Room Temperature Bonding of Sapphire with Sapphire or Metal Substrates in Air using Au Films

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1. Introduction

◇ Sapphire shows various attractive properties
- High mechanical stress resistance (Young's modules)
- High thermal conductivity
- High chemical stability
- Wide band transmittance property for optical light.

◇ Widely used as a wafer material for electronic or light devices, MEMS, watches, and so on.

Figure 1. sapphire substrates

Room temperature bonding using Au films in air [1,2] was applied for bonding sapphire–sapphire and sapphire–metal substrates.

<Purpose> To develop the potential applications of sapphire using room temperature bonding.

[1] T. Shimatsu and M. Uomoto, ECS Trans., 33, 61 (2010)
[2] H. Kon, M.uomoto and T. Shimatsu, WaferBond'13, P18, Srockholm (2013)

2. Bonding procedure

Bonding using Au films in air

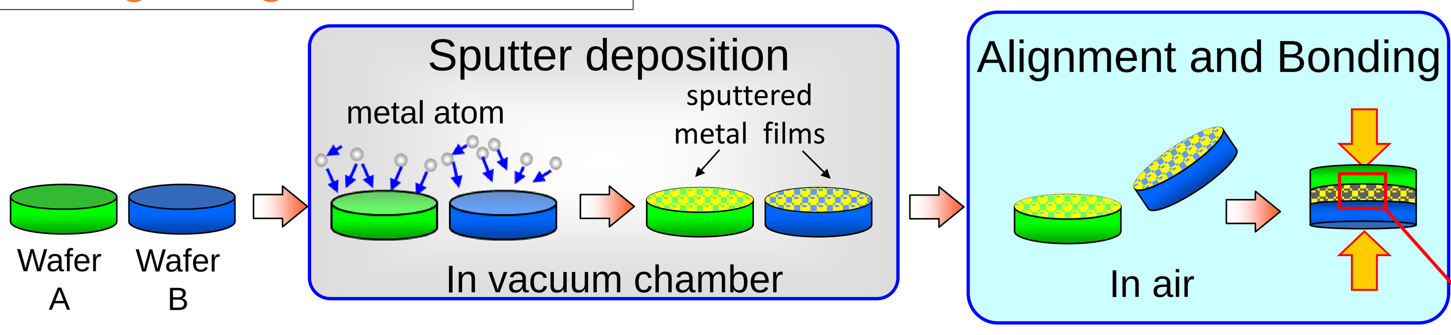


Figure 2. bonding using Au films

◇ Au (20, 50, and 75 nm) films with Ti (5 nm) underlayers on both side.

◇ Bonding was performed in air at room temperature.

◇ Bonding samples: Sapphire
Mirror-polished (CMP) SUS and Al

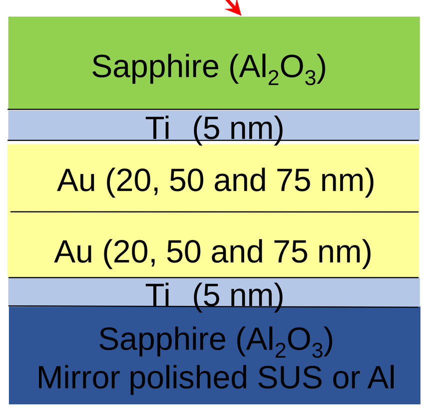
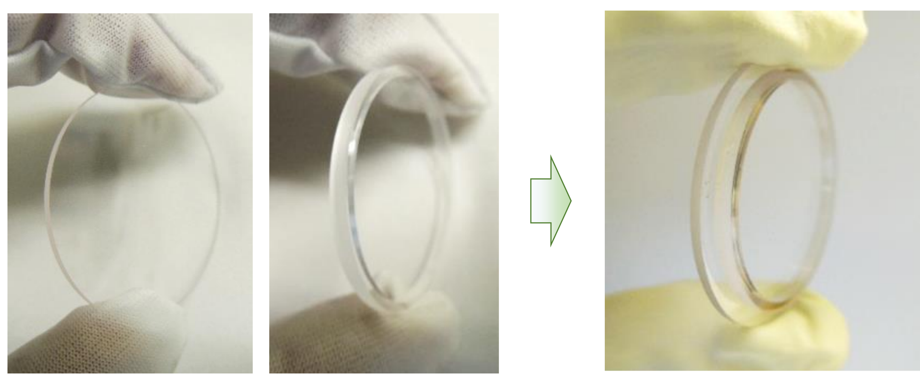


Figure 3. film thickness

3. Bonding of sapphire and sapphire

◇ Sapphire substrates were bonded over the entire bonding area.



Sapphire plate Sapphire ring Bonded sample

Figure 4. Bonding samples

- Sapphire ring:
  φ32 mm-φ29.5 mm-2 mmt
- Sapphire plate:
  φ36 mm-1.2 mmt
- Bonded area: 1.23 cm^2
- Loading pressure force:
  10-50 MPa

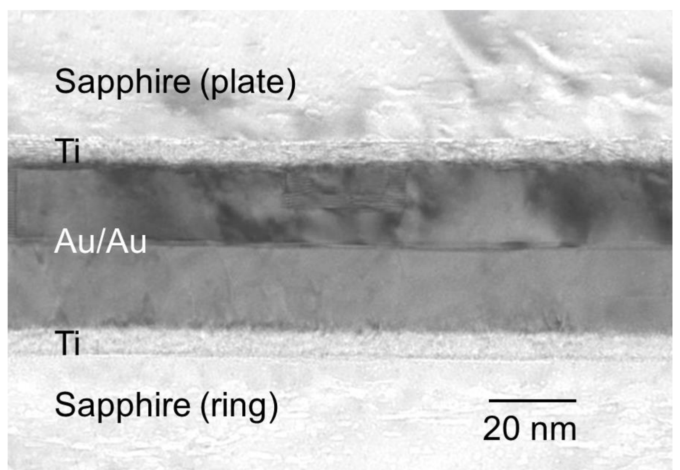


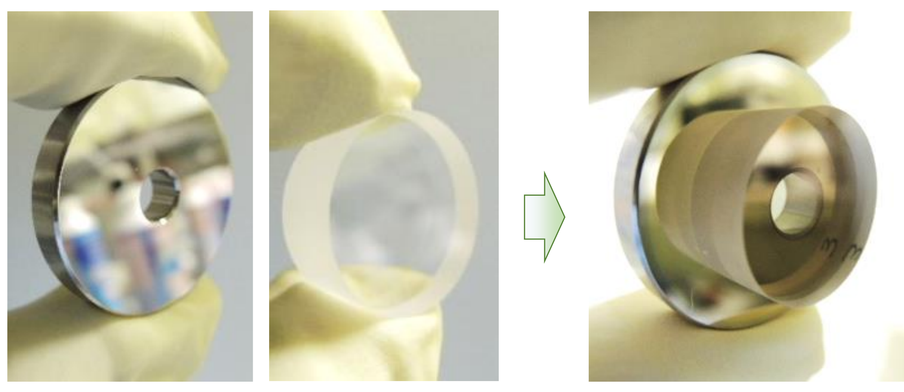
Figure 5. TEM cross-section image (BF)

<Structure (TEM cross-section images)>
- No vacancy was observed at the bonded interface.

<The bonding strength>
- Samples passed the 1 m height drop test using a metal case.
- No problems with water resistant test of 1 MPa.

4. Bonding of sapphire and mirror-polished metal

Bonding of sapphire and SUS was achieved.



SUS Sapphire Bonded sample

Figure 6. Bonding samples (SUS and sapphire)

- SUS ring
  φ24 mm-φ5 mm-4 mmt
- Sapphire plate
  φ15 mm-6 mmt
- Bonded area: 1.57 cm^2

A loading pressure force F of 10–50 MPa was necessary for bonding (depending on the surface flatness of these substrates).

<TEM cross-section image>

◇ Images show that no interface corresponding to the original Al surfaces is visible; no vacancy is observed.

⇒ Recrystallization occurred at Au/Au bonded interface.

◇ BF and HAADF images show that the interface between Ti underlayer and SUS is unclear compared to that on the other side.

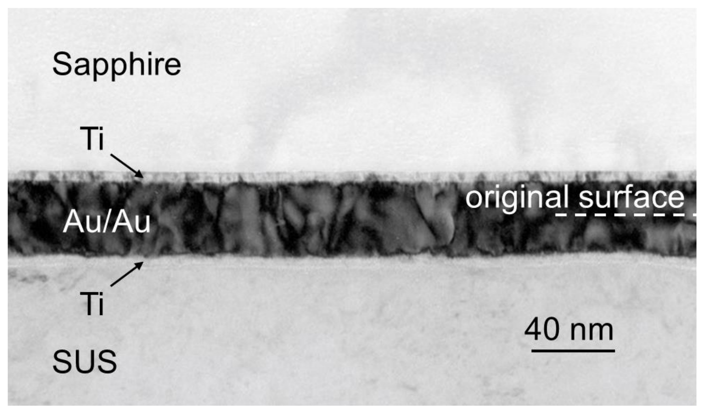


Figure 7. TEM cross-section image (BF)

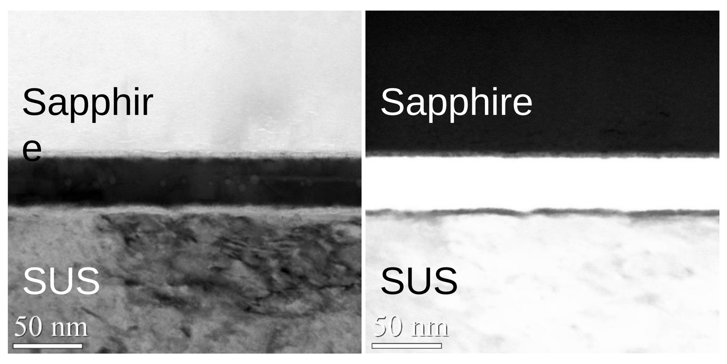


Figure 8. TEM cross-section image
(1) BF-STEM (2) HAADF-STEM

<EDX Elemental mapping> Measured elements: Ti, O, Au, Fe, Cr and Ni

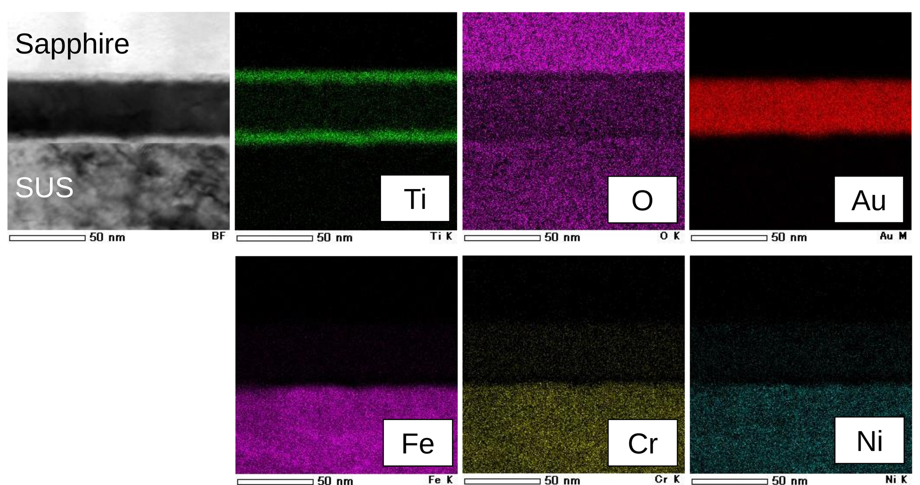


Figure 9. elemental mapping

◇ Ti is clearly observed on both side of Au/Au bonded films.

◇ Oxygen exists overlapping with Ti underlayers.

⇒ The Ti underlayer is likely to be oxidized.

<EELS spectrum> Comparing Ti layers on both sides to reference TiO_2.

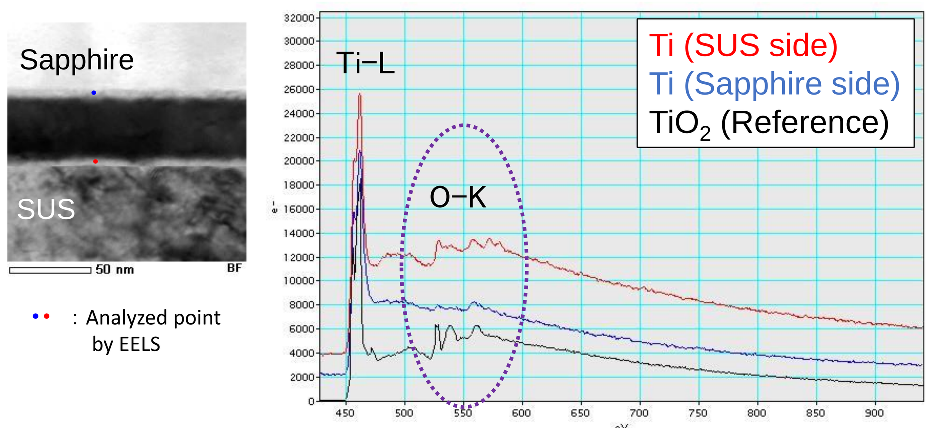


Figure 10. EELS

◇ Spectrum peek of Ti (Lα) is observed in both Ti layers.

◇ Ti layer on the SUS side shows a clear peek of O (Kα), and its spectrum is similar to that of reference TiO_2.

Oxidization of the Ti layer on the SUS side is probably caused by the oxygen dissociated from the CrO_2 surface layer of SUS. Actually the free energy of formation of oxide compounds from Ti is smaller than that of Cr.

Bonding of sapphire and Al was also achieved.

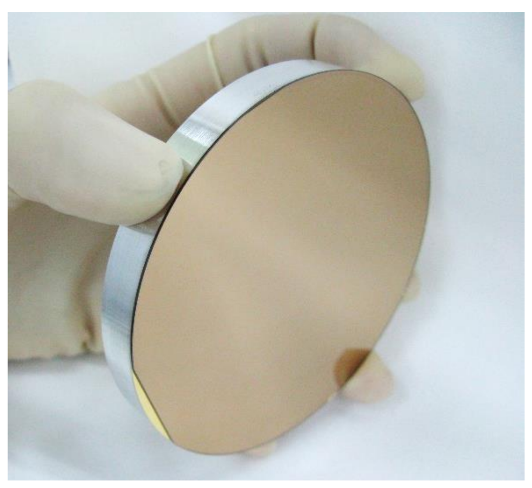


Figure 11. Bonding sample
(Al and sapphire)

- Aluminum substrate
  φ76 mm-8 mmt
- Sapphire substrate
  φ76 mm-0.55 mmt
- Bonded area: 45.37 cm^2

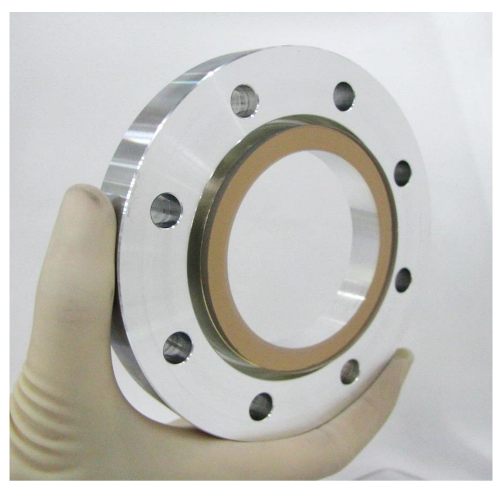


Figure 12. Viewing port
(bonded Al and sapphire)

- Bonding area of the Al flange
  φ70 mm- φ58 mm- 8 mmt
- Sapphire substrate
  φ70 mm-3 mmt
- Bonded area: 12.06 cm^2

5. Summary

◇ Room temperature bonding of sapphire with sapphire and metals (SUS, Al) was achieved using Au films in air with reliable bonding strength.

◇ The bonding technique can support expansion of the potential applications of sapphire in diverse industries.