

Atomic Layer Deposited (ALD) Al₂O₃ on Si

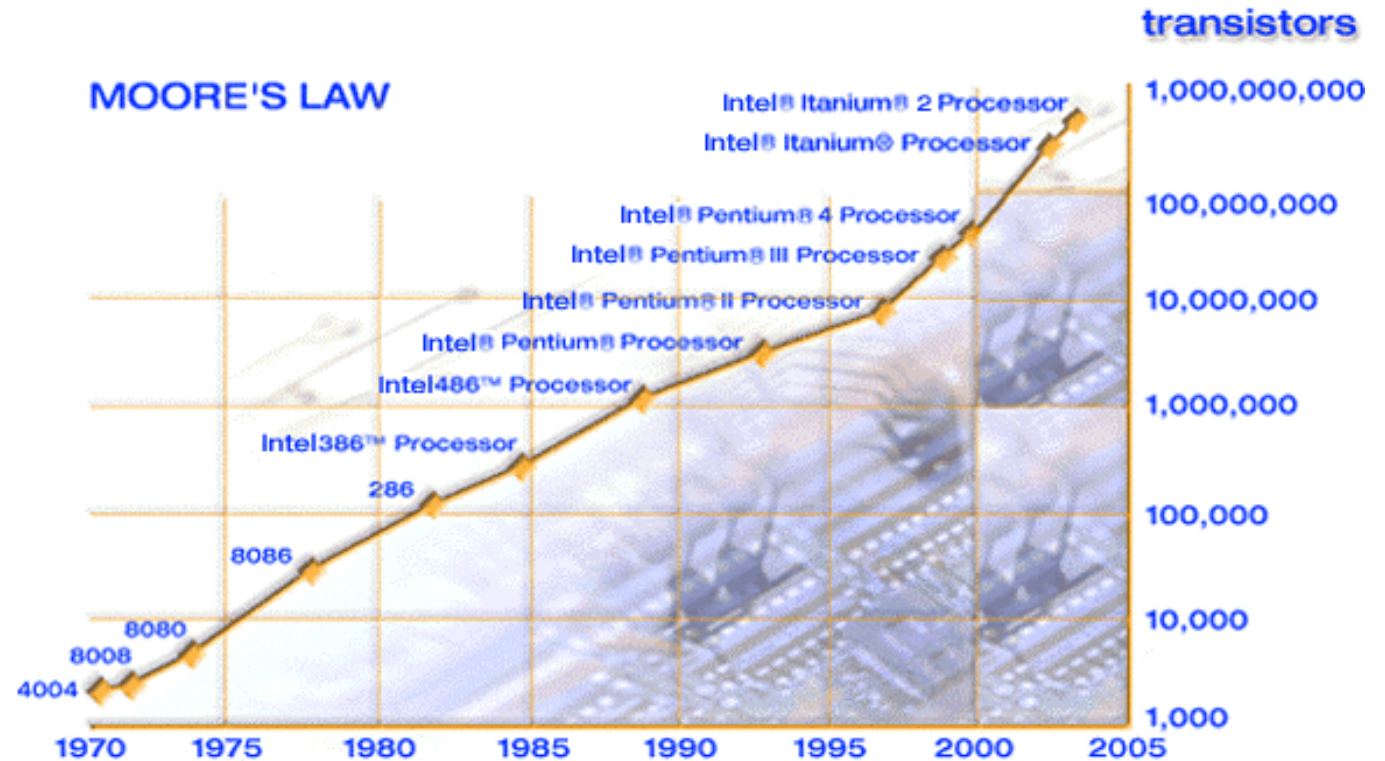
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Introduction

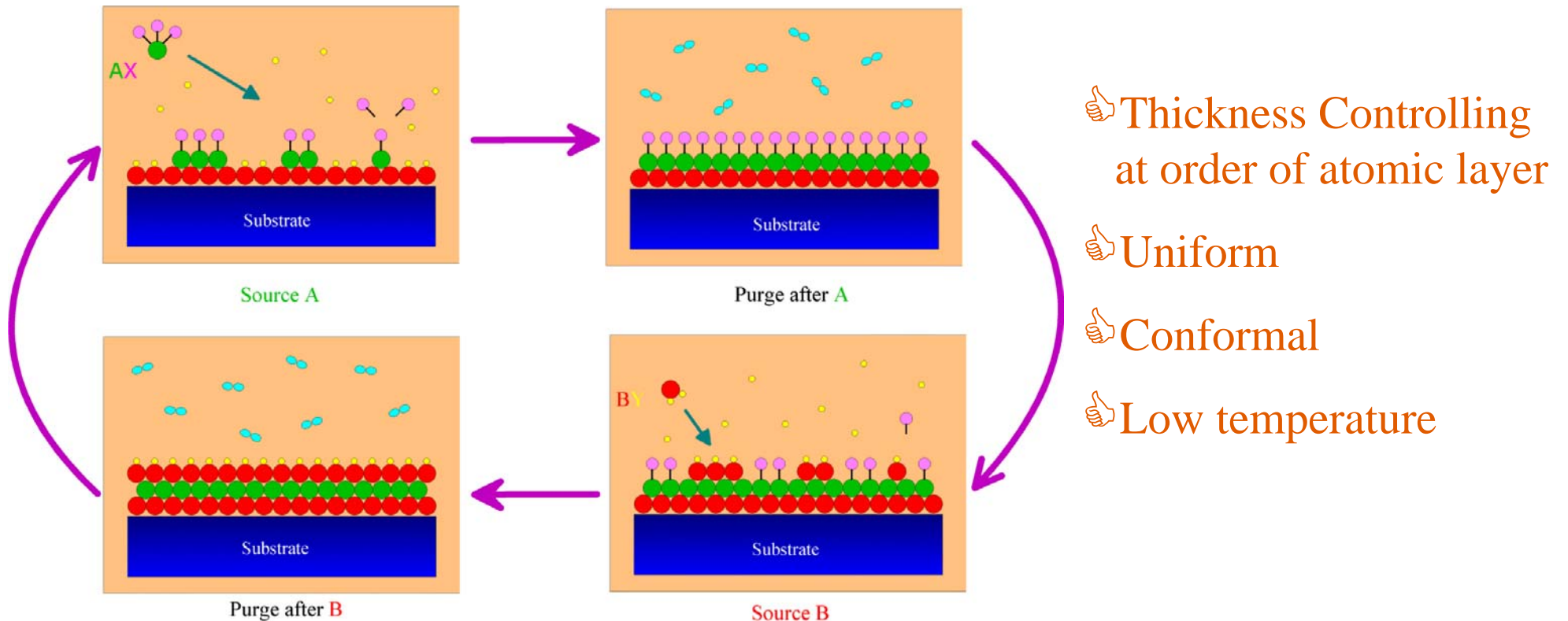


- Moore's law*: the data density, i.e., the number of transistors per square inch on integrated circuits has doubled every 18 months.
- In 2007, SiO_2 less than 1 nm ~ only 4 atomic layers → quantum mechanical tunneling currents↑↑.
- Therefore, oxide with a larger dielectric constant (high k) will be used to replace SiO_2 .
- Al_2O_3 is a good candidate: $k \sim 8-10$, $E_g > 7$ eV, stable on Si & SiO_2 .

***Cramming more components onto integrated circuits**, G.E. Moore, Electronics, Vol. 38, No. 8, 114 (1965).

Atomic Layer Deposition

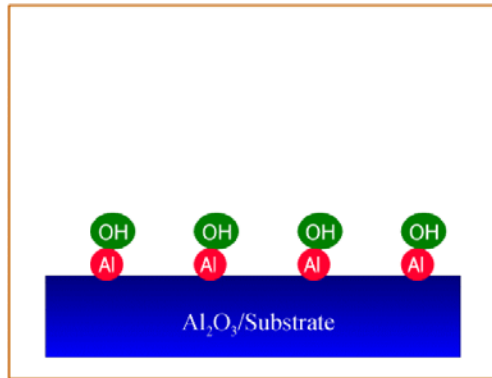
ALD



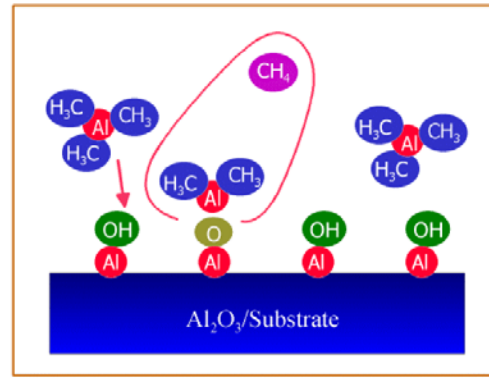
- 👍 Thickness Controlling at order of atomic layer
- 👍 Uniform
- 👍 Conformal
- 👍 Low temperature

ALD procedure

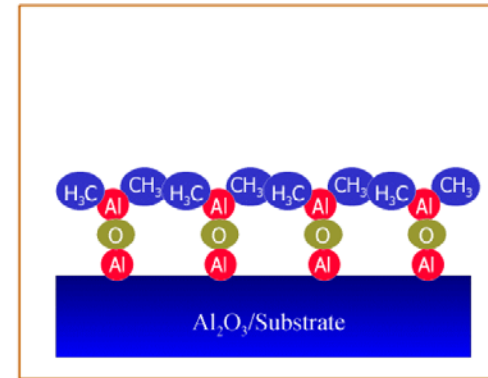
Deposition of Al_2O_3 with ALD



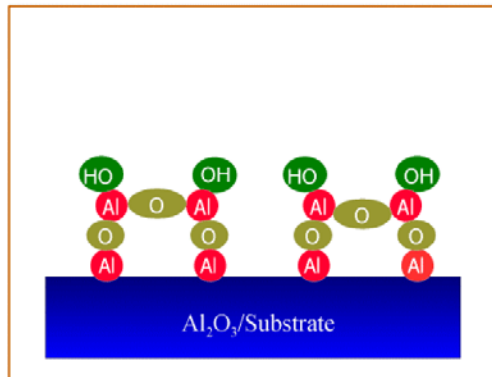
Starting Surface



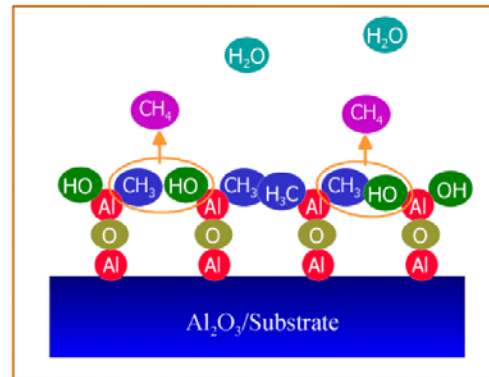
Chemisorption of $\text{Al}(\text{CH}_3)_3$



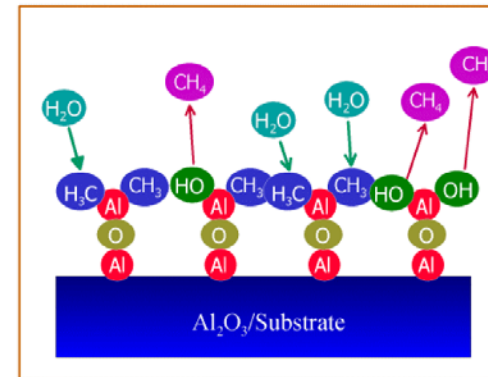
after inert gas purge



Inert gas purge



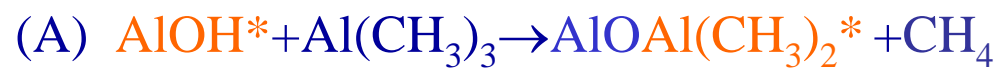
Reaction to form Al_2O_3



Chemisorption of H_2O



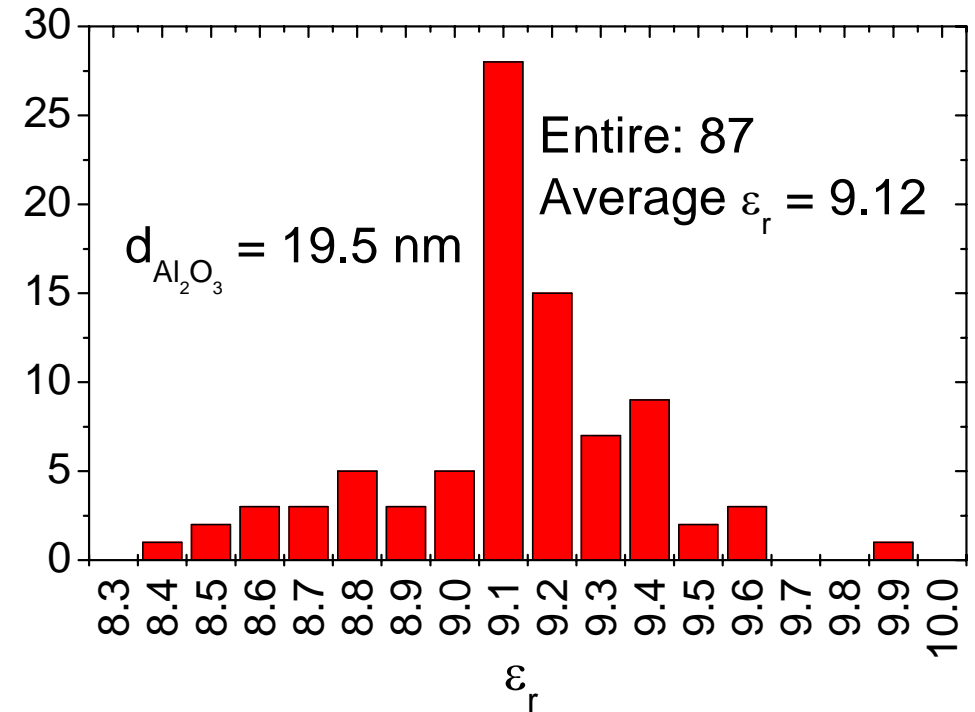
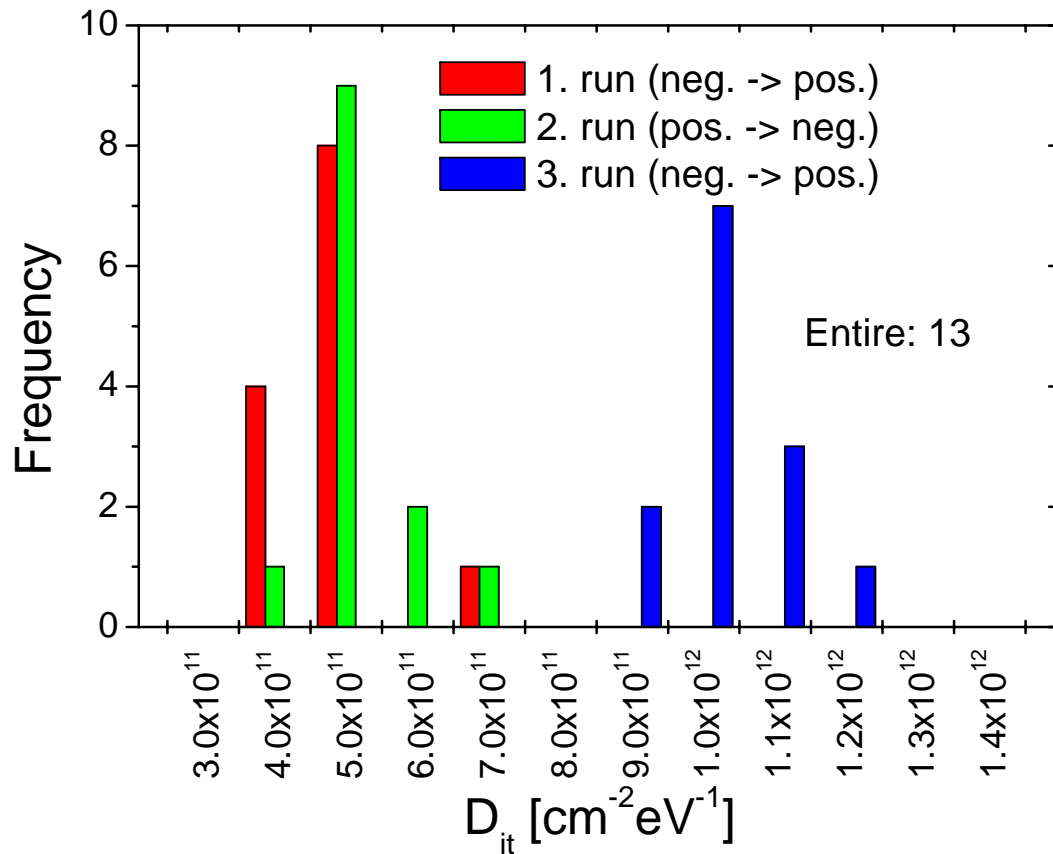
Reaction Temp.:
300°C



*: surface species

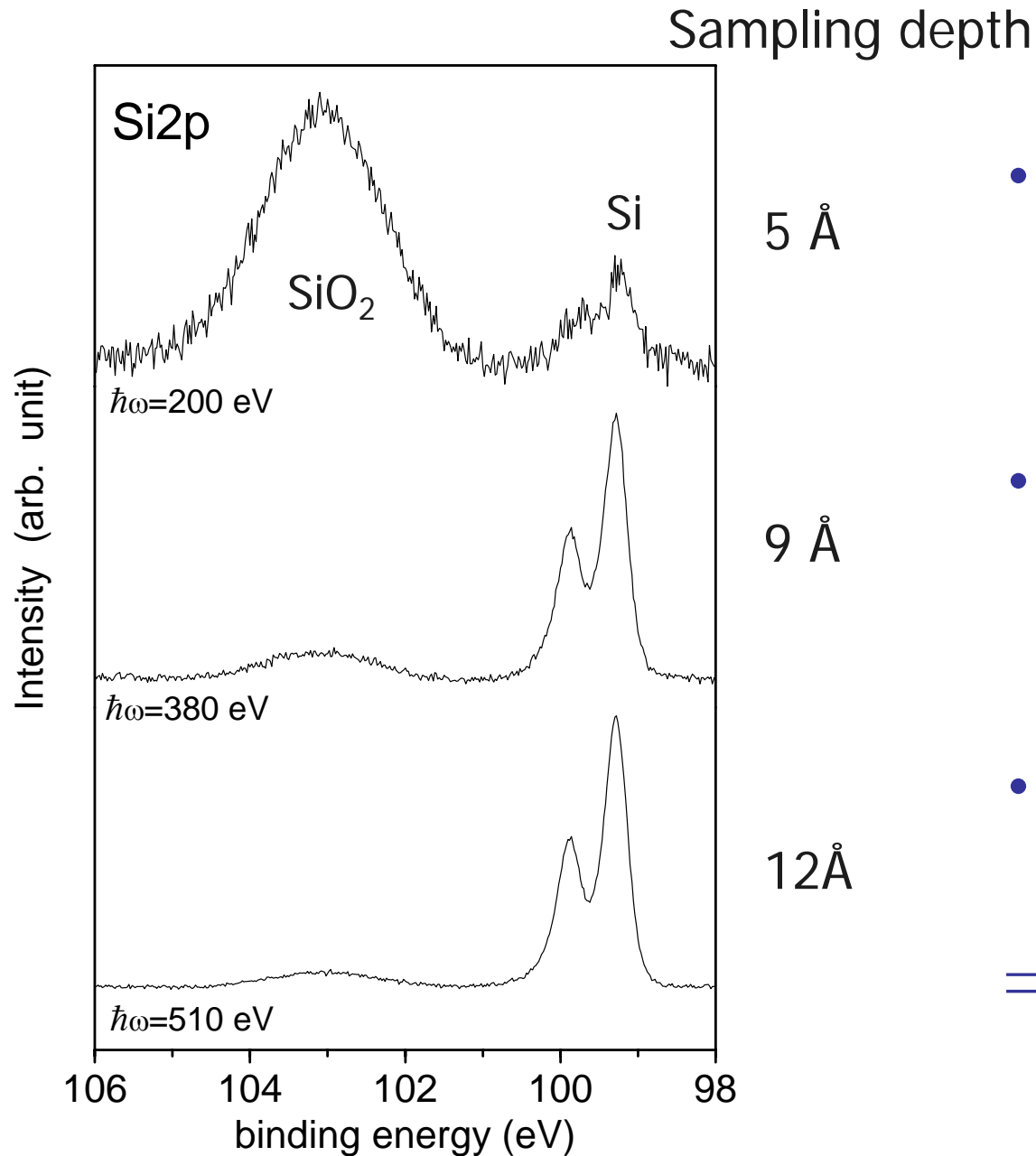
Electrical properties of ALD- Al_2O_3 on HF-last Si(100)

Data from Michael Oswald and Prof. Dr. Walter Hansch at TU München



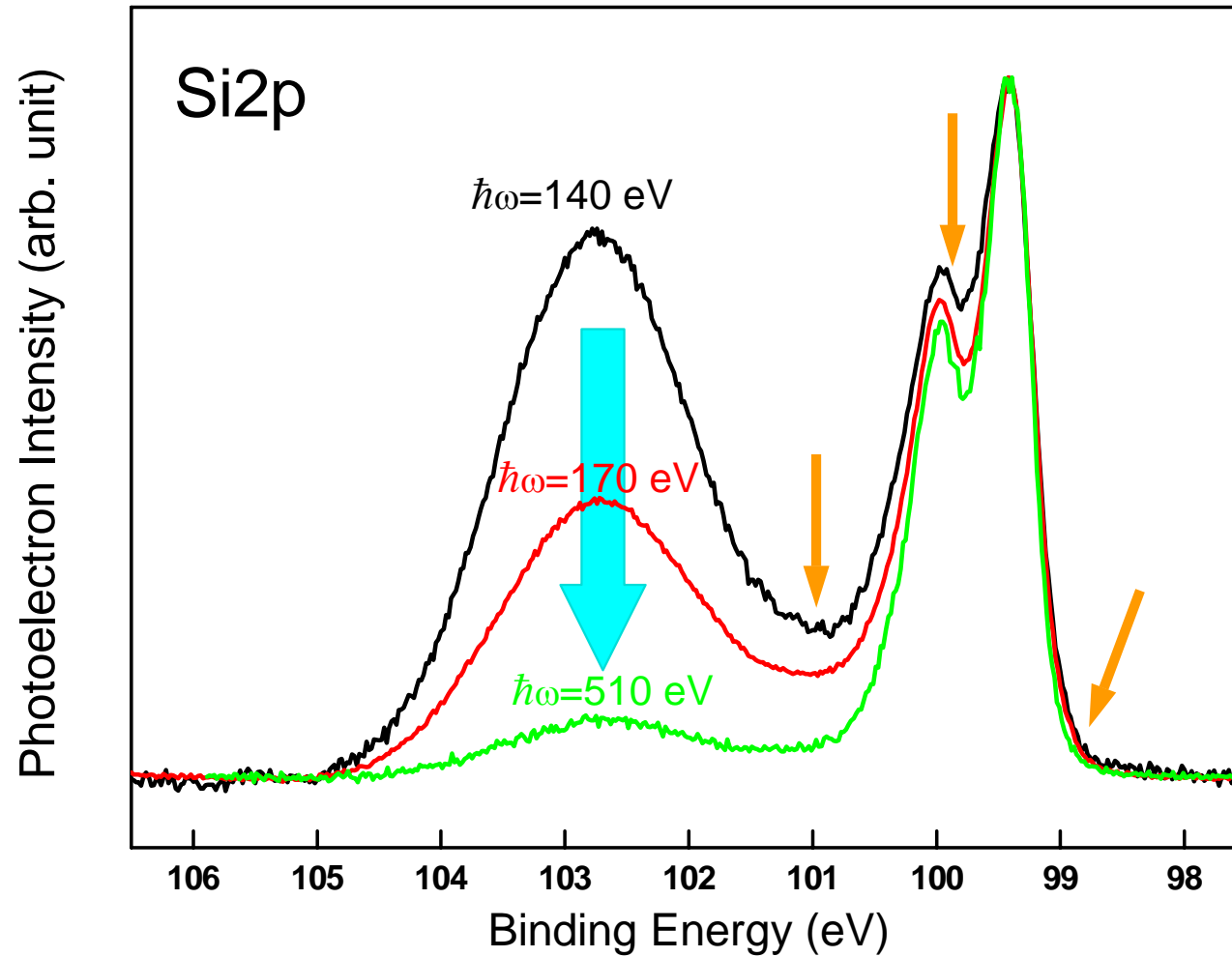
- First attempt gives good value of dielectric constant, but the density of interface states are quite high and depend on the number of runs.

How is Si affected by 15 cycles Al_2O_3 on HF-stripped Si(100)



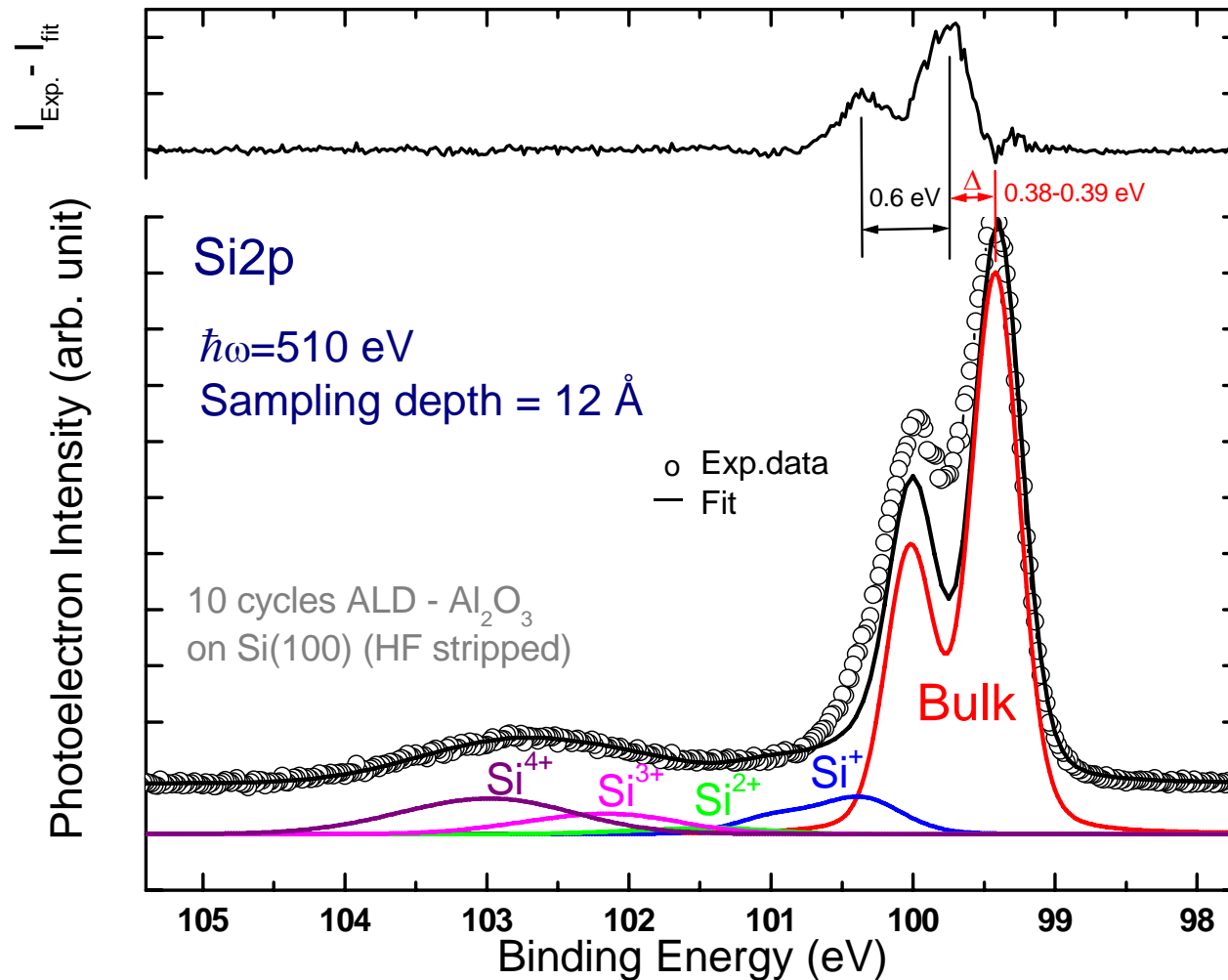
- ALD @ 300°C leads to oxidation of Si wafer.
 - Most of SiO_2 is located on top of Al_2O_3 films.
 - Problem: Interface too strongly attenuated.
- ⇒ Try thinner Al_2O_3 layer

The interface of 10 cycles Al_2O_3 on HF-stripped Si(100)



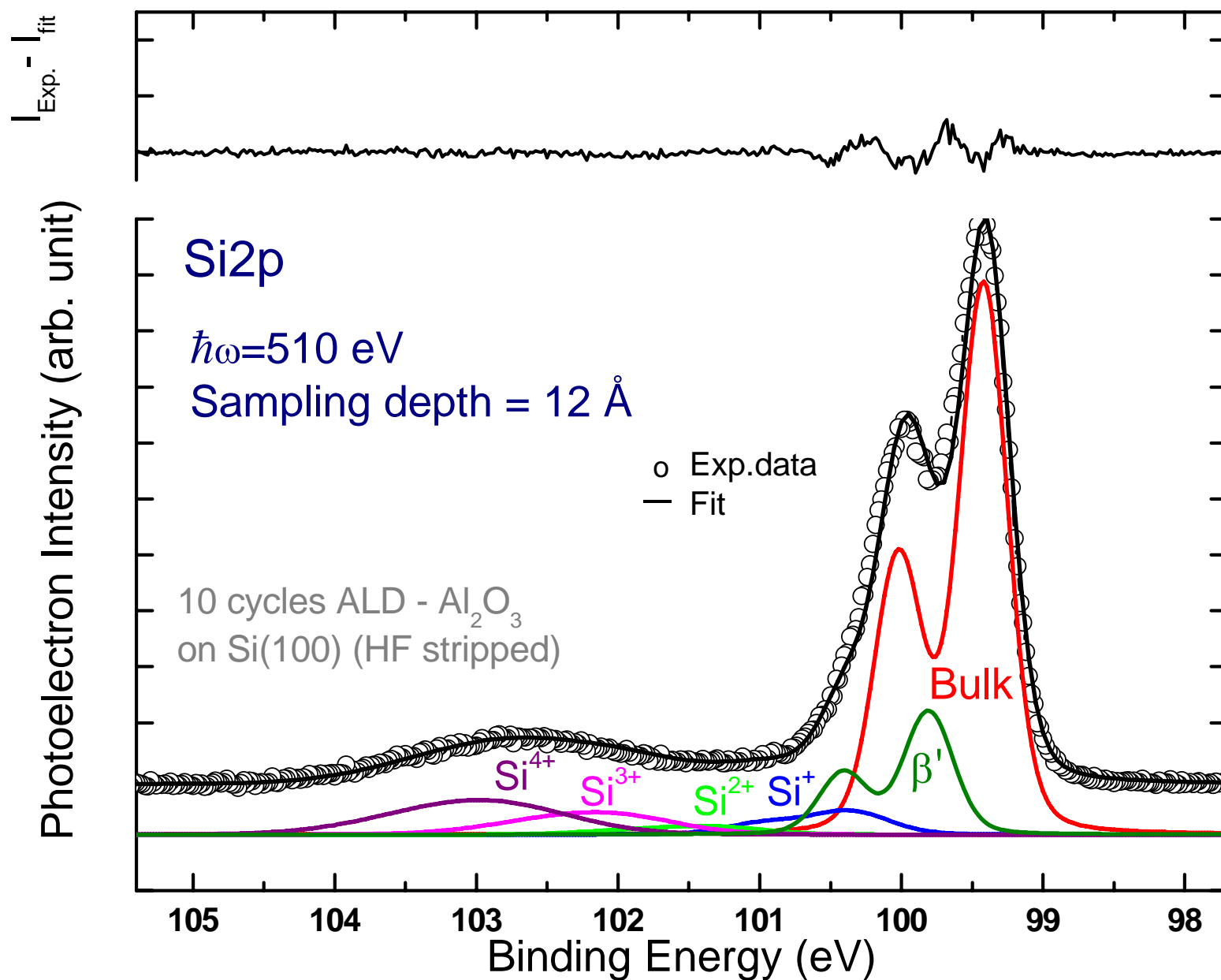
- Interface between Si and Al_2O_3 better observed

Fitting Interface Sensitive Si2p spectrum 10 cycles Al_2O_3 on HF-stripped Si(100)

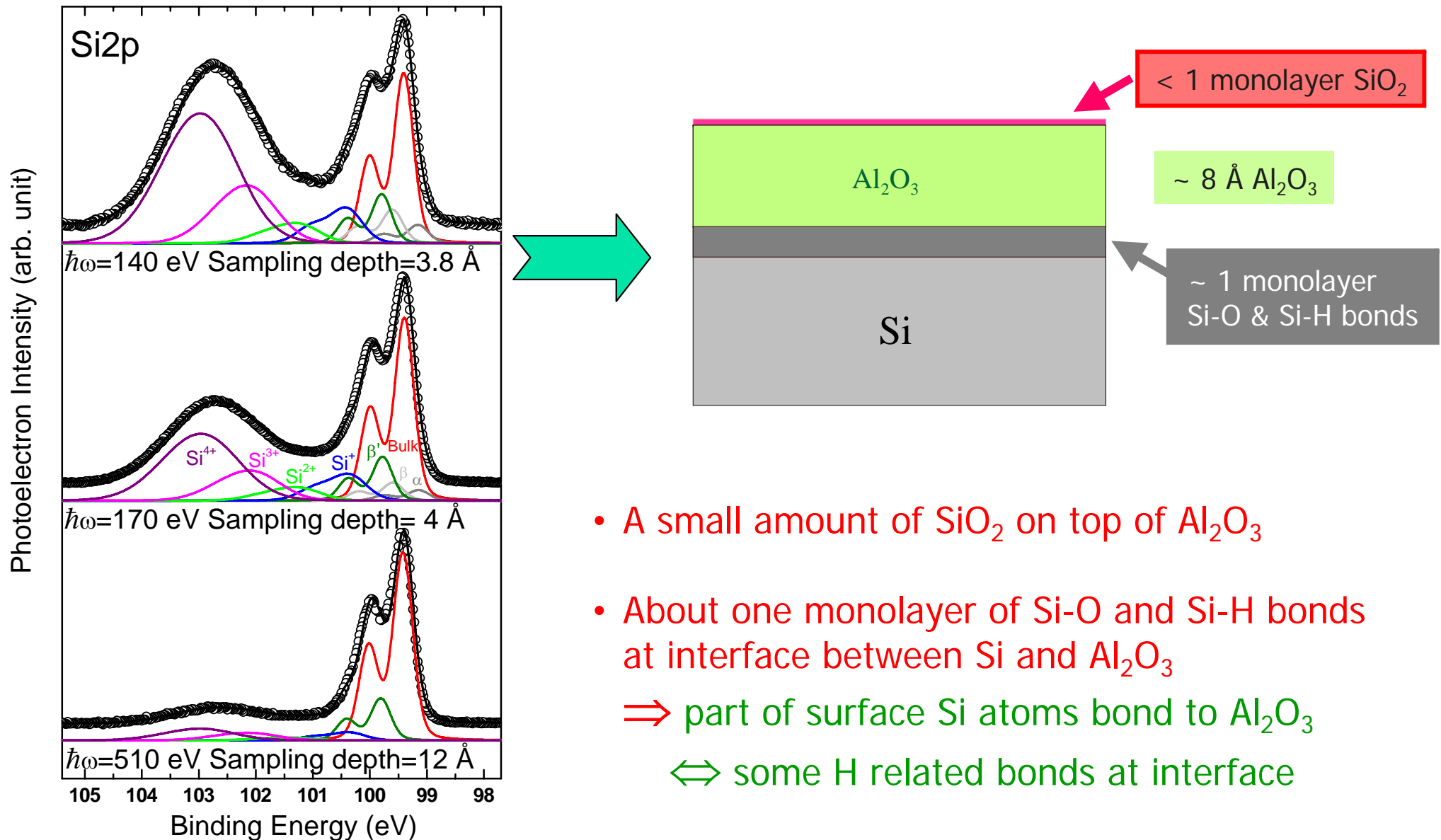


- In addition to suboxides and bulk components
- New interface component

Fitting Si2p spectrum with interface component β'

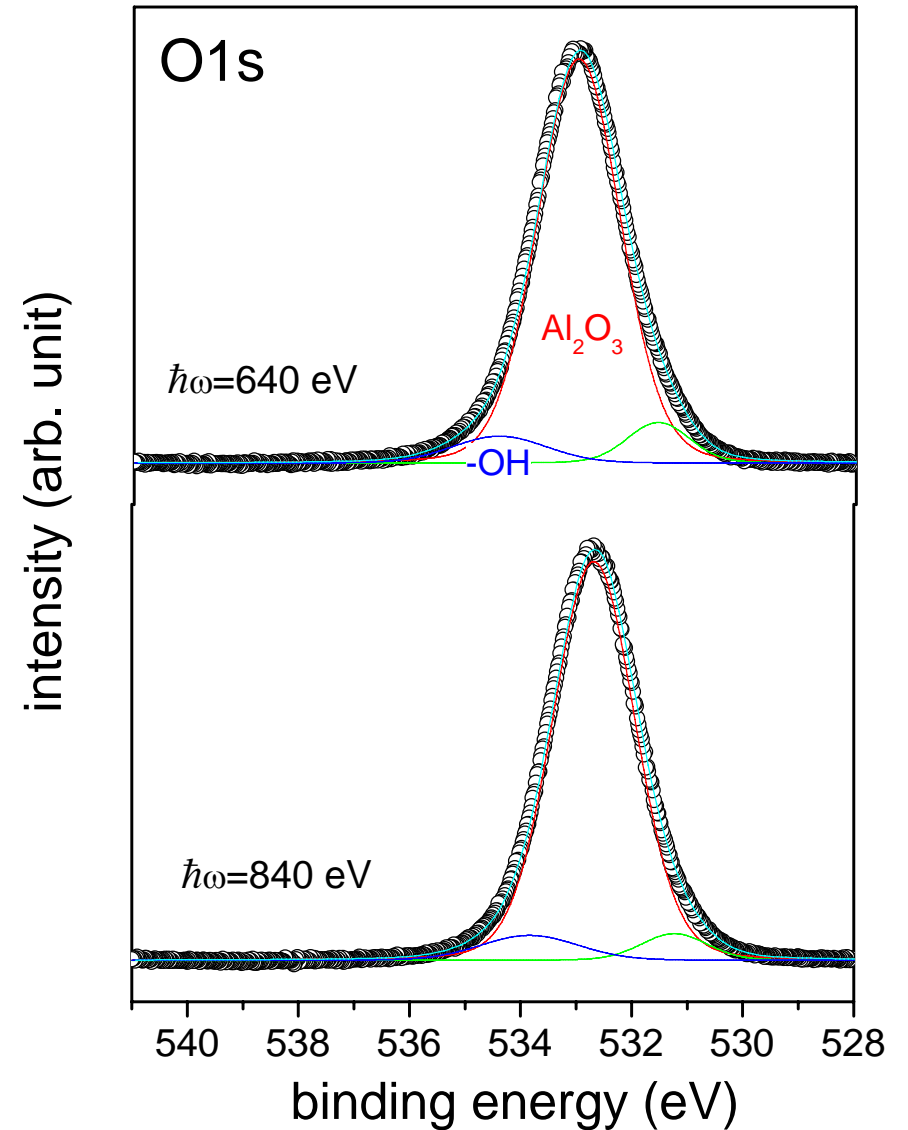
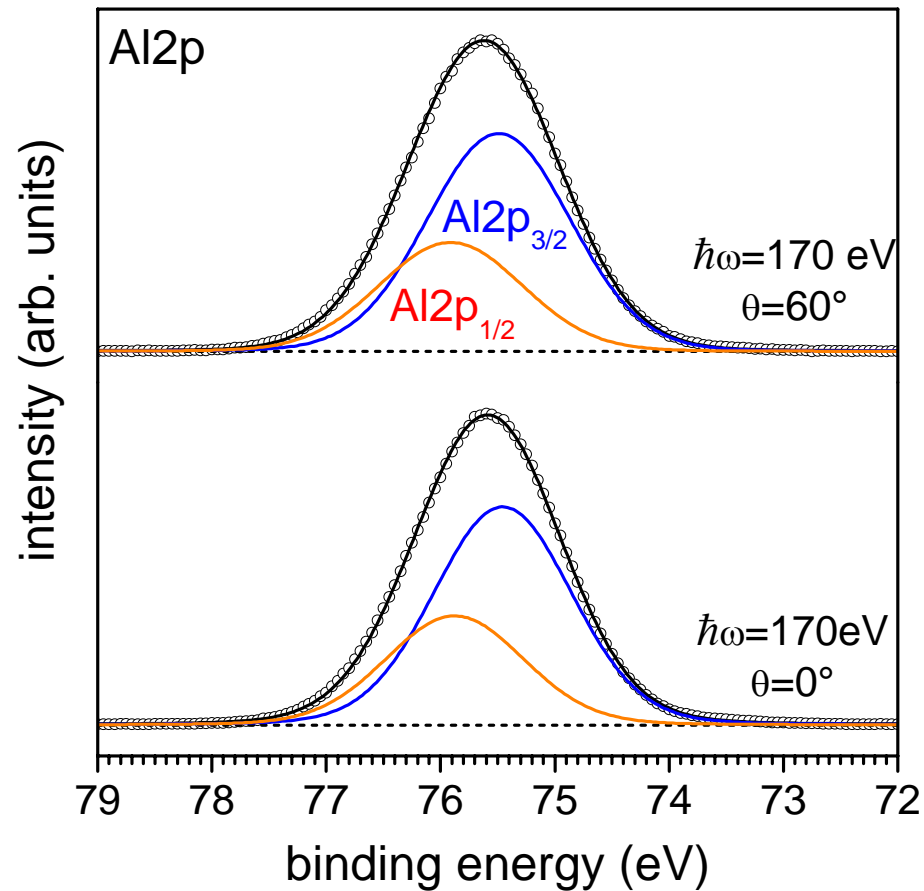


Modeling results of the as-deposited $\text{Al}_2\text{O}_3/\text{Si}(100)$

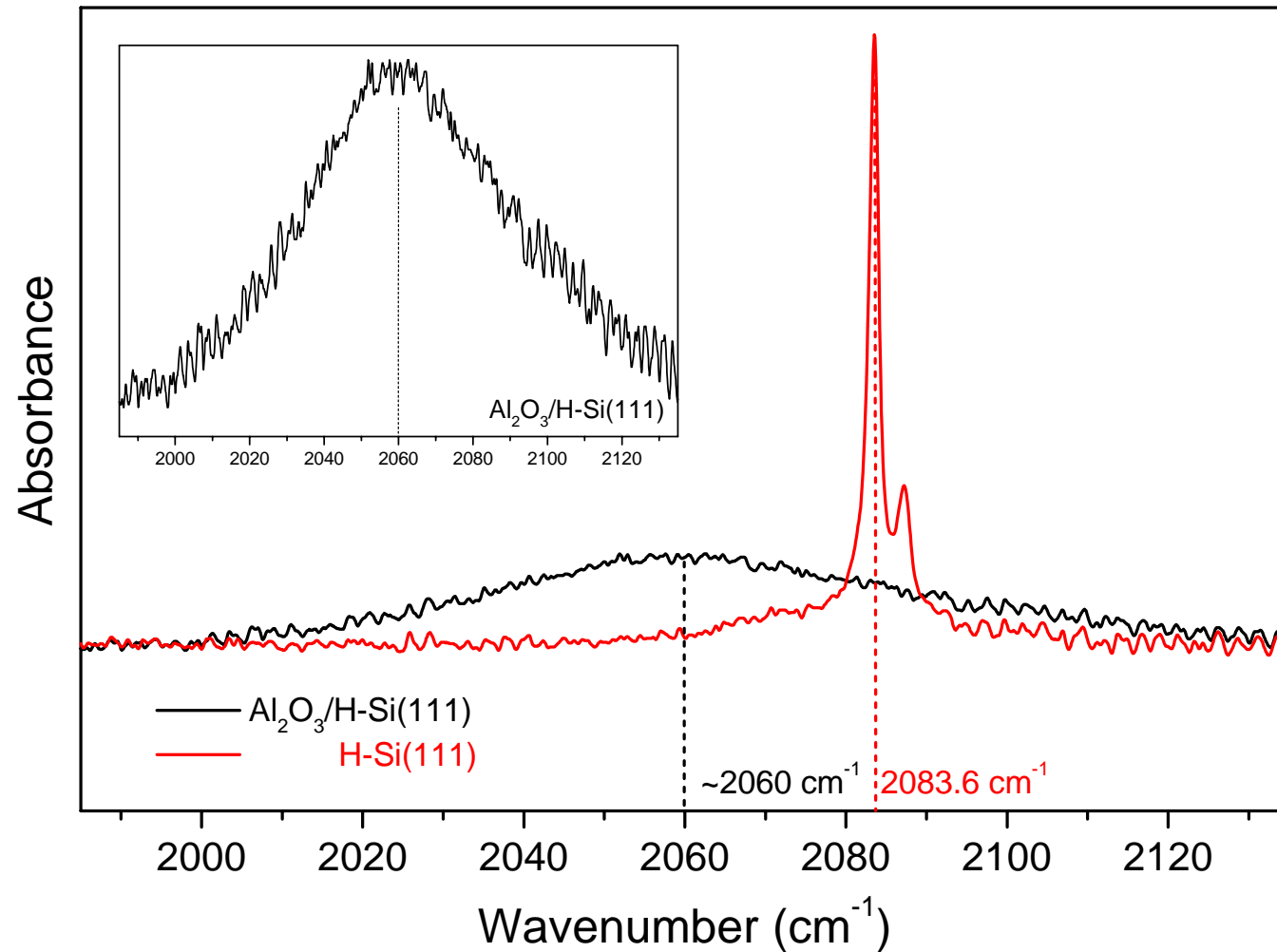


- A small amount of SiO_2 on top of Al_2O_3
- About one monolayer of Si-O and Si-H bonds at interface between Si and Al_2O_3
- ⇒ part of surface Si atoms bond to Al_2O_3
- ⇔ some H related bonds at interface

Al2p & O1s spectra: 15 cycles Al₂O₃ on H-stripped Si(100)



FTIR spectra of Si-H monohydrides: H-term. Si(111) and 15 cycles Al_2O_3 /H-Si(111)



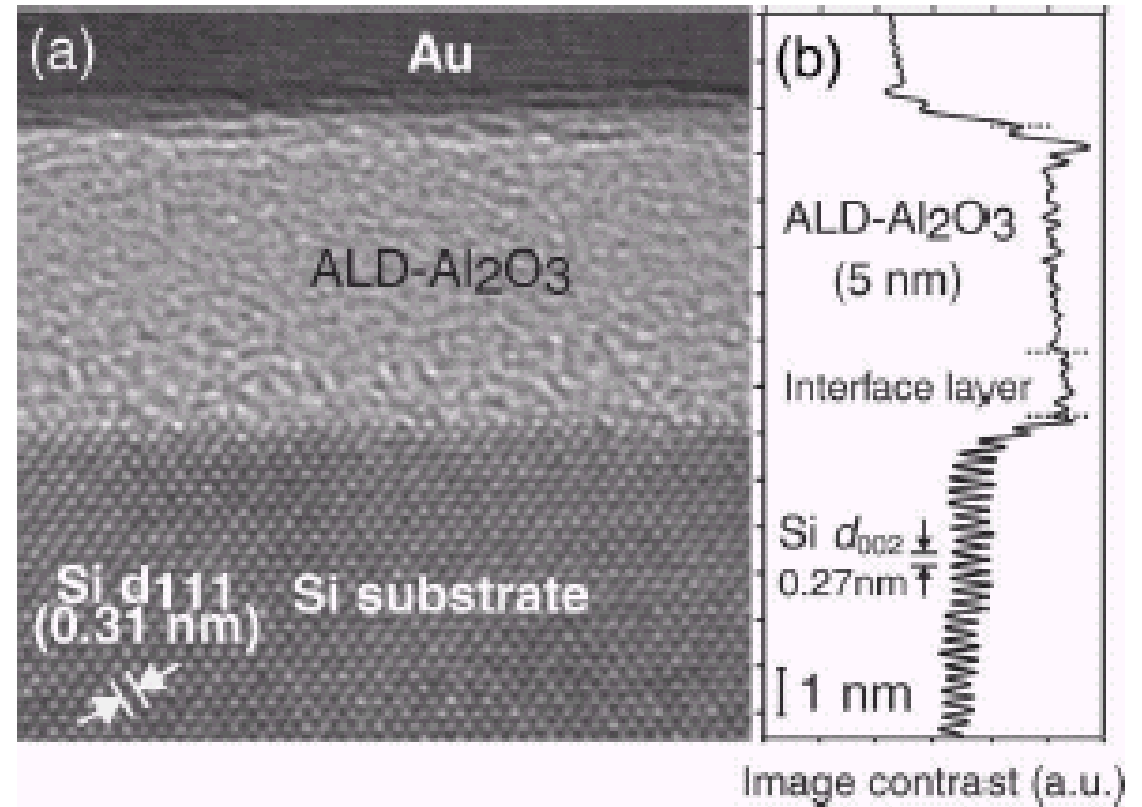
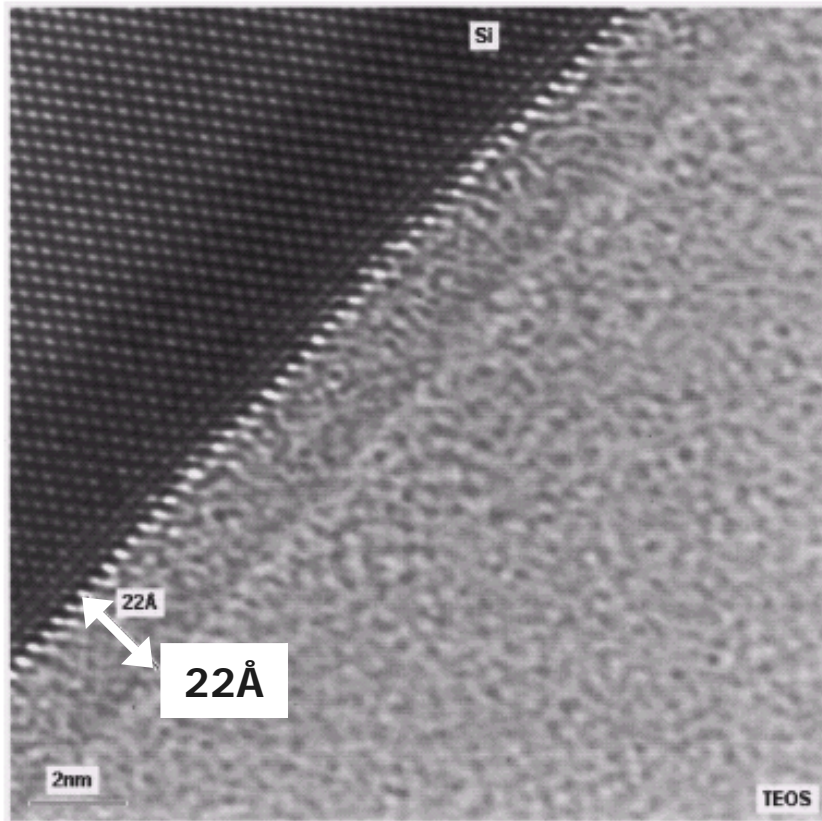
After deposition,

- the wavenumber of Si-H moves from 2083.6 to 2060 cm^{-1}
- the peak becomes very much broader.

⇒ The existence of Si-H bonds is proved

Its configuration is being under investigation

TEM images of Al_2O_3 films grown on HF-stripped Si(100) by ALD technique(Literature)



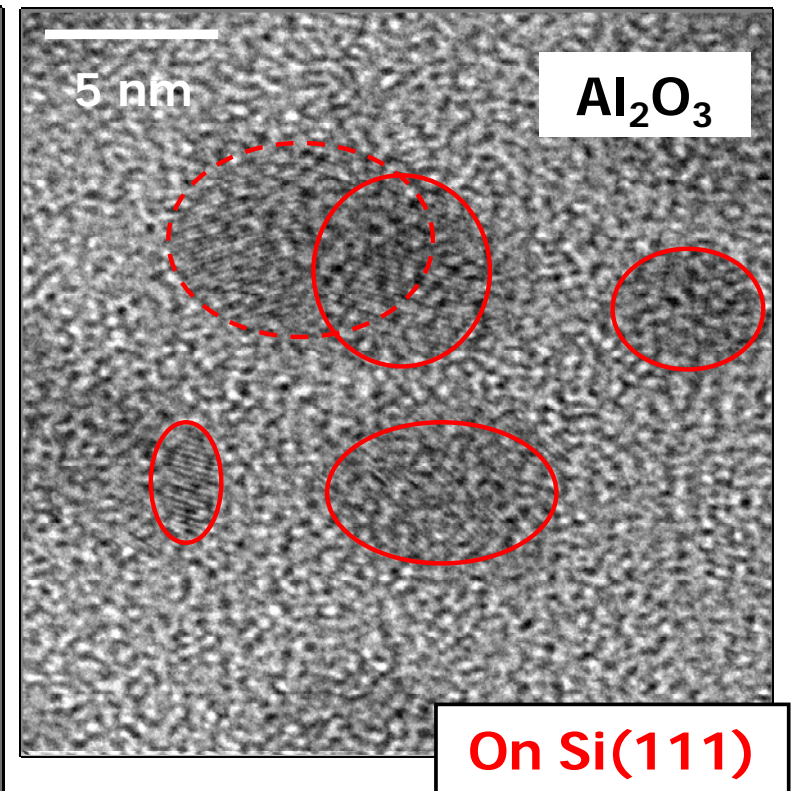
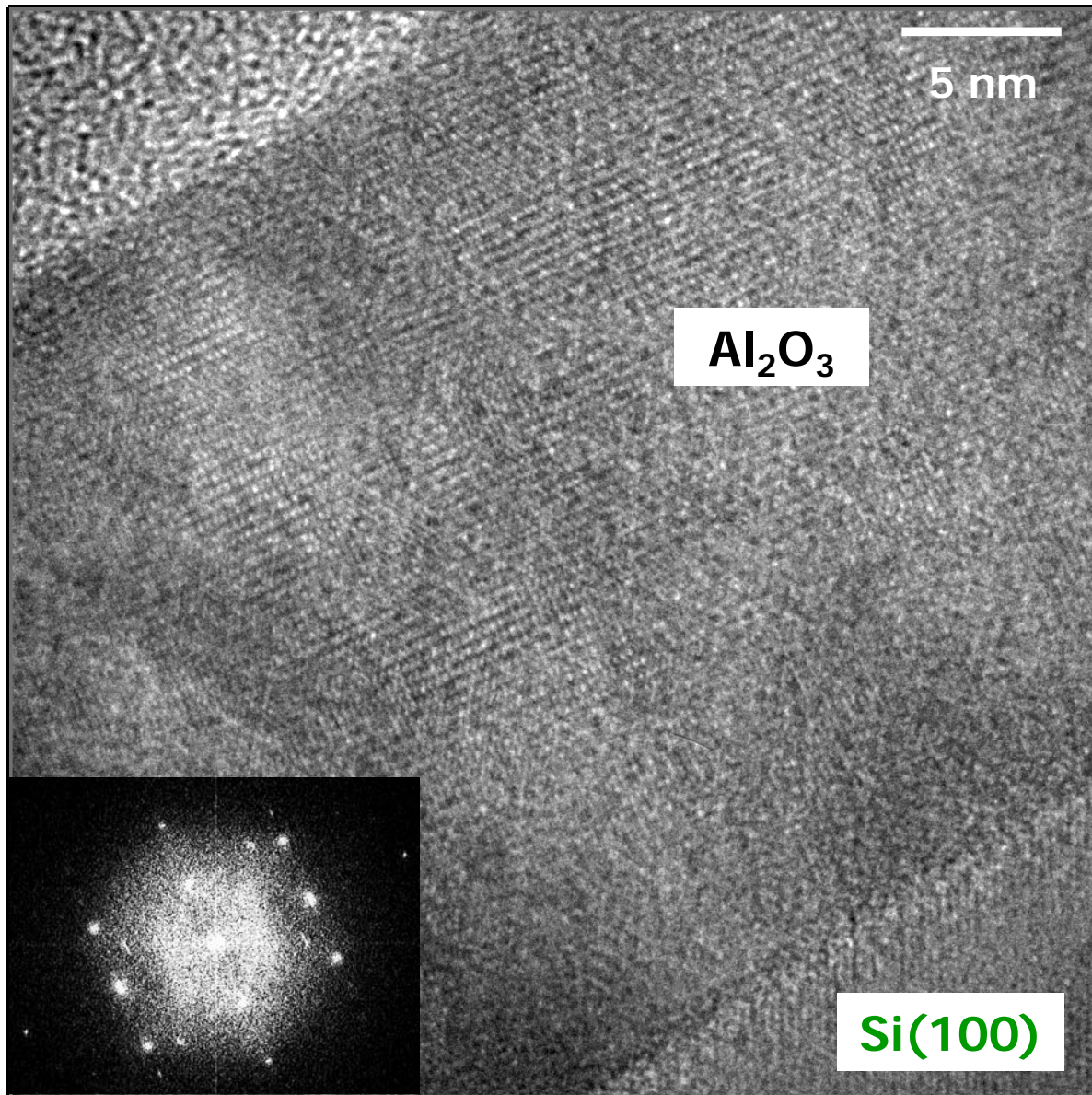
➔ As-deposited Al₂O₃ formed on Si : uniform, continuous, amorphous, atomic abrupt.

High-resolution depth profiling in ultrathin Al₂O₃ films on Si, E. P. Gusev et al, Applied Physics Letters, 76(2), 176(2000).

➔ RTA in Ar+1%O₂ at 750°C: amorphous, with interfacial layer.

Coordination and interface analysis of atomic-layer-deposition Al₂O₃ on Si(100) using energy-loss near-edge structures, K. Kimoto et al, Applied Physics Letters, 83(21), 4306(2003).

High resolution cross-sectional TEM images

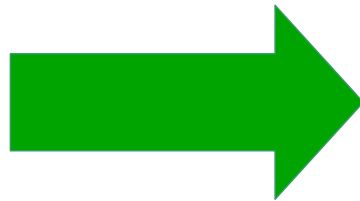
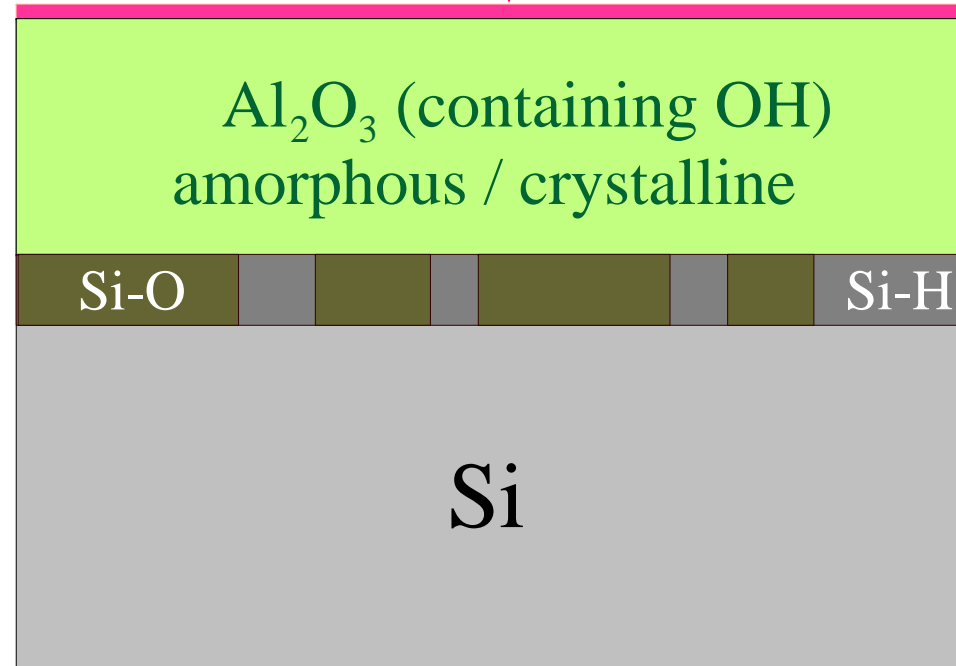


40 nm Al_2O_3 on Si(111):
amorphous, containing
nanocrystalline particles

40 nm Al_2O_3 on Si(100): >80% polycrystalline

Summary

< 1 monolayer SiO₂



The possible Si-H bonding at interface and OH-groups in the oxide films could be the clue to understand their electrical behavior.

Outlook

- In ALD process, using ozone (O_3) instead of water (H_2O) as precursor to provide oxygen, in order to get OH-free Al_2O_3 films.
- Using FTIR to indentify Si-H bonds at interface between Al_2O_3 and Si upon annealing.