High Performance Circuit Pastes for Solid Oxide Fuel Cell Applications

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Conventional Silver-Copper Oxide Reactive Air Brazes Have Many Benefits

• Ag-4CuO Brazes Are Less Permeable to $\text{H}_2$ and $\text{O}_2$ than Glass Seals
• Ag-4CuO Brazes Are More Ductile than Glass Seals, So CTE Mismatch is not a concern
• Ag-4CuO Brazing can be performed in air
• No flux is needed to utilize Ag-4CuO brazes
• The enhanced wetting provided by CuO allows Ag-4CuO brazes to be used to bond to a variety of ceramics
Reactive Air Brazes Have Several Fatal Flaws

1. Reactive air silver brazes are only partially wetting, resulting in occasional manufacturing defects (**Type I Pores**);

2. Reduction of reactive air additions (CuO) by hydrogen during SOFC operation can result in **Type II Pores**;

3. After ~ 10,000 hours, **Type III pores** form when dissolved hydrogen and oxygen in the Ag react to form water pockets/pores.

Porous Nickel Layers Can Be Used To Promote Silver Wetting and Spreading on Ceramics

Porous Nickel Layers Can Be Used To Promote Silver Wetting and Spreading on a Variety of Ceramic Substrates

Without Porous Ni

With Porous Ni

Ag-Ni Braze/Circuit Fabrication Procedure

Step 1: Print Ni paste on the substrate
Step 2: Print Ag paste overtop the Ni paste pattern,
   Or place Ag foil on “nearby” contiguous Ni pattern
Step 3: Heat to 850°C for 2 hours in Ar with carbon as an oxygen getter
to sinter the Ni and then hold at ~1000 °C to melt Ag

Porous Nickel Layers Can Be Used Instead of Reactive-Air Brazes to Bond Metals to Ceramics

The Nickel That Promotes Ag Wetting is Transient When Used to Bond to Stainless Steel

Porous Nickel Layers Can Also Be Used For Ceramic-Ceramic Bonding

Ni is Green, Pores are Black, Sapphire is Gray, and Silver is Transparent

The data for this 3D X-Ray tomography reconstruction was obtained at Argonne National Laboratory

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Patterned Silver Circuits Can be Made by Applying Silver Ink Over Nickel Ink and Firing Together

As-printed

As-fabricated

Air/850°C, 5 hrs

Patterned Silver Circuits Can Also Be Made by Infiltrating Molten Silver Into a Pre-Patterned Nickel Network

MOVIE: Molten Silver Defying Gravity as it Infiltrates Into a Pre-Patterned Nickel Network

Temperature: ~1000ºC
Atmosphere: Carbon and Nickel Oxide Buffered Argon

Ag-Ni Current Collectors Adhere Better than Commercial Silver Paste

Ag-Ni Current Collectors Have Similar In-Plane Electronic Resistivity as the Best Commercial Silver Pastes

Ag-Ni Current Collectors Have Similar Contact Resistances on LSM to the Best Commercial Ag Pastes

LSM ferromagnetic-paramagnetic transitions

Bhatlawande et al., In Preparation., (2022).
Ag-Ni Current Collectors Adhere Better than Silver Paste, Have Similar Electronic Resistivity

We are working on lowering the nickel content/optimizing the nickel microstructure

Conclusions

- The use of porous interlayers to direct the wetting and spreading of molten metals can be used to produce better brazes and better electrical contacts than those possible with sintered metal contact pastes or reactive air brazes.
Backup Slides
Both Ag and Ag-Ni Samples Fractured Along the Metal-Sapphire Interface

The fracture of (a) air annealed Heraeus C8710, (b) as-produced Ag-Continuous Ni, (c) air annealed Ag-Continuous Ni, (d) air annealed DAD-87