Fabrication of Sapphire nano-membrane by solid phase epitaxy

Byoungsoo Kim

Oxide Nanostructure & Nanoelectronics Lab
Department of Materials Science and Engineering
Seoul National University, South Korea

Outline

Introduction

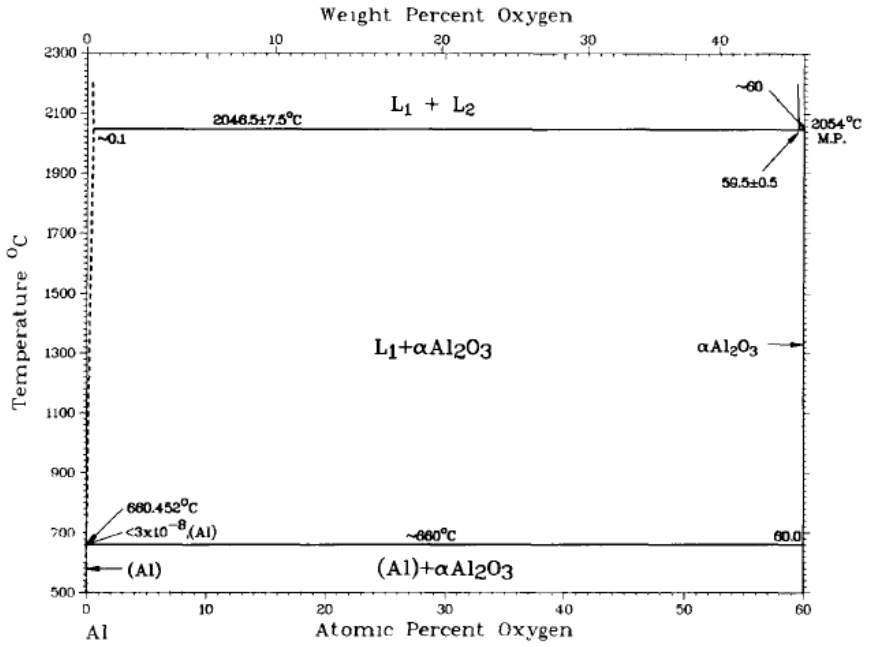
- Solid phase epitaxy of Al_2O_3 system

Sapphire(Al_2O_3) nano-membrane by Atomic Layer Deposition

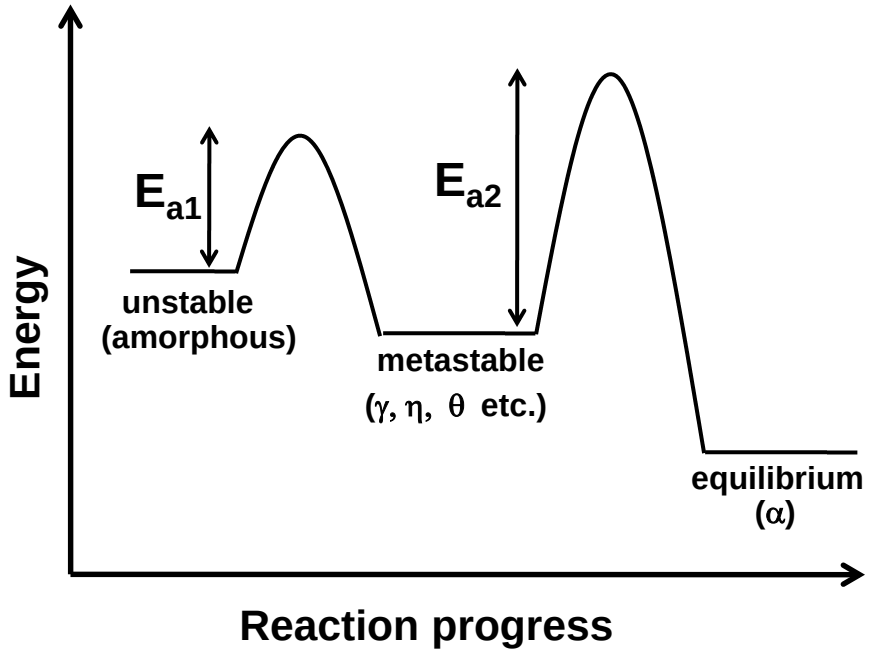
- Fabrication of sapphire nano-membrane
- Application of Sapphire nano-membrane for flexible device

Summary

Phase diagram of Al-O system



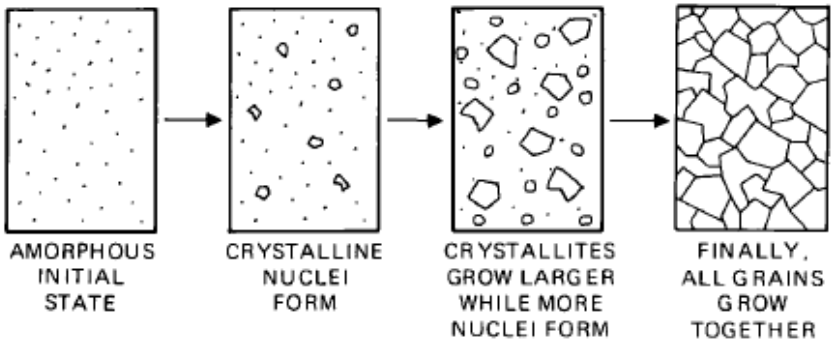
*Wriedt, Bulletin of Alloy Phase Diagrams **6**, 548 (1985)*



- **α-Al_2O_3 is the only stable alumina phase at all temperatures.**
- **Other metastable phase can occur during heat treatment, but it transformed to the most stable phase of α-phase.**

Random nucleation vs solid phase epitaxy

Nucleation and growth



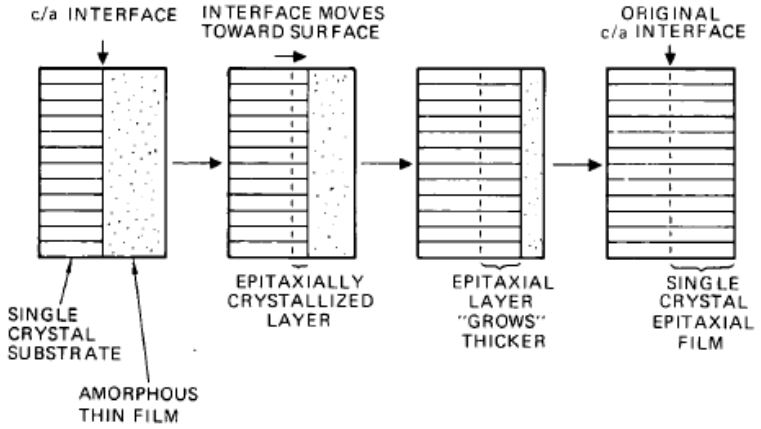
Si: E_a= ~4 eV, occurs above 1330 °C

Formation of small ordered arrangement due to thermal agitation

During random fluctuation, some clusters grow.

Poly crystal forms with excess energy by grain boundary.

Solid phase epitaxy

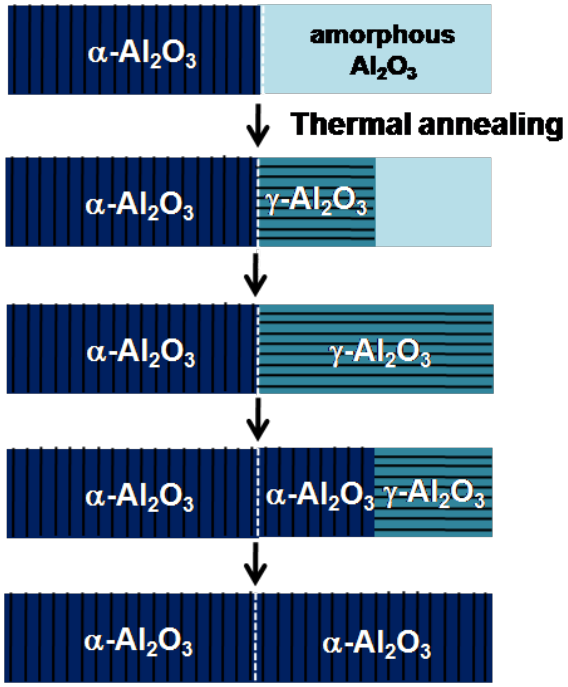


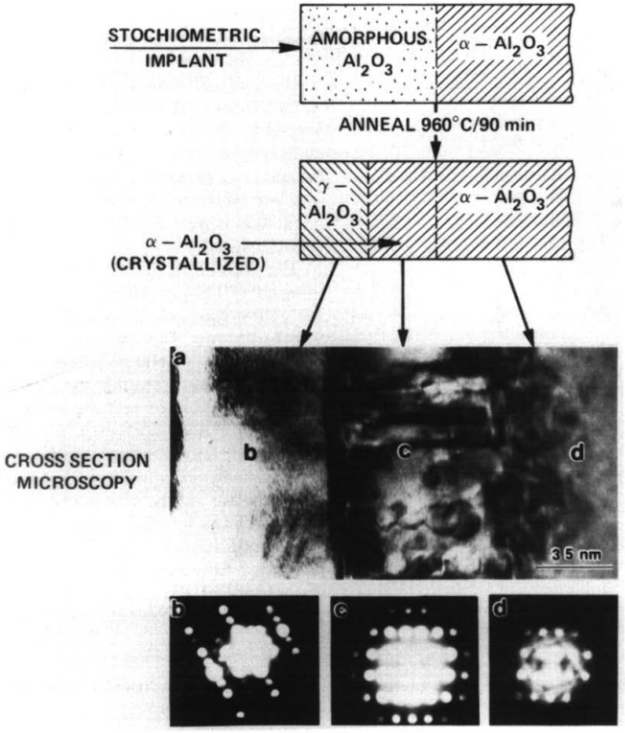
Si: E_a = ~2.7 eV, occurs at 470 ~ 1350 °C

- **The crystalline substrate provides a template for ordered crystallization.**
- **A layer-by-layer conversion of atoms occurs by the atom rearrangement with lower activation energy than random nucleation and growth.**

Olson et al, Materials Science Reports ***3,*** *1-78 (1988)*

SPE procedure of alumina

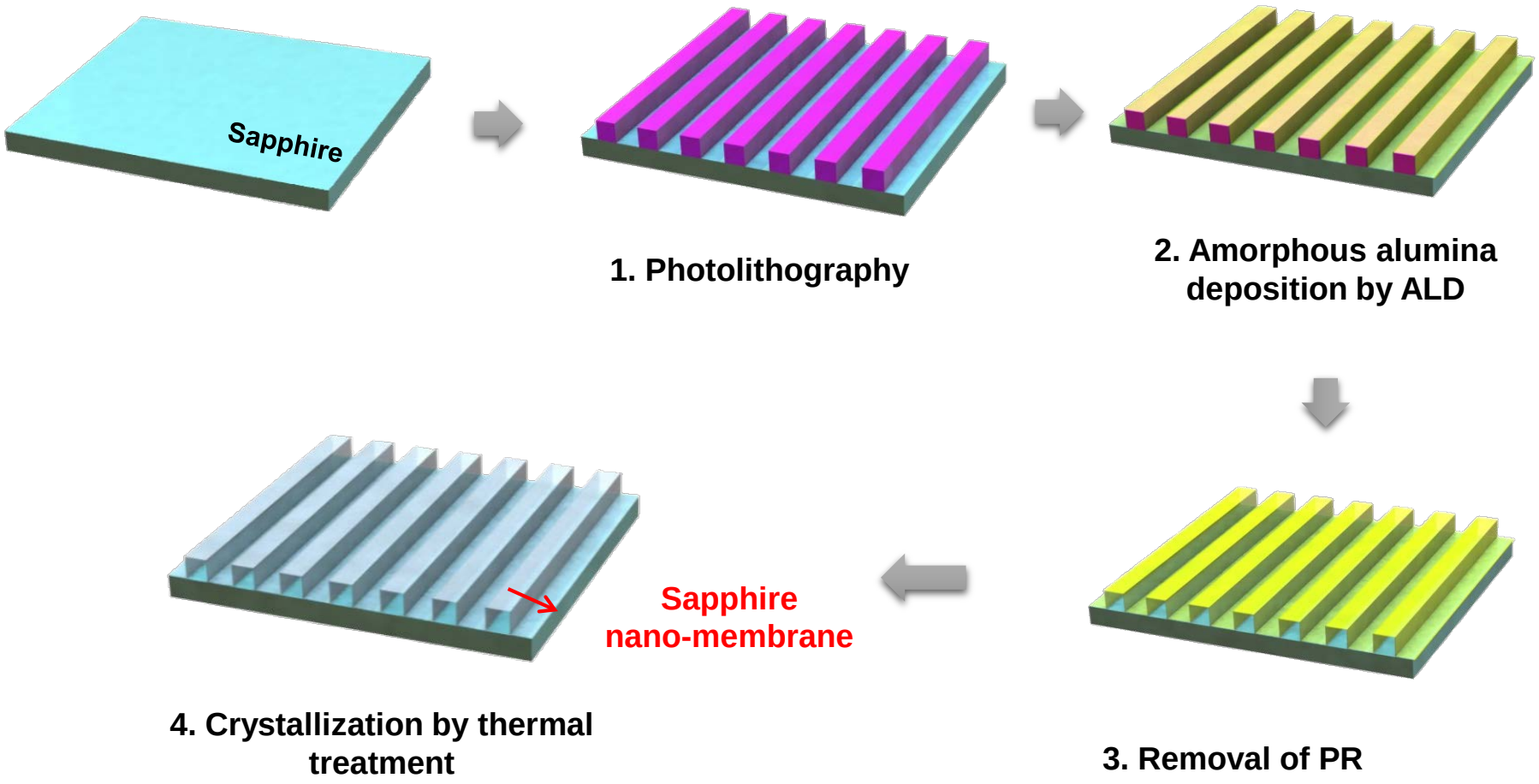




White et al., Nuclear Instruments and Methods in Physics Research B32, 11-22 (1988)

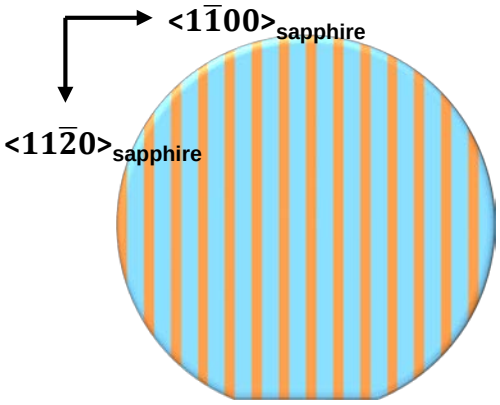
- **SPE process occurs in two stages from amorphous to γ and then to α**
- **Crystallographic orientation between γ and α: $(0006)_\alpha // (222)_\gamma$, $\langle 10\text{-}10\rangle_\alpha // \langle 110\rangle_\gamma$**

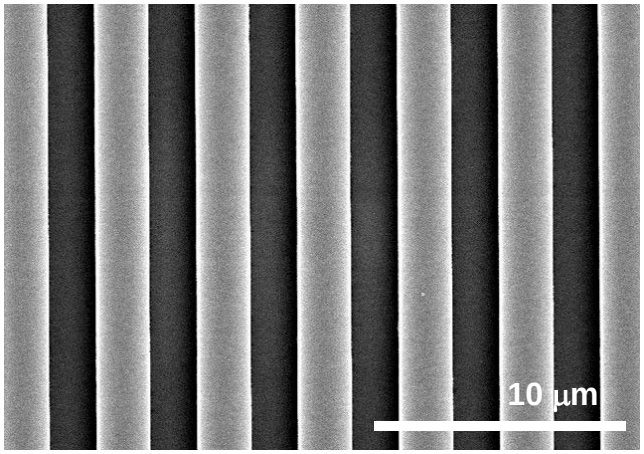
Fabrication of stripe patterned sapphire nano-membrane

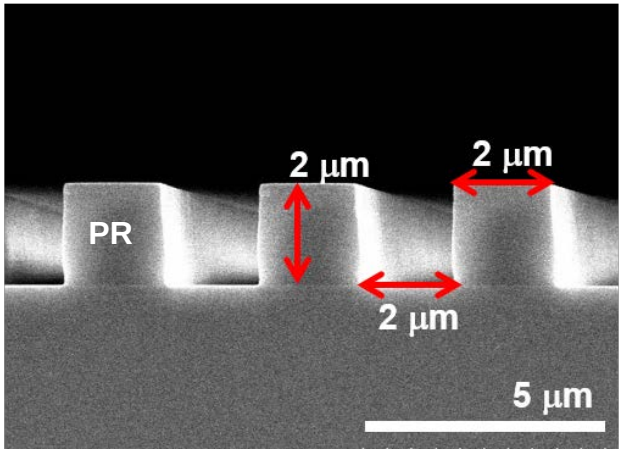


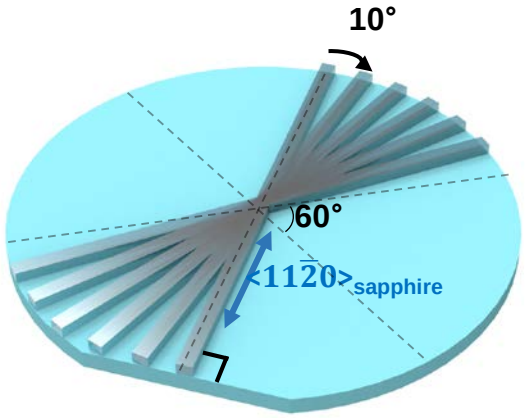
Photolithography

- **PR pattern (PR, GXR 601): width 2 μm, spacing 2 μm, thickness 2 μm**



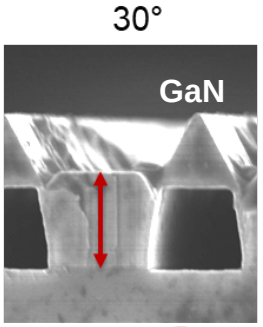




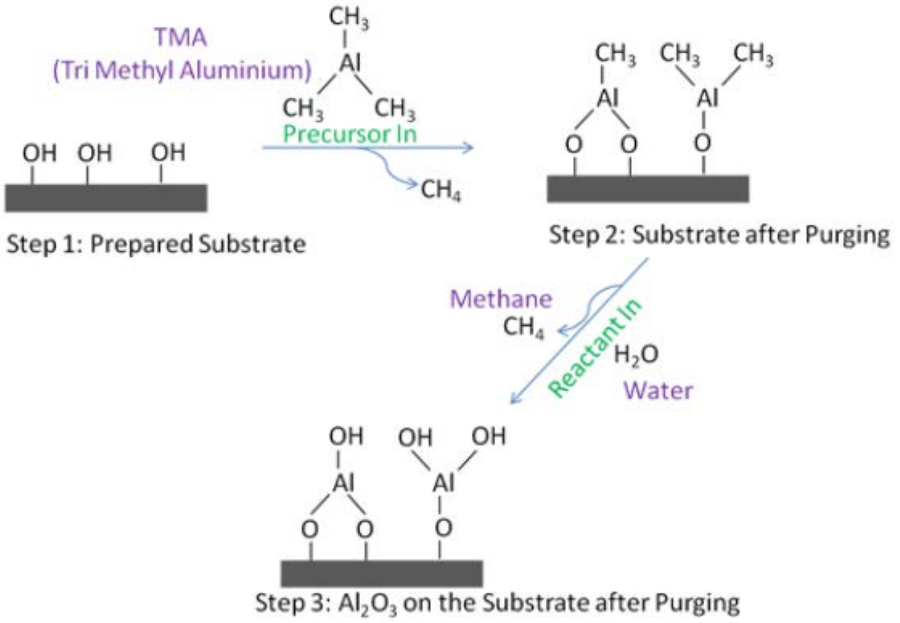


- The photolithography process was carried out by changing the direction from 0° to 50° by 10° based on the <11$\bar{2}$0>$_{sapphire}$ direction.

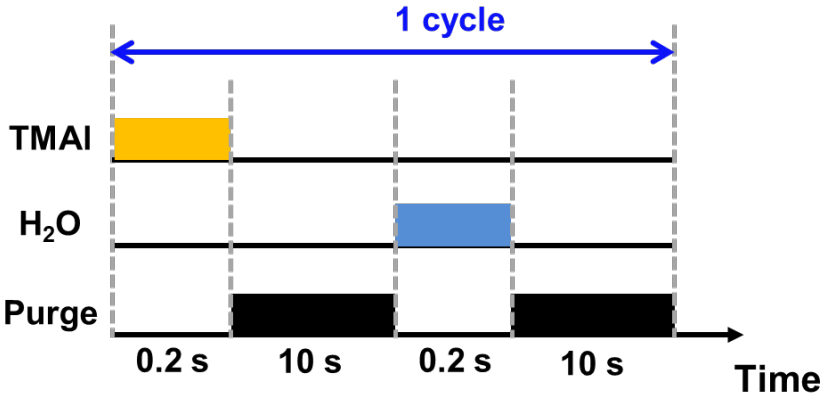
- **0°: <11$\bar{2}$0>$_{sapphire}$**
- **30°: <1$\bar{1}$00>$_{sapphire}$**

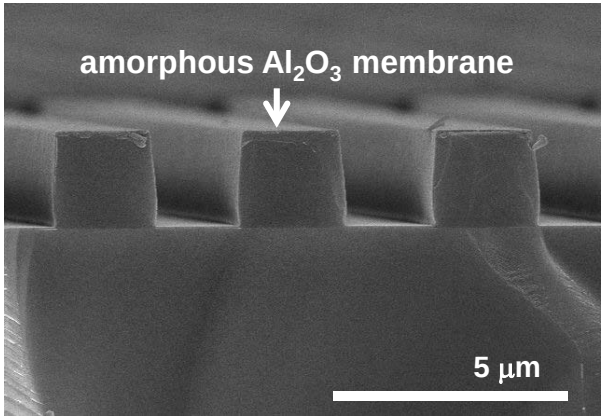


Atomic layer deposition (ALD) of alumina



http://www.dileepnanotech.com/ALD_Saturating__Chemical_Reaction.htm

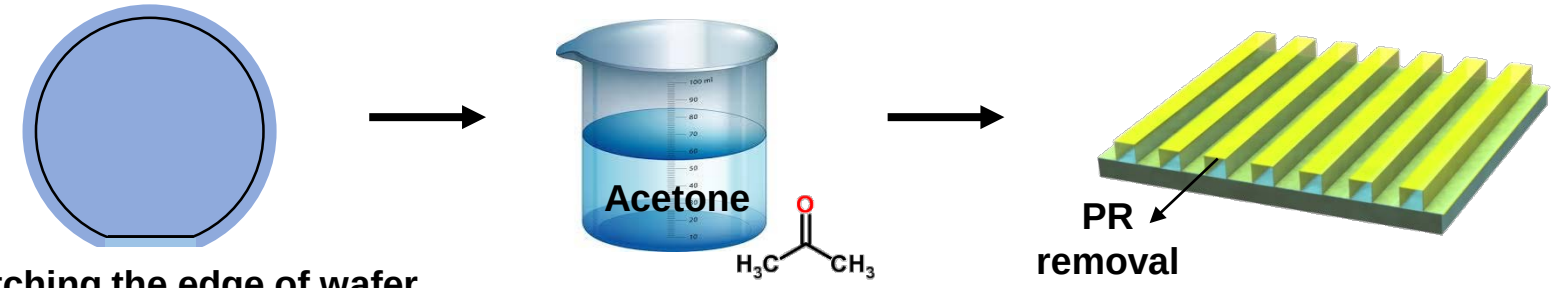




- Amorphous-Al_2O_3 was deposited at **110 °C for 1500 cycle** to prevent thermal deformation of PR.
- **Thickness of membrane: ~ 125 nm**

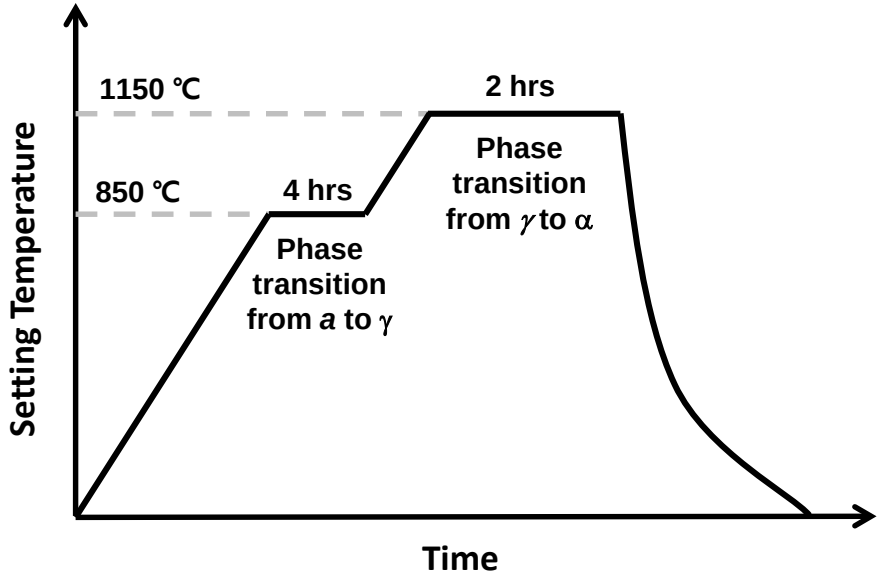
PR removal & Phase transformation of ALD alumina film

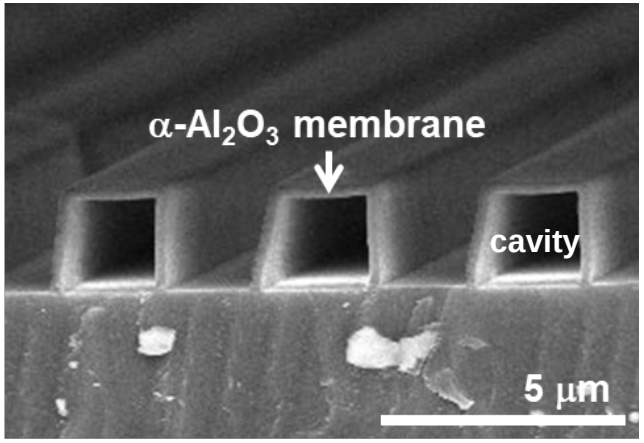
- **PR removal: Dipping in acetone solution**



Scratching the edge of wafer

- **SPE process by thermal treatment**

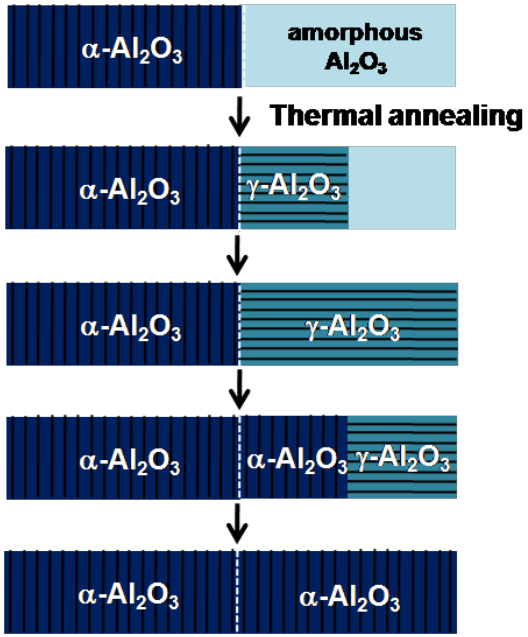




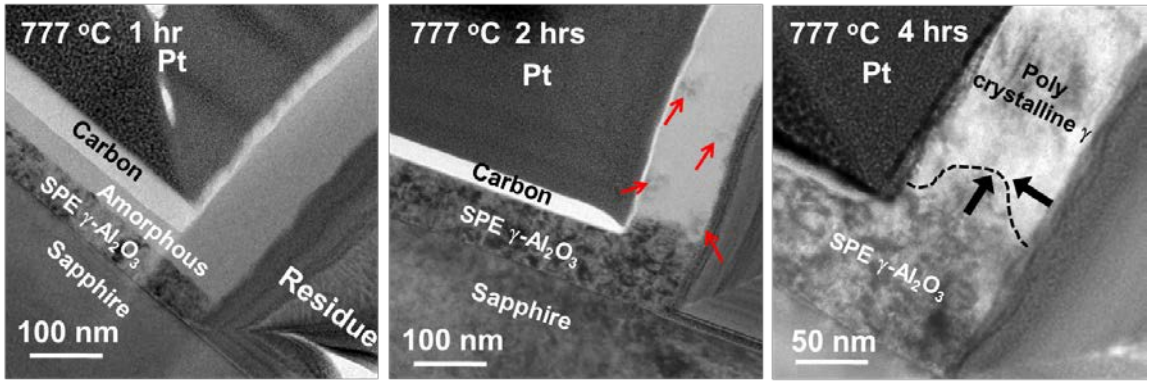
- **Single-crystalline α-Al_2O_3 is formed from the poly γ-Al_2O_3 through SPE.**

Solid phase epitaxy of alumina

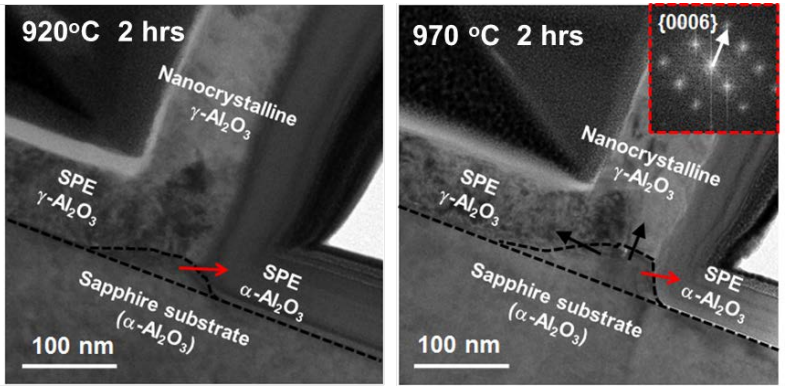
SPE process: a-Al_2O_3 → γ-Al_2O_3 → α-Al_2O_3



White *et al.*, Nucl. Instrum. Methods Phys. Res.B32, 11-22 (1988)



a-Al_2O_3 → γ-Al_2O_3



γ-Al_2O_3 → α-Al_2O_3

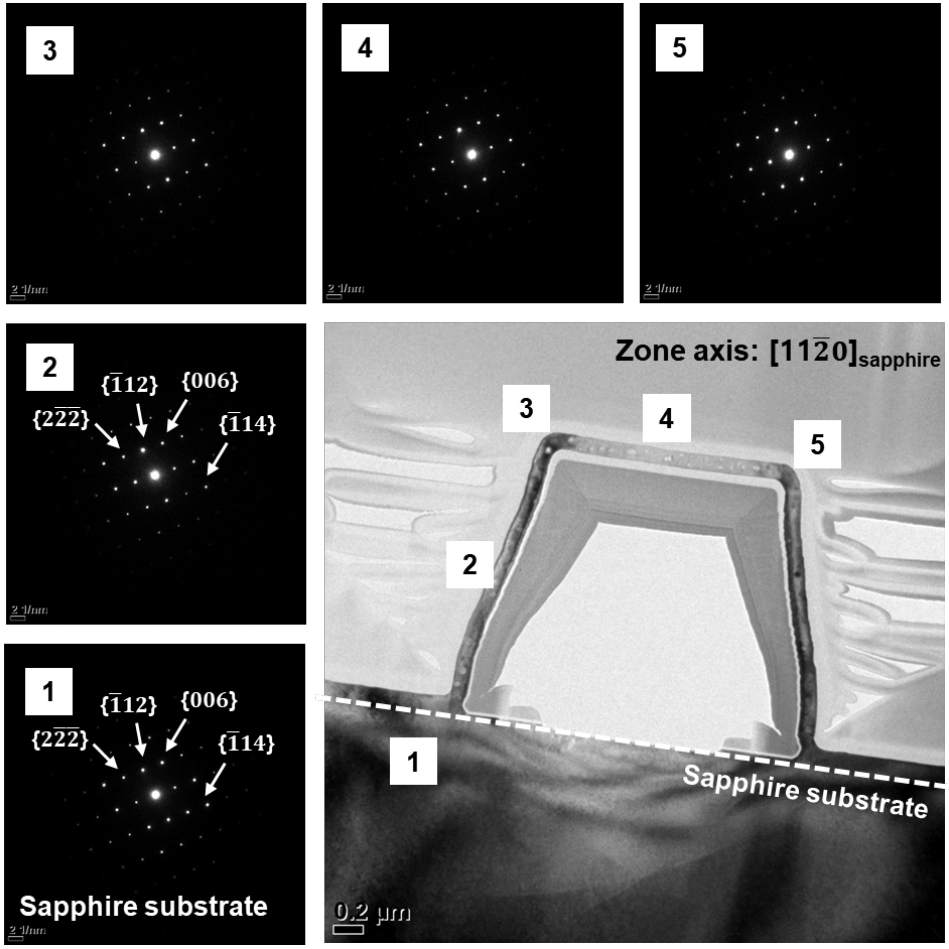
- **SPE process occurs in two stages from amorphous to γ and then to α**

Crystallized sapphire nano-membrane

*Selected area electron diffraction (SAED)

*Transmission electron microscopy (TEM)

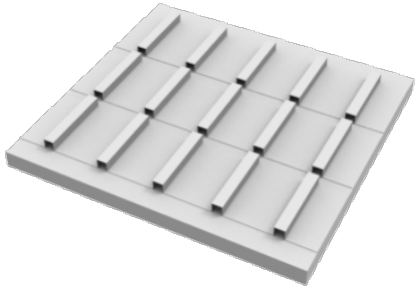
- SAED patterns and TEM images of sapphire nano-membrane



- All parts of nano-membrane were crystallized into α-phase Al_2O_3 (sapphire).

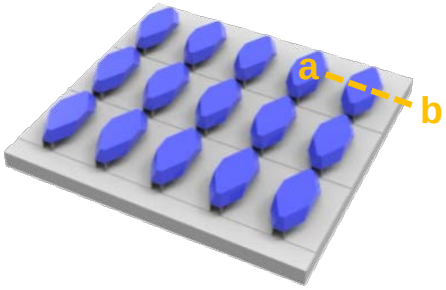
Sapphire nano-membrane for flexible electronics

- Growth of discrete epitaxial thin film array

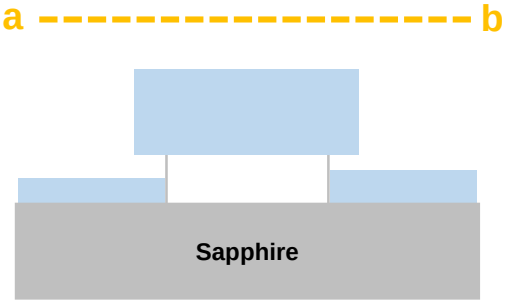


Sapphire
nano-membrane array

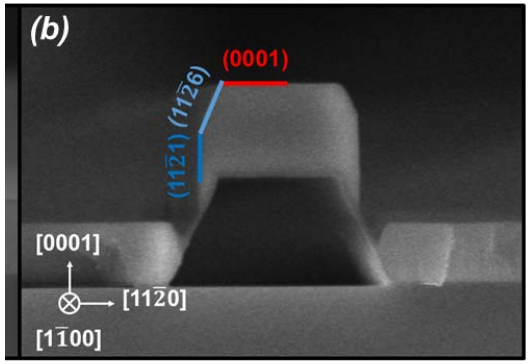
Epitaxial
growth

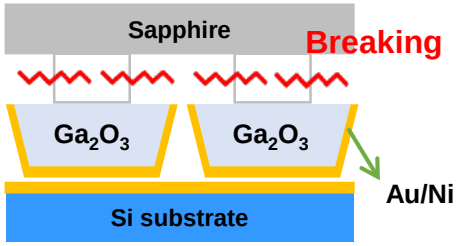


A discrete
epitaxial thin film arrav

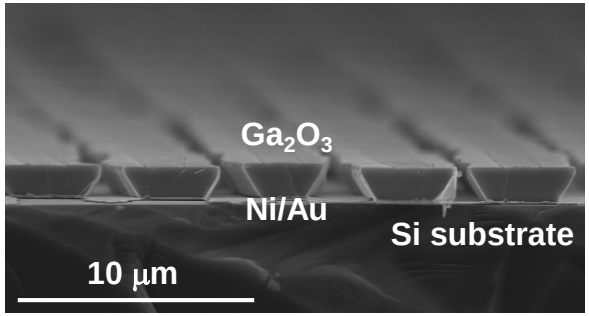


- Mechanical lift off to support layer (Flexible substrate)





Wafer bonding



Transferred $Ga2O_3$ by MLO

Summary

- ✓ **Solid-phase crystallization of 3-D Al_2O_3 membrane structure was investigated, showing the phase transformation sequence from amorphous to γ-(SPE & RNG) and then to α-phase (SPE).**

- ✓ **TEM analysis show the fully crystalized sapphire nano-membrane, which means it can be used for sapphire substrate**

- ✓ **Selective growth of epitaxial Ga_2O_3 thin film on sapphire nano-membrane was successfully achieved.**

- ✓ **Sapphire nano membrane is the novel strategy of transfer to flexible substrate.**

THANK YOU FOR LITENING