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Diffusion Bonding of ITER First Wall Structures

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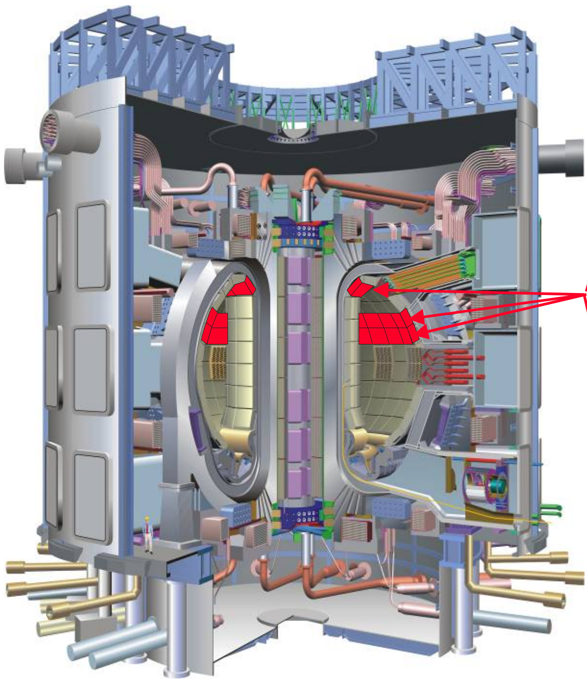
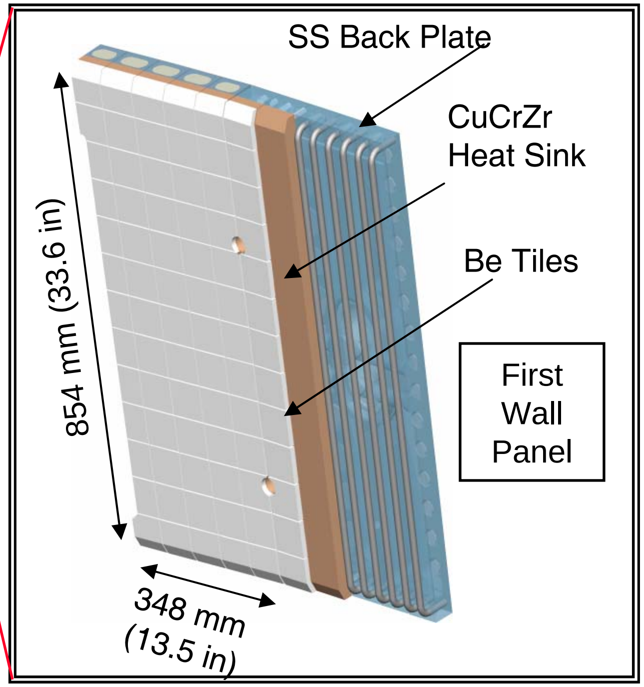
ITER – Joint International Effort on Fusion Energy





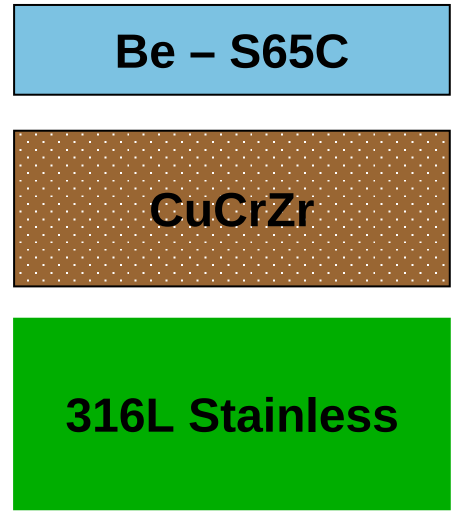
Party Teams

- **China**
- **EU**
- **India**
- **Japan**
- **Korea**
- **Russian Fed.**
- **USA**

- **Goal: Demonstrate fusion can be used to generate electrical power**
  - **Generate 500 MW of power (10x input power)**
  - **First fusion reactor to actually produce power**
- **Hardware mostly provide "in-kind" by the party teams**
- **First wall faces plasma and current design uses Be armor tiles**
- **Goal is to bond beryllium to copper alloy substrate**

Requirements and Limitations

- **Final structure requires two bonds**
  - SS to Cu alloy
  - Cu alloy to Be
- **Copper alloy is age hardenable**
  - C18150 - 0.1% Zr, 1.0% Cr, 98.9% Cu
  - Solutionize ~ 980 °C and H_20 quench
  - Peak aging ~ 475 °C
  - Requires solutionizing and aging!
  - CuCrZr YS/UTS(MPa) 175/280@RT, 150/220@250C
- **Environment necessitates robust bonds**
  - Components be intimately bonded to transfer heat
  - Tens of thousands of thermal cycles
  - Occasional very rapid high heat loads
    - 60 MJ/m^2 in 0.5 sec VDE load



Requirements and Limitations Cont.

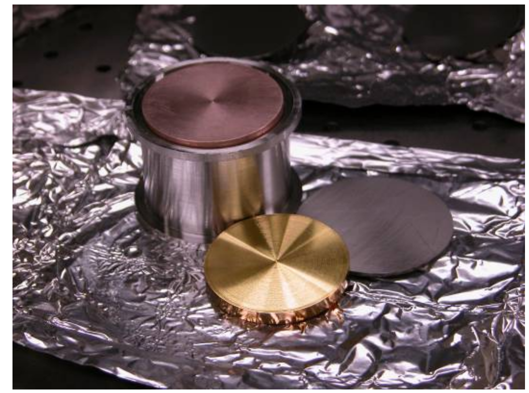
- **End result is many limitations**
  - **Melting point must be high – no Al**
  - **Can't add appreciable thickness – compliance layers?**
  - **No materials that activate – Ag » Cd, Au » Hg**
  - **Copper alloy needs to be heat treated**
  - **Sundry engineering issues**
- **Most obvious (logical?) approach**
  1. **Join copper alloy to stainless base**
  2. **Solutionize copper alloy**

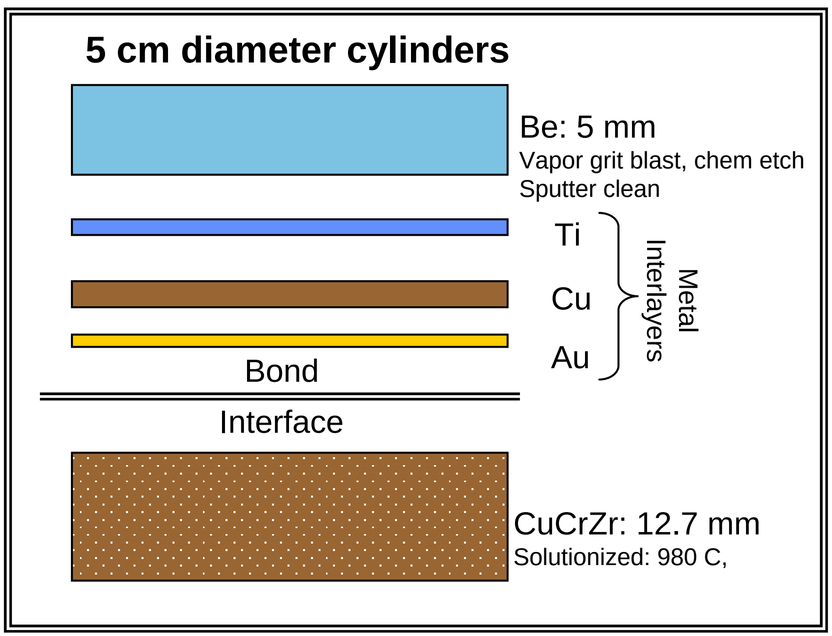
     } Combine? (items 1 and 2)
  3. **Develop a low temperature bonding process that joins and ages the copper at the same time**
     - **Aging characteristics of CuCrZr require < 600°C**

Traditional Joining Techniques Generally Not Acceptable

Approach

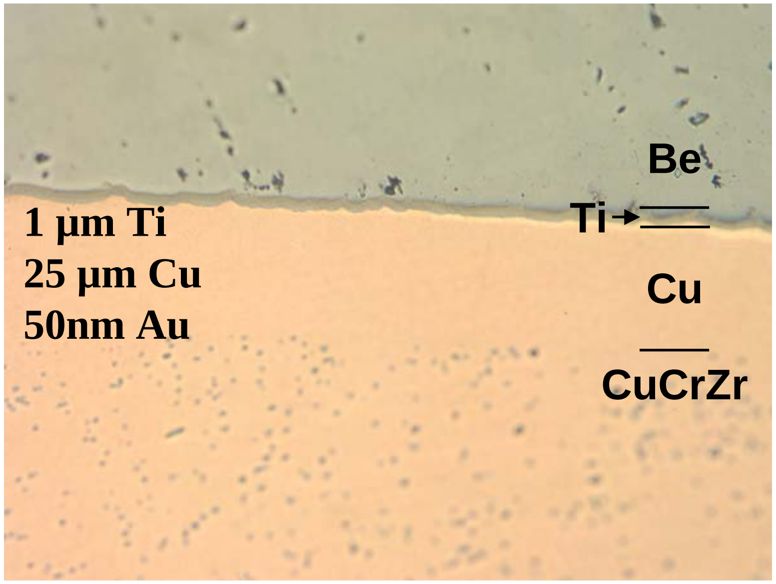
- **Metallization layers – physical vapor deposition (PVD)**
  - **Promote adhesion,**
  - **Provide compliance,**
  - **Inhibit undesirable intermetallics, e.g. Be-Cu**
  - **Provide an oxidation barrier**
- **Diffusion bond by hot isostatic pressing (HIP)**
  - **100 MPa, 580°C for 2 hours**

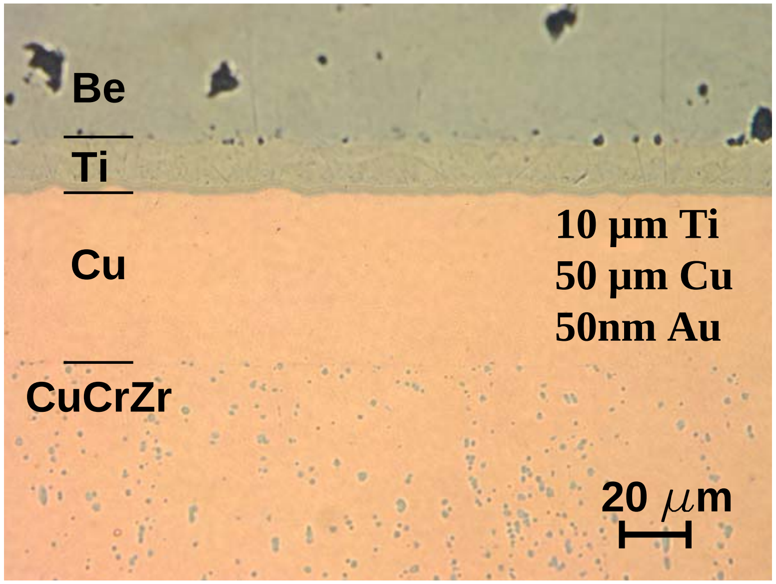




Index #	Ti Diffusion Barrier (μm)	Cu Compliant Layer (μm)	Au Oxidation Barrier (nm)
1	1	25	50
2	10	25	50
3	1	50	50
4	10	50	50

Metallography





- Specimens appear fully bonded – no obvious lack of bond defects
- Thickness of copper layer did not vary as expected (not 2x different)
  - "25 µm" specimen much thicker than expected ~ 50 microns
  - "50 µm" ~ 60 microns thick
  - PVD thickness incorrect, chrome diffusing???
- Titanium layer appears to be completely reacted for 1 micron

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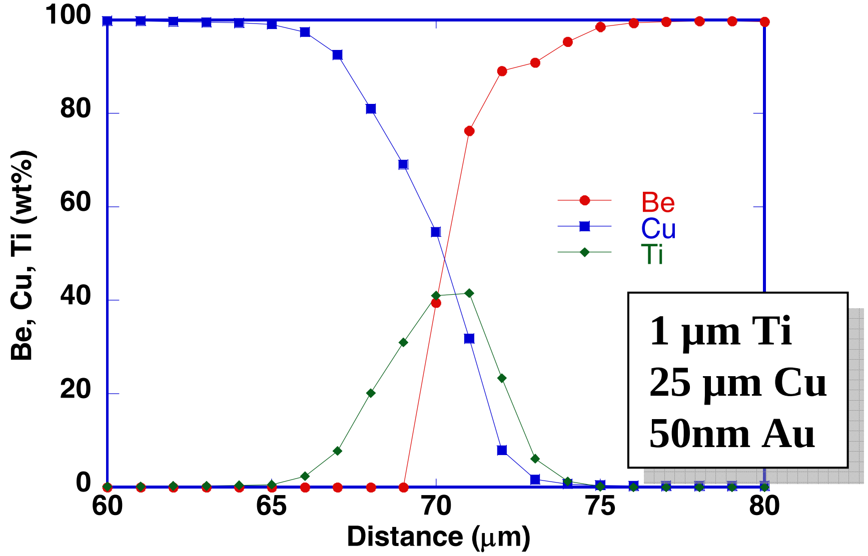
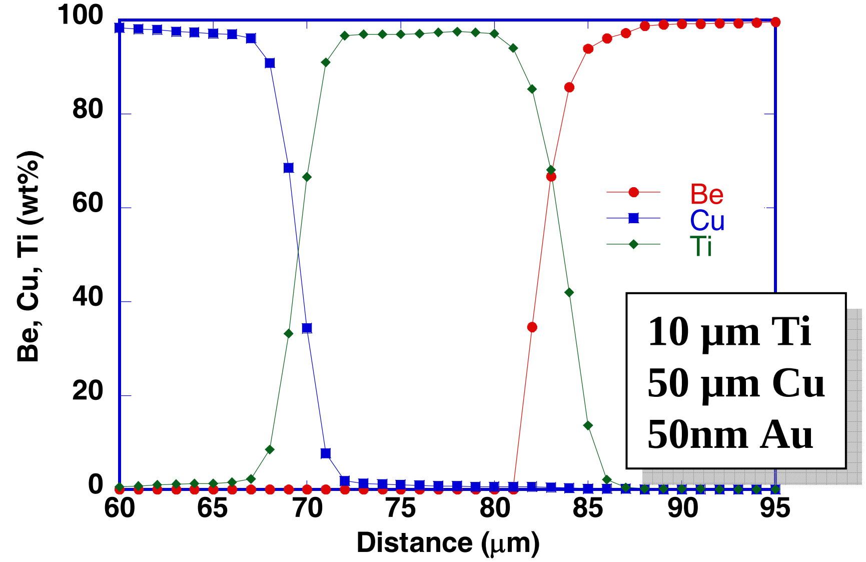
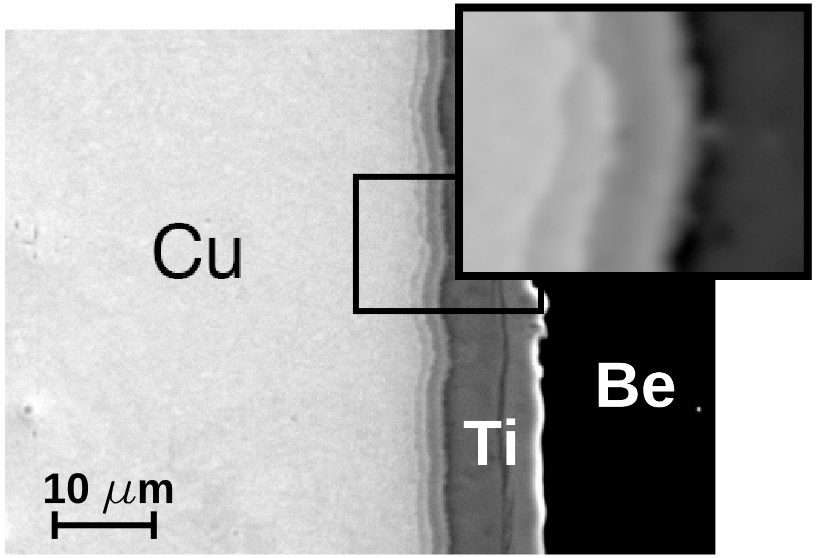
Electron Microprobe Traces of Interface







- **Backscattered images from the probe suggest that there may be multiple layers of interdiffusion**
- **Ti is effective in preventing copper and beryllium diffusion**
- **Insufficient resolution:**
  - **1 micron is Ti**
  - **Intermetallic layers?**

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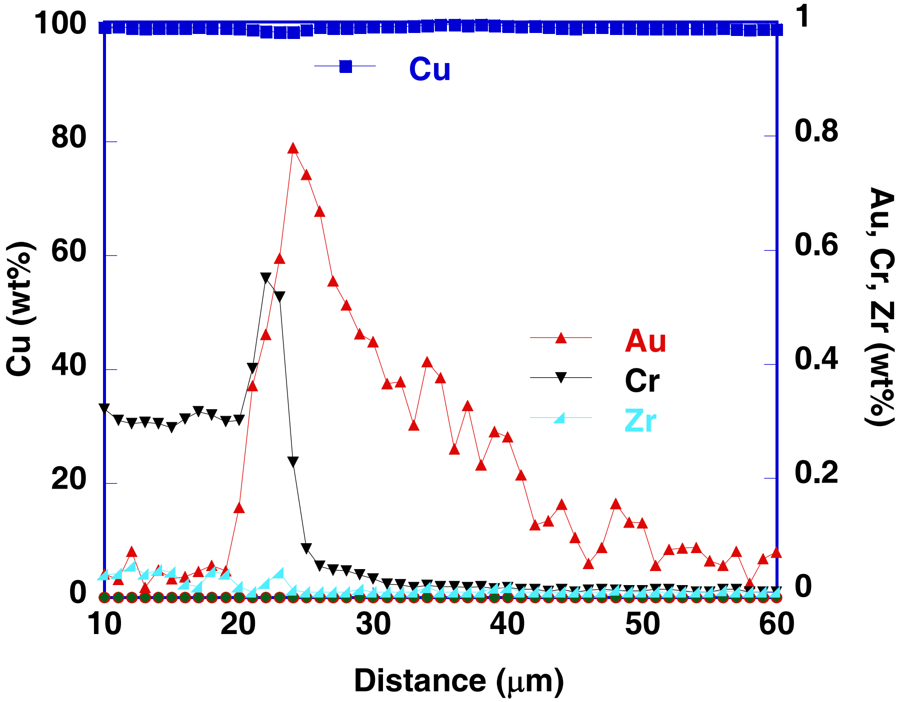
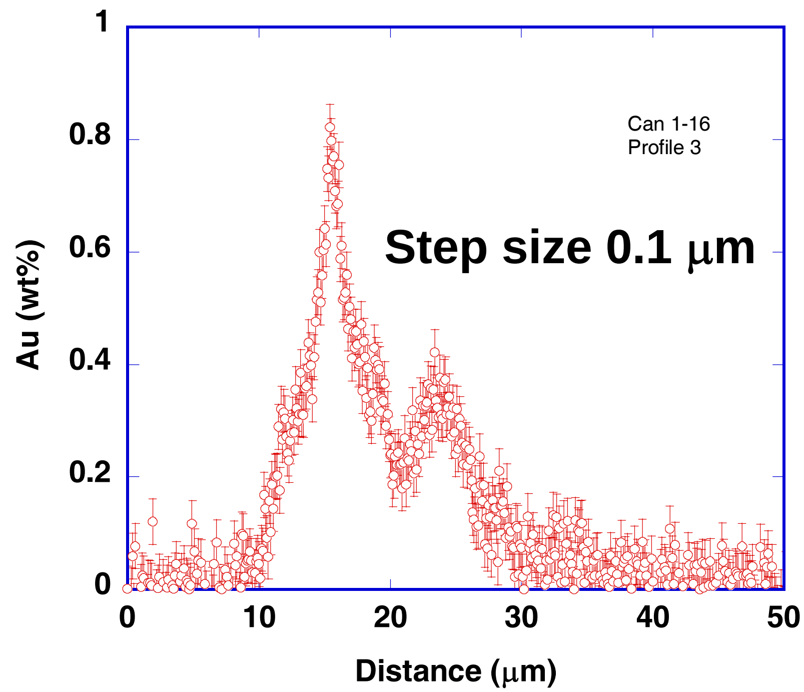
Gold Diffusion





- Same generic profiles for all samples
- Gold profiles displayed significant variability, maximum peak value <1 wt%
- Starting thickness was 50nm, so actual peak concentration may be higher
- After bonding there is still a significant amount of gold at the interface
- Future work will minimize or eliminate the gold

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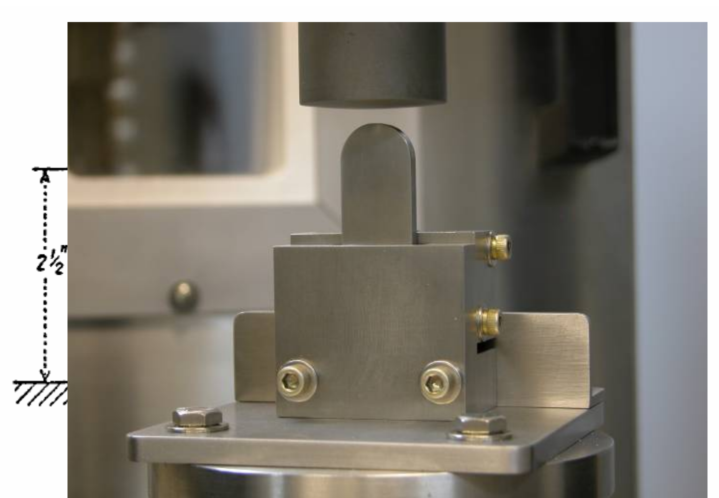
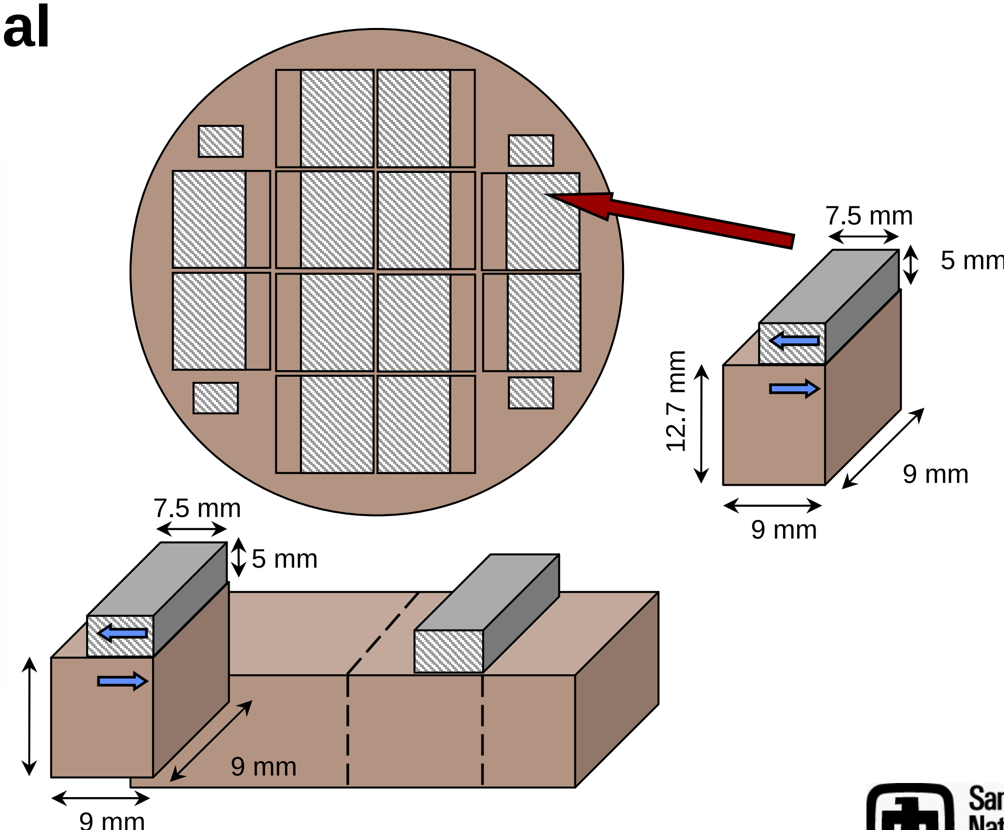
Shear Strength Testing

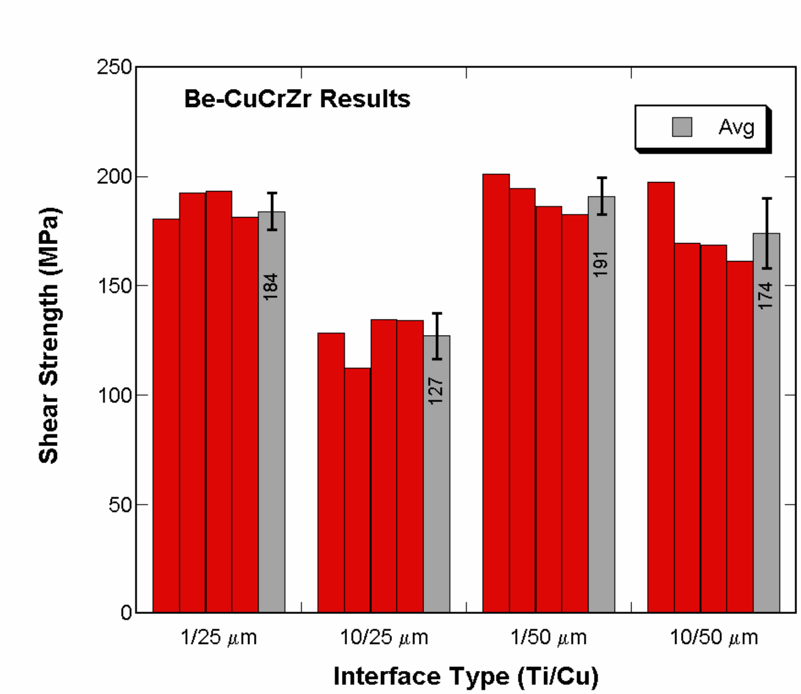
- **Shear coupons and metallographic specimens are extracted from bonded cylinders**
  - **Modified ASTM A263/DIN 50162 shear tests**
  - **Conserves material**

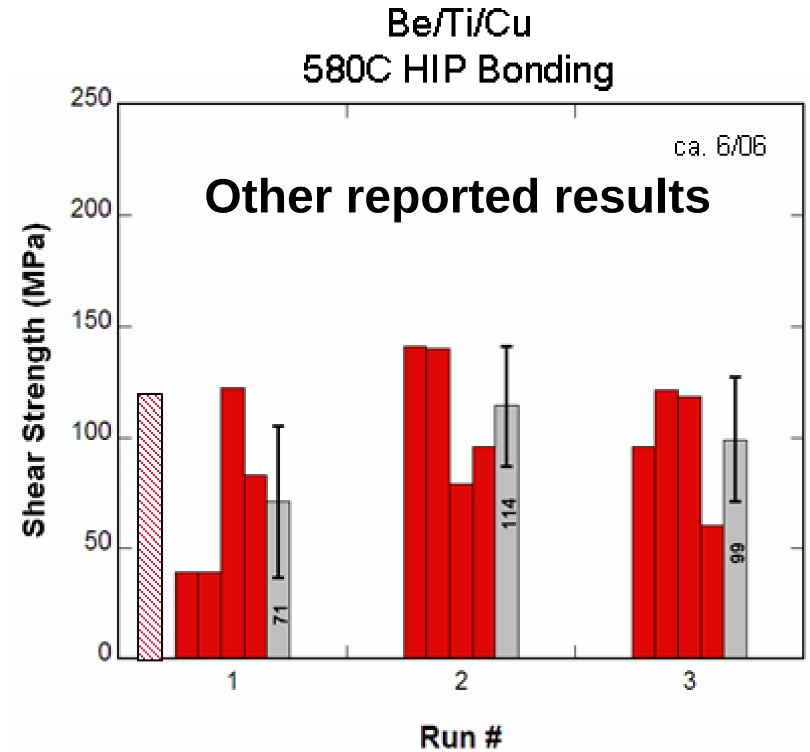


From ASTM A263



Shear Strength Testing Results





- Actual component requirements are for heat loads and cycles
  - No mechanical tests or requirements have been specified
- Shear samples were consistent within any group
- All results compared favorably with other reported results for similar testing

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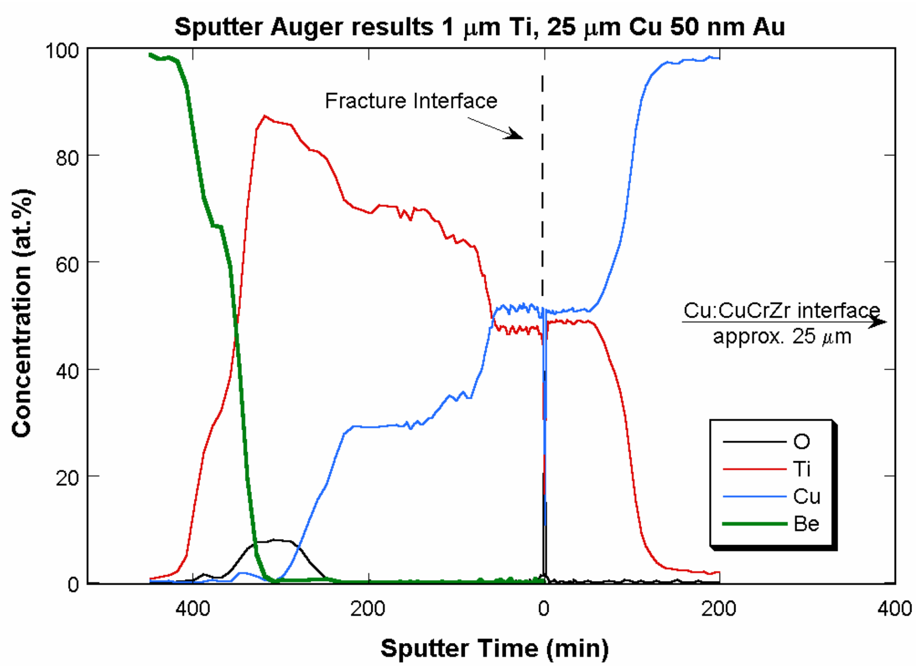
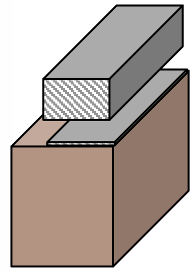
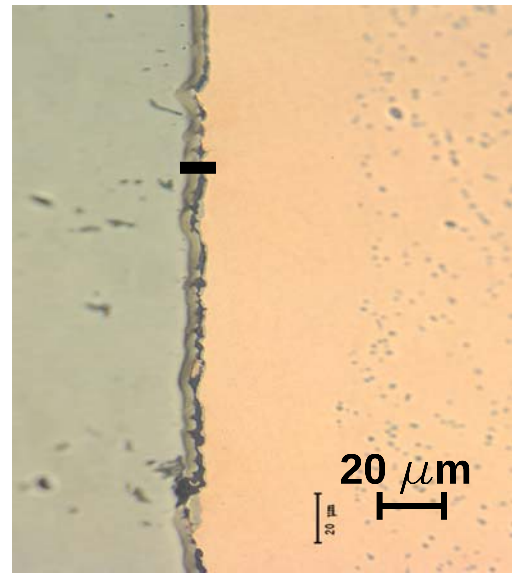
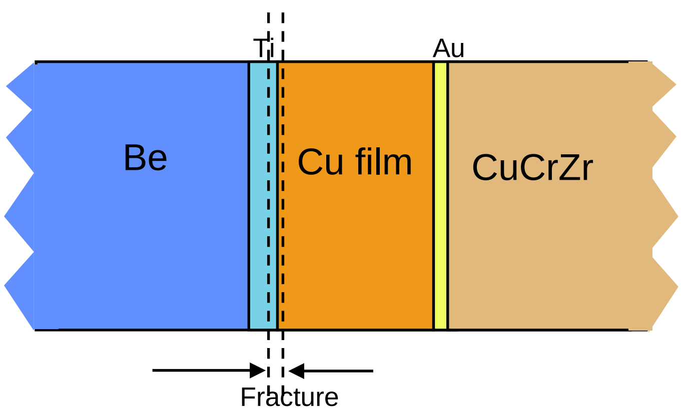
Auger depth profiling of fracture surface









- 1 µm Ti metallization
  - –Fracture is coincident with 50 at% Cu-50 at.% Ti that extends over some depth on either side of the fracture surface
  - –Cu penetration nearly to Be/Ti interface
    - Specify 2 µm Ti (min) metallizations for all future bonding studies

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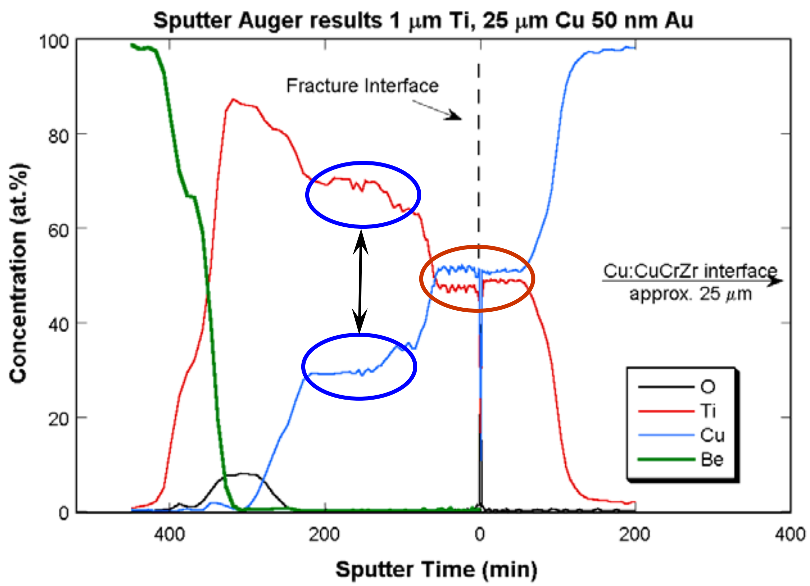
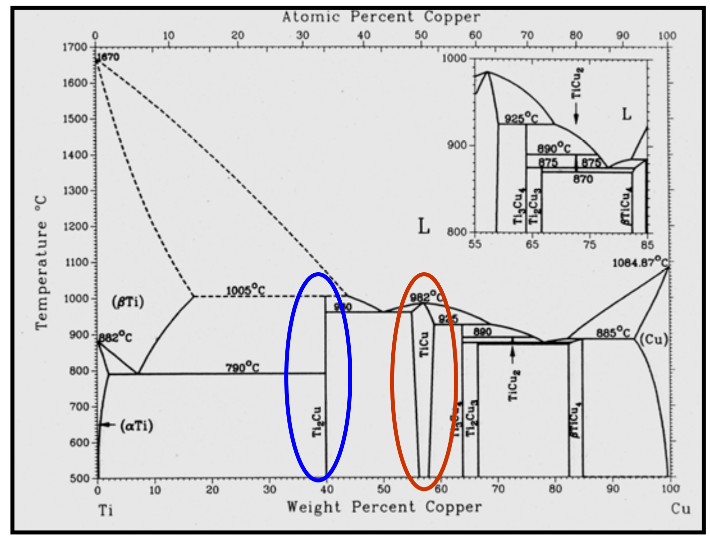
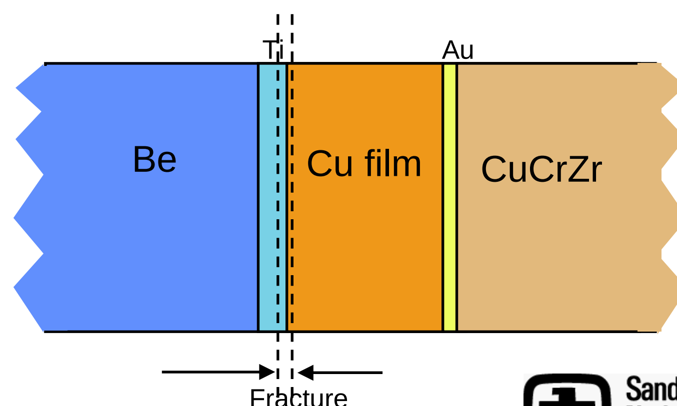
Auger Profiles/Intermetallic ID's





- •Plateaus in Cu-Ti depth profiles correspond to specific intermetallic compounds identifiable in the Ti/Cu phase diagram
  - –Ti_2Cu (η–phase)
  - –TiCu (ζ-phase)
- •No obvious Cu and Be interaction
- •Same generic profiles for all 4 joint types



Conclusions

- •Diffusion bonding using HIP produced favorable bonds
- •Ti, Cu and Au interlayers were effective
- •A minimum of 1 micron of Ti is necessary
- •Gold can still be detected after bonding
- •Two Cu/Ti intermetallics have been identified
- •Relatively high shear strength values were measured
- •Failure occurs in the TiCu intermetallic layer