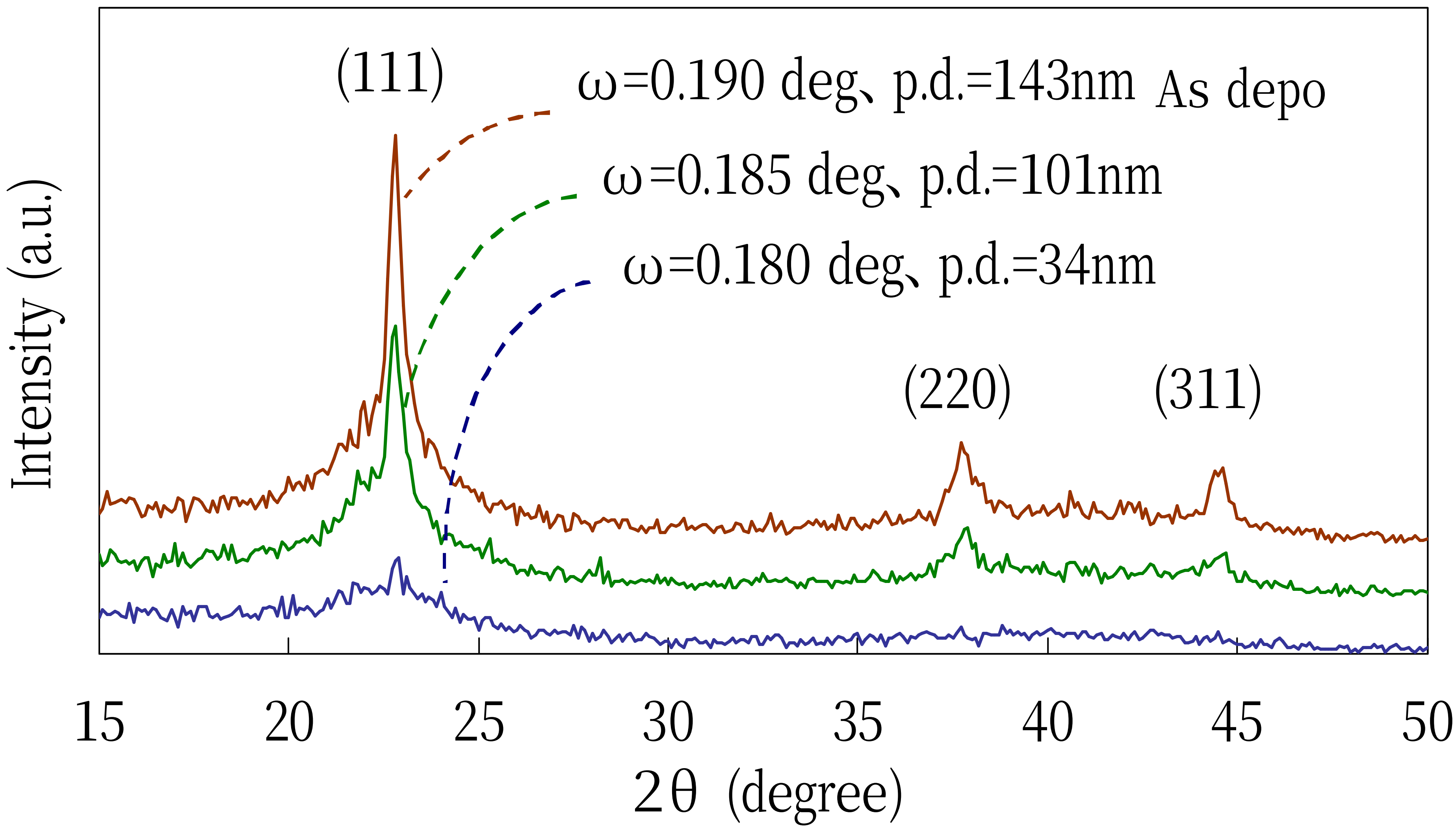


angle accuracy : 0.001°

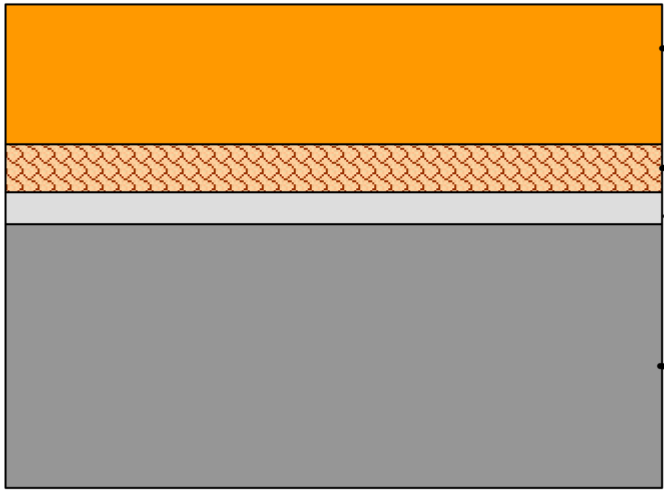
Test piece 1(Amo/Poly double layer)



Incident angle dependence

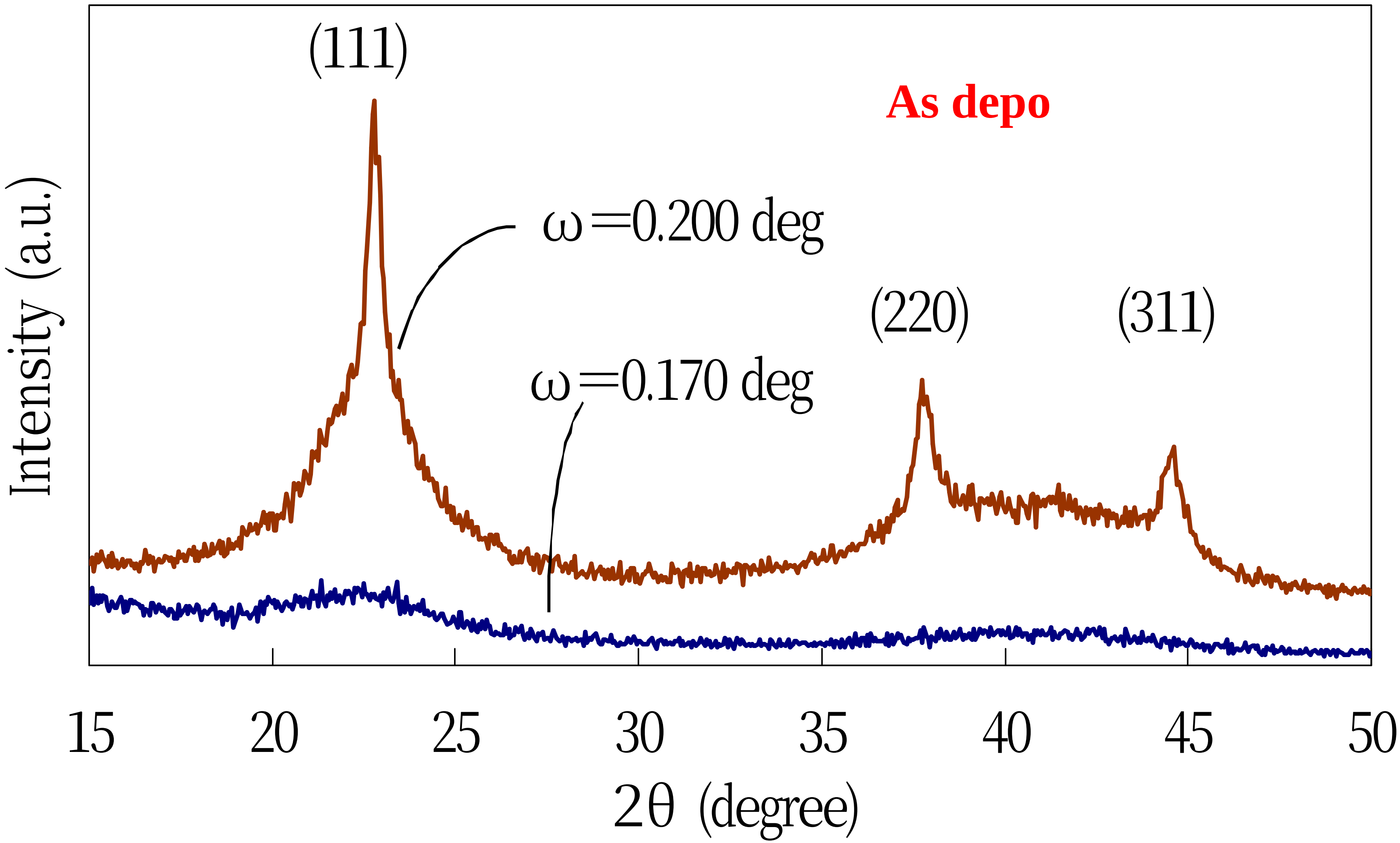


Test piece 2(Amo/Poly double layer)

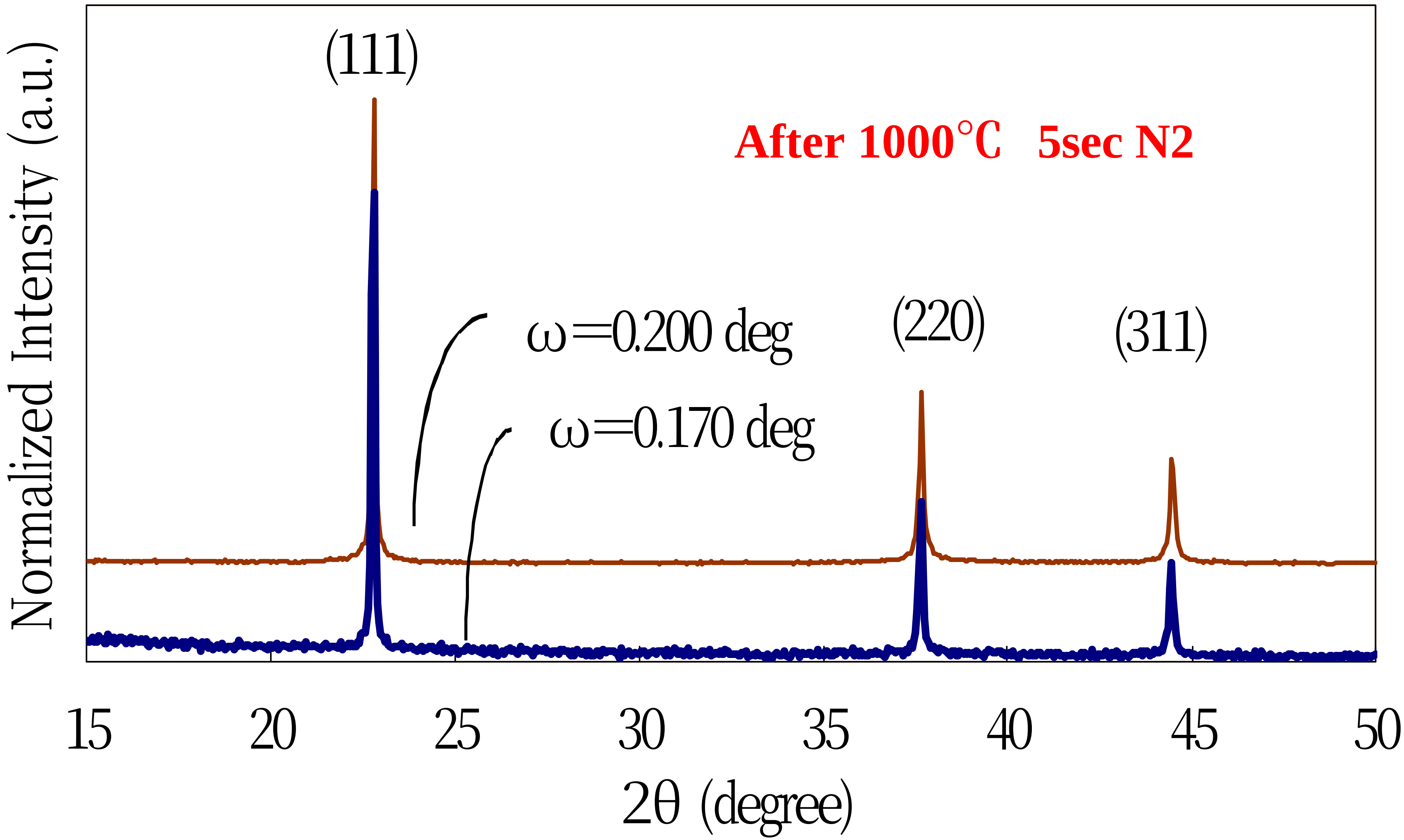


Thick amorphous Si layer to measure annealing effect

Crystallographic change by annealing



Crystallographic change by annealing



Crystallographic change by annealing

	Incident angle	Penetration depth	index					
			111		220		311	
			FWHM	grain size	FWHM	grain size	FWHM	grain size
as depo	0.170 °	9.5nm	---	---	---	---	---	---
	0.200 °	204nm	0.5 °	13nm	0.5 °	14nm	0.6 °	12nm
after anneal	0.170 °	9.5nm	**0.08 °**	**82nm**	**0.13 °**	**52nm**	**0.13 °**	**53nm**
	0.200 °	204nm	**0.08 °**	**82nm**	**0.13 °**	**52nm**	**0.14 °**	**49nm**

FWHMs of each index are almost same value after anneal treatment

⇒ change uniform crystallographic structure in depth direction

Summary

- High S/N in-plane XRD measurement for thin film is available using BL16XU XRD system.

- It is possible to evaluate crystal structures of poly-Si thin films in the depth direction by precise control in incident angle of 0.001°.

- Crystallographic characterization of SOI and epitaxial layer is next step.