Effect of sheath material and reaction overpressure on Ag extrusions into the TiO_2 insulation coating on Bi-2212 round wire

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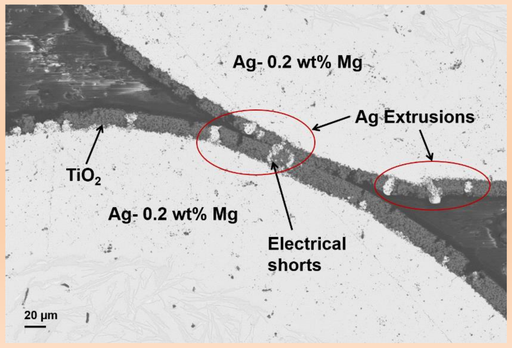
Our Motivation:

- TiO_2 has emerged as a suitable insulation material for Bi-2212 round wire.
- However, a large Bi-2212 test coil with TiO_2 insulation suffered from severe electrical shorting after overpressure heat treatment (OPHT) due to frequent silver "extrusions" through gaps in the TiO_2.
- In this study, we tried to understand what caused the Ag extrusions and how we can prevent them.

Coil cross section

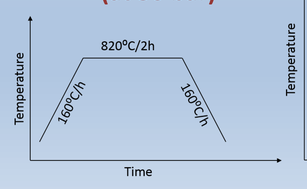


Bi-2212 coil with TiO_2 insulation coating

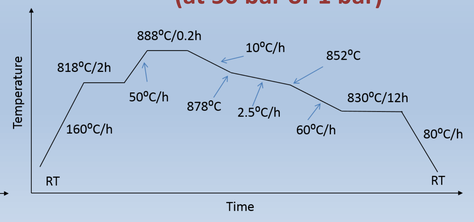
What we did:

- Standard heat treatment at 50 bar overpressure (OPHT) or at 1 bar using Ag-0.2 wt% Mg alloy sheathed Bi-2212 wires (hereafter Ag(Mg) wire) was carried out to understand the role of pressure in Ag extrusions. 1 bar oxygen partial pressure (PO_2) was maintained in both cases.
- Standard OPHT of pure Ag sheathed Bi-2212 wires were also performed to investigate the effect of sheath material.
- Densification of Bi-2212 wires occur during OPHT. To understand what happens if we densify the wire before coating with TiO_2, we carried out a predensification (PD) heat treatment of Ag(Mg) wire at 50 bar (800°C for 2 hours, 1 bar PO_2) followed by insulation with TiO_2 and 50 bar OPHT (PD+OPHT).

Predensification heat treatment (at 50 bar)



Standard heat treatment (at 50 bar or 1 bar)

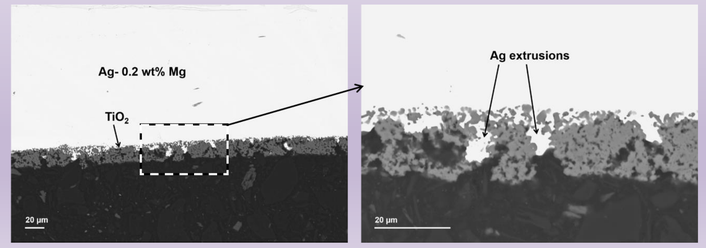


- Wire diameter generally reduces by around 4% during OPHT. PD allows 80% of this shrinkage due to densification to occur before full OPHT.
- High angle annular dark field scanning transmission electron microscopy (HAADF-STEM) revealed the distribution of MgO in the Ag(Mg) wire after the usual full OPHT.

Things we observed using SEM and HAADF-STEM:

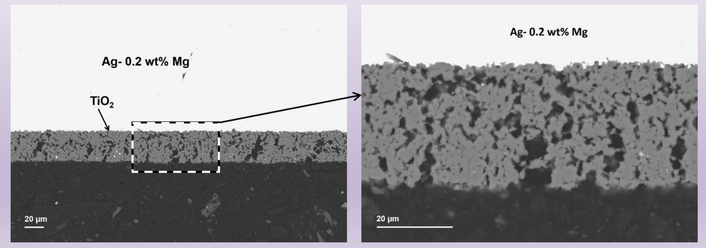
Effect of pressure: *50 bar OPHTed Ag(Mg) wire:*

- **Frequent Ag extrusions** through the TiO_2 insulation layer was evident in 50 bar OPHTed Ag(Mg) wires.
- Ag extrusions were randomly distributed throughout the sheath-insulation interface. Their size and shape were uneven.



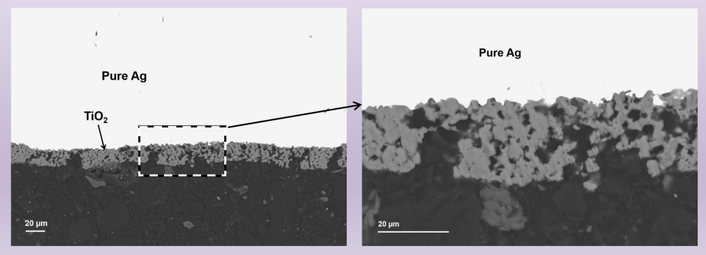
Effect of pressure: *1 bar processed Ag(Mg) wire:*

- **No extrusions** through the insulation layer were found.



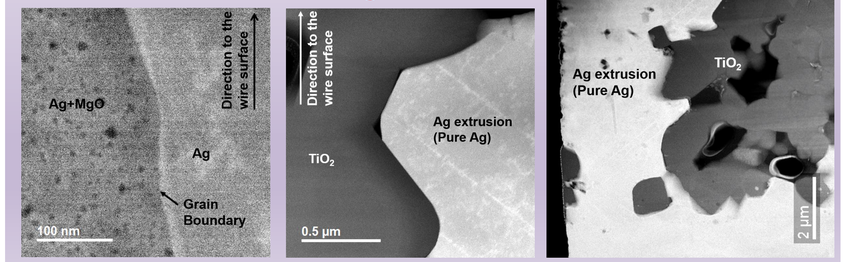
Effect of sheath material: *50 bar OPHTed pure Ag sheathed wire:*

- Pure Ag-sheathed wires were **free from extrusions** just like 1 bar processed Ag-Mg sheathed wire.



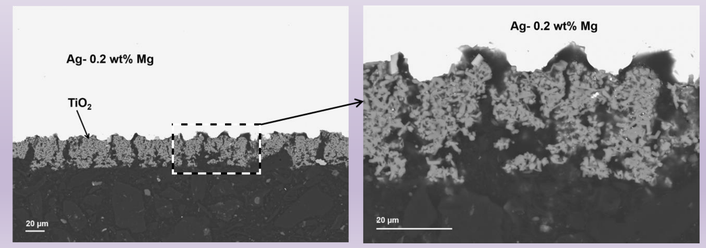
HAADF-STEM analysis: *50 bar OPHTed Ag(Mg) wire:*

- **Variation in the distribution of magnesium oxide** (MgO) was found between different grains in the Ag(Mg) sheath.
- In general, the density of MgO decreses towards the wire surface.
- The **Ag extrusions** through the insulation were found to be **devoid of MgO**.



Effect of Predensification: *50 bar PD+OPHTed Ag(Mg) wire:*

- **No Ag extrusions** into the gaps of TiO_2 were found in this wire but quasiperiodic undulations appeared at different places under the insulation layer.



Our conclusions:

- Ag extrusions occur only when Ag(Mg) wire undergoes the full heat treatment at substantial overpressure with TiO_2 insulation.
- Ag extrusions through the Ag(Mg) sheath are MgO-free, or atleast lack MgO precipitates compared to the bulk of the sheath, suggesting that extrusion occurs due to local, heterogeneous deformation of the outer sheath under hydrostatic overpressure.

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