Surface Modification for High Reliability and Reversible Hybrid Interconnection

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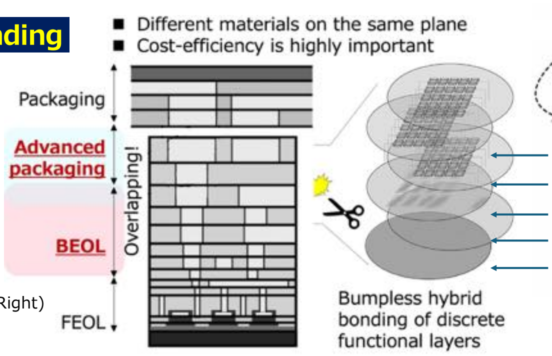
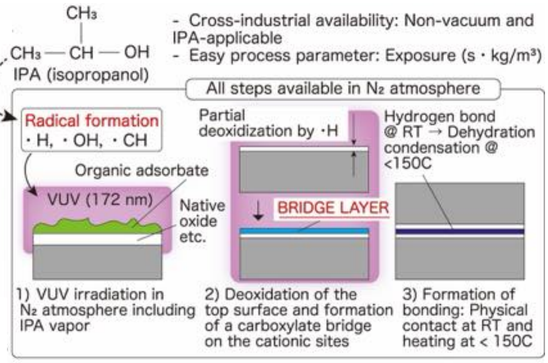
Background: Reversible Bonding

For the ecology and economy of hybrid bonding in E packaging:

- Multi-materials compatibility
- **Non-vacuum**
- **Low temp <150°C**
- **High interfacial reliability**
- **Easy solid-state debonding**

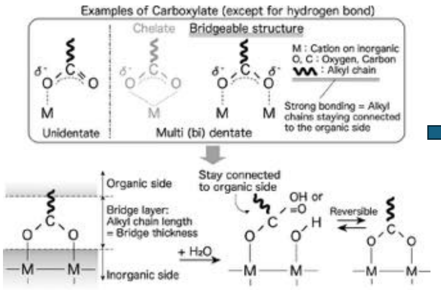




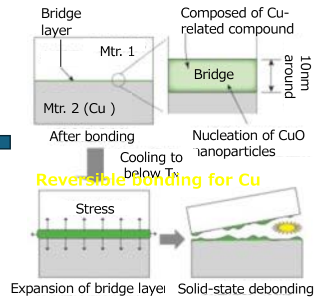
(Left) Concept of seamless hybrid bonding; (Right) Outline of the vapor-assisted VUV surface modification method.

Methodology: Anti-hydrolytic bridge layer with CuO nanocrystals for easy debonding through cooling

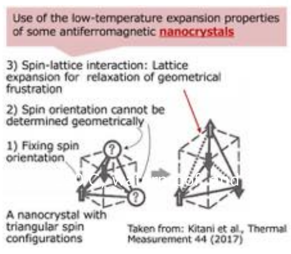
- A **multidentate carboxylate**-carrying bridge layer with self-generating CuO nanocrystals
- **Steep expansion of CuO due to the spin-lattice interaction** at around -100℃



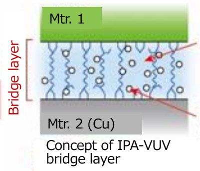
Concept of an anti-hydrolysis bridge structure utilizing multidentate inorganic carboxylate materials

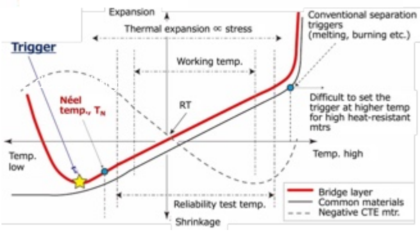


Concept of a solid-state debonding from the bond interface ← Pat JP 07597418, PCT 027099



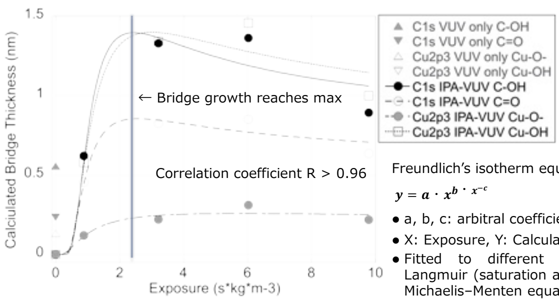
Spin-lattice interaction in antiferromagnetic nanocrystals with a triangular spin configuration





Concept of a new solid-state debonding trigger

Results : Reversible bonding for Cu – bonding @ 150℃, waterproof, and solid-state debonding @ -100℃



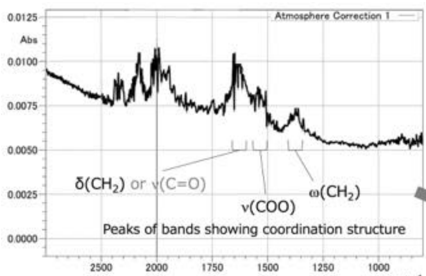
Relationship between Exposure and the calculated bridge layer thickness obtained from the curve fitting results of angle-resolved spectra.

- Approximate curve was forced to go 0 when E is 0, assuming that no beidge formation at E=0.
- Maximum point was evaluated from different element peaks.

Freundlich's isotherm equation :

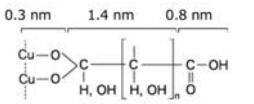
$$y = a \cdot x^{b \cdot x^{-c}}$$

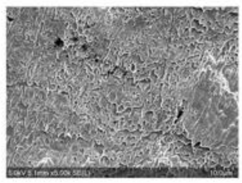
- a, b, c: arbitral coefficient
- X: Exposure, Y: Calculated bridge thickness
- Fitted to different isotherm equations . 1) Langmuir (saturation at monolayer formation), 2) Michaelis–Menten equation (layer growth including chemical reaction inside) , 3) **Freundlich equation (successive adsorption, only at the top of the layer)**



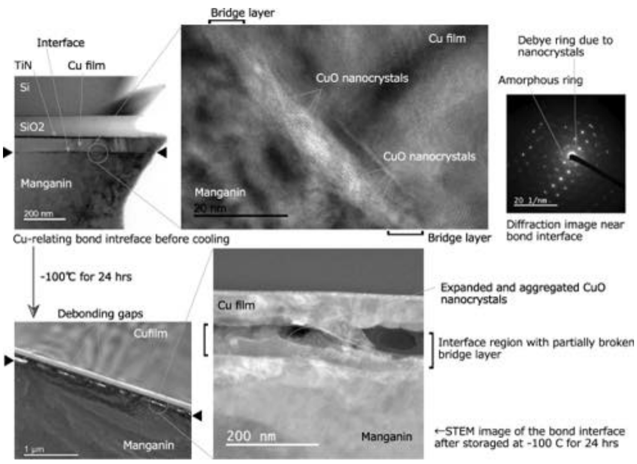
ATR-FTIR spectra of oxygen-free copper surface treated with IPA-VUV E=6.028 s·kg/m -3. Ref : Fausto et al., J. Molecular Structure 349 (1995) 439.

JIEP/IEEE EPS/iMAPS ICEP2024, ADMETA Plus Tutrial 2023 etc.





Scanning electron microscope (SEM) image of fracture surfaces after shear test of oxygen-free copper.



- Easy solid-state debonding: < 20 MPa @ 85℃-85% RH testing ⇒ > 0.4 MPa after cooling @ -100℃
- Self-generation and expansion of CuO nanocrystals were confirmed

Summary & future challenges

- Reversible bonding for Cu relating materials were realized with V-VUV method

- Future chip replaceability in Chiplet Packaging
- Reliable and cost-effective system integration with various signals, including organic substrates
- Batch fabrication process and equipment, from wafer cleaning to bonding