U.S. MAGNET DEVELOPMENT PROGRAM

Addition of a barrier layer for Cu/Ag-sheathed 122-type wires and tapes

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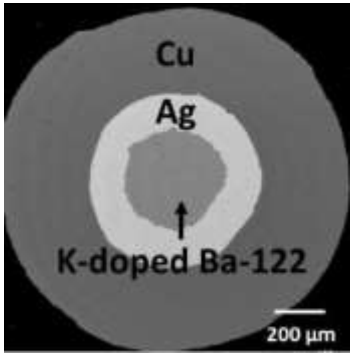
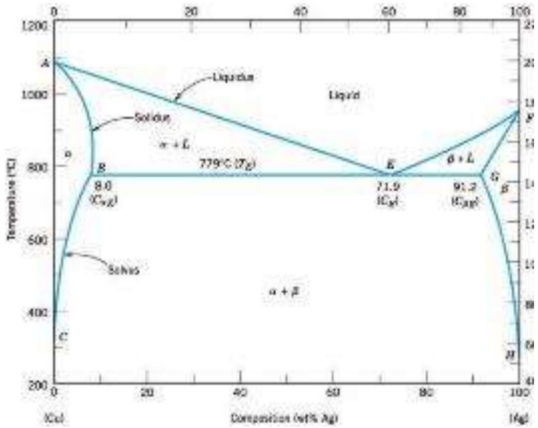
Motivation

- ❑ **This work was inspired by some issues mentioned in some talks in the ASC'20 & CEC-ICMC'21.**
- ❑ A promising design for 122 wires/tapes: Cu/Ag sheath. To avoid liquid formation, HT below 779C.



Weiss et al., *Nat. Mater.* 2012; 11: 682-5

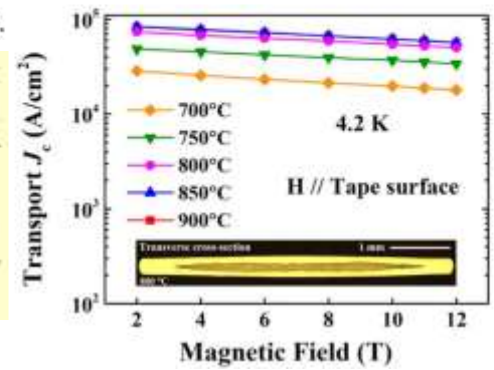


Issue #1: compromised HT

✓ Low sintering temperature is one of the problems existed in Cu/Ag composite sheathed wires.

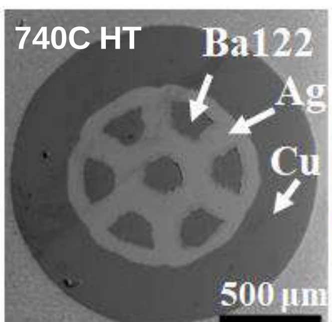
- ➢ Restricted by the meating temperature of Cu/Ag, the final sintering temperature must be lower than 750°C.
- ➢ But for 122 tape, the optimal annealing temperature is higher than 850°C.

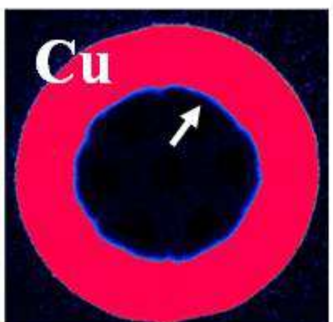
Zhang, **WK2MOr2B-08, ASC'20**



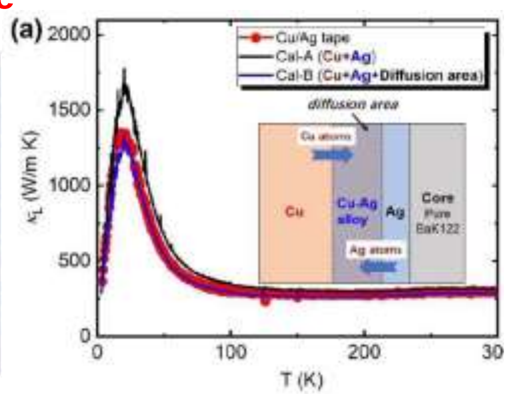
Huang et al, SUST, 2019, 025007

#2: Cu-Sn interdiffusion in solid state





Yao, **M4Or1B-01, CEC-ICMC'21**



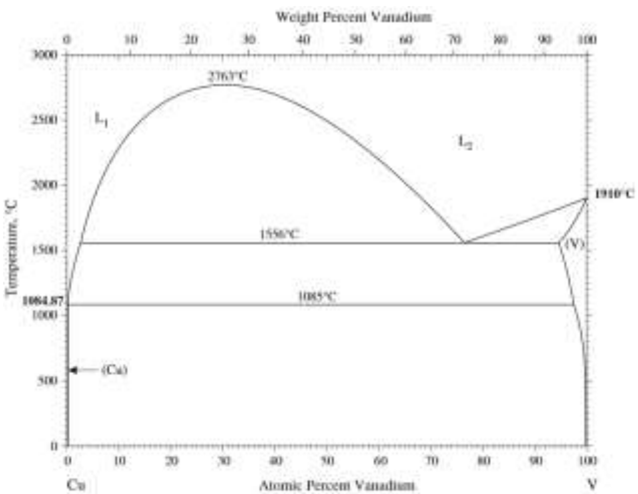
Dong, **M4Or1B-02, CEC-ICMC'21**

- A possible solution: add a barrier.
- The key is the barrier material.
- Meanwhile, I was asked to join an existing IBS LDRD (PI: Z Sung).
- Decided to use this opportunity to explore the feasibility.

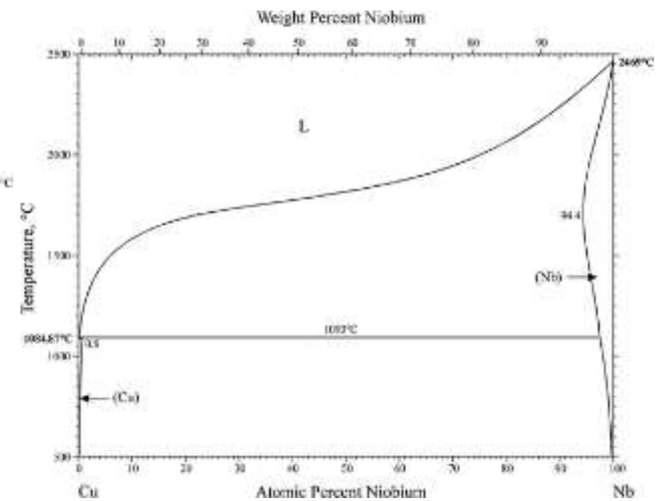
Selection of the barrier materials

- The group-VB metals (V, Nb, Ta) are generally inert to both Cu and Ag, making them good candidates.
- All of these metals have already been used as barrier materials for Nb_3Sn conductors.

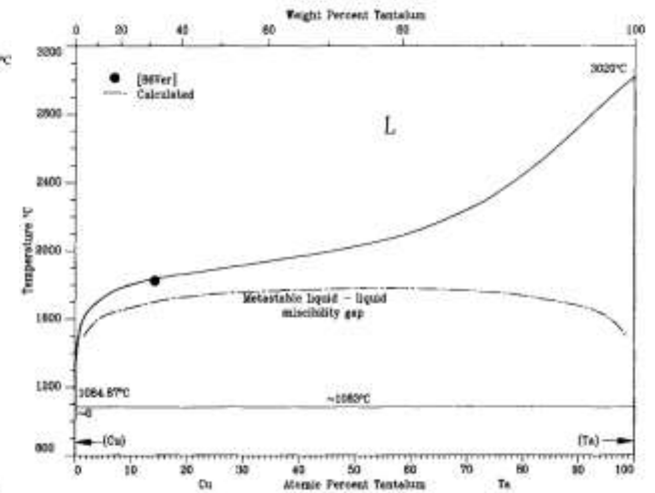
Phase diagram: Cu-V



Cu-Nb



Cu-Ta



No phase diagram for Ag-V, Ag-Nb, Ag-Ta can be found, because they are immiscible.

- The major questions this work needs to answer are:
  - Can the barrier layer withstand severe deformations – wire drawing & flat-rolling (wires → tapes)?
  - Can they really prevent Cu-Ag interdiffusion even at 900C, allowing a wider HT window?
- Started with Nb and Ta, due to limited availability of the high-ductility V.

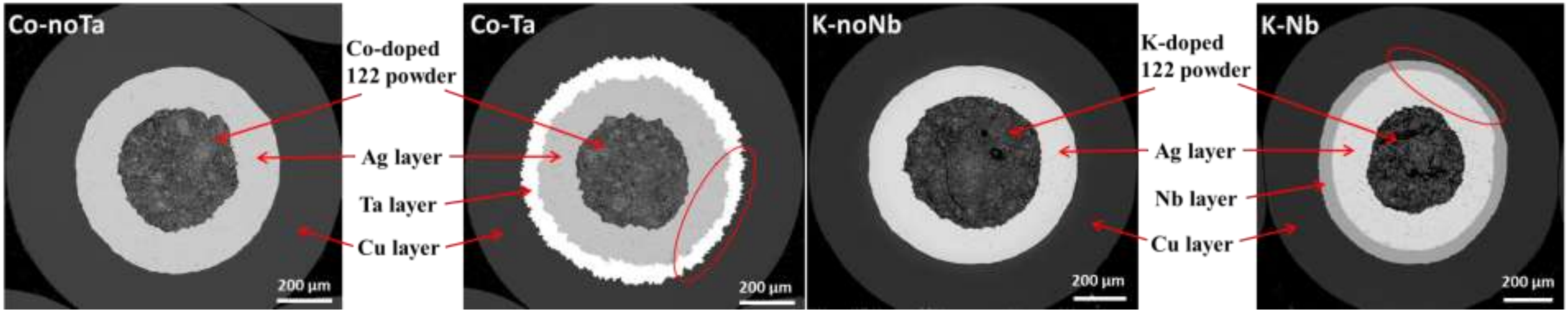
Mono-filamentary wires fabricated

- 2 IBS powders were made in TUAT: $BaFe_{1.84}Co_{0.16}As_2$, $Ba_{0.6}K_{0.4}Fe_2As_2$; each filled into an Ag tube (4x6 mm).
- The Ag tubes were sealed in plastic bags under Ar and sent to Fermilab for wire fabrication.

Half of the Ag tube w/ Co-doped powder was wrapped tightly by >2 but <3 turns of 140 μm thick pure Ta foil.

Half of the Ag tube w/ K-doped powder was wrapped tightly by >2 but <3 turns of 130 μm thick pure Nb foil.

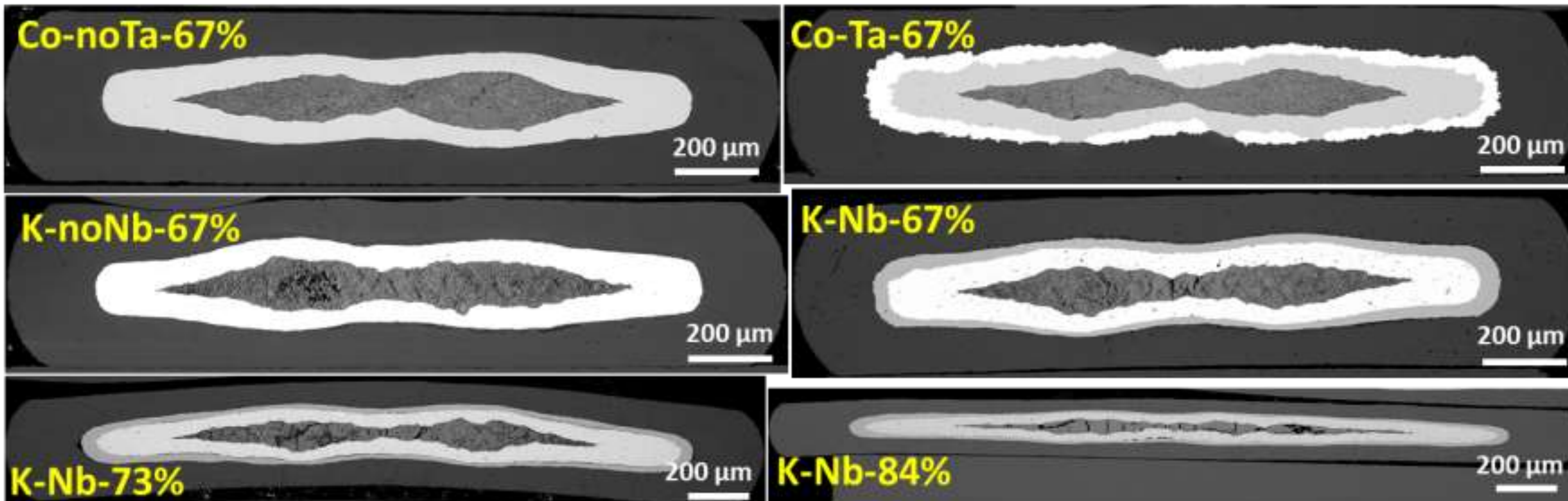
- Each Ag tube was inserted into a 12.7mm O.D. Cu tube, then drawn to Φ1.21mm. No breakage occurred.
- So we obtained 4 wires:



- Both the Ta and the Nb layers kept integral after wire drawing, indicating they should be usable for wires.
- Circled regions are thinner than the rest, because not covered by the 3rd foil turn. Use of tubes can solve it.

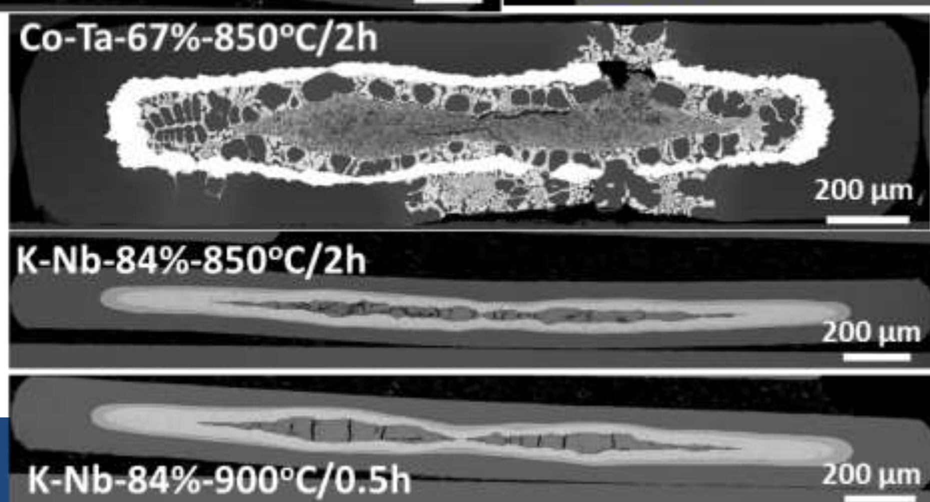
Tapes fabricated & after HT

- The 4 wires were flat-rolled to 0.4 mm thickness (67% thickness reduction).
- We also rolled the K-Nb wire to 0.33 & 0.2 mm thick (73% & 84% reduction). So totally 6 tapes:



HT: in vacuum at 740ºC/12h.

Additional HT for the Co-Ta and K-Nb wires/tapes: 850ºC/2h & 900ºC/0.5h.



The intact Nb avoided forming liquid in K-Nb-84% even at 900C.

Nb performed better than Ta during flat-rolling because Nb is more ductile.

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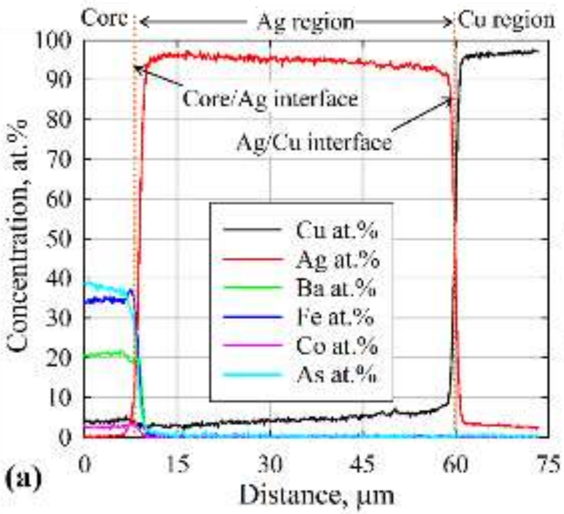
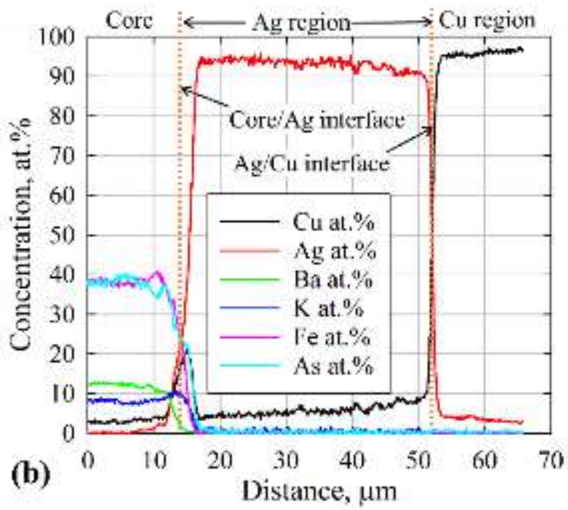
Composition studies

EDS line scans for (a) Co-noTa-67%, (b) K-noNb-67% after 740ºC/12h HT:

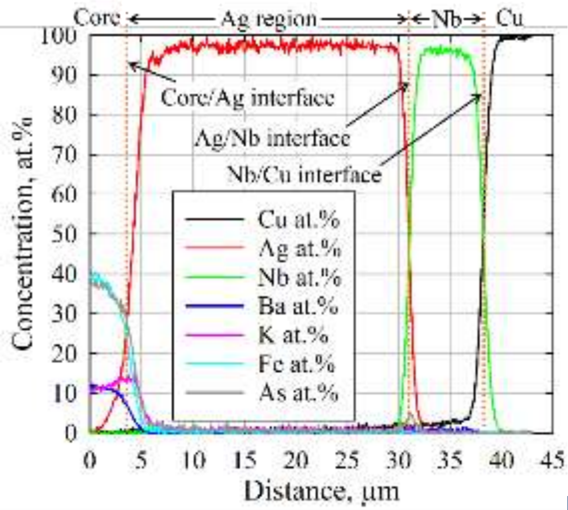




Co-noTa & K-noNb had similar phenomena:

- Ag diffused into Cu, reducing Cu RRR and thermal conductivity.
- Cu diffused into Ag, with Cu content as high as 9at.%.
- Cu also diffused into the IBS core, with a content as high as 5at.%.

K-Nb-84%-850ºC/2h:



- Ag did not diffuse into the Cu layer.
- Some Cu diffused into Nb, but Cu at.% in Ag was very low and was negligible in the IBS core, indicating that the Nb effectively blocked the Ag-Cu interdiffusion.
- An As peak is seen at the Ag/Nb interface, but no influence on IBS core composition. So we expect no effect on IBS properties.
- EDS on Co-Ta-850ºC/2h: no Cu in Ta or Ag. So, Ta may be a better barrier for wires.

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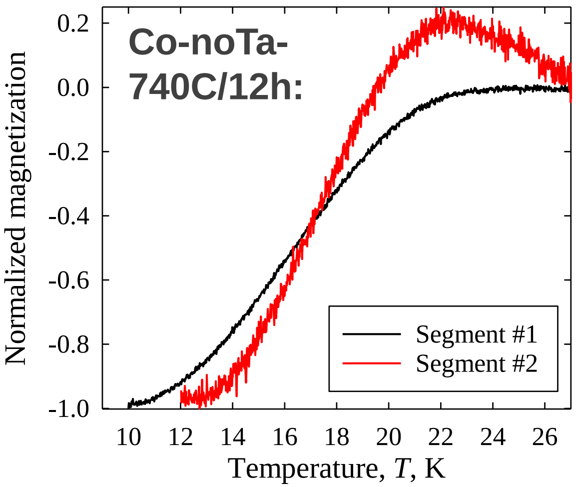
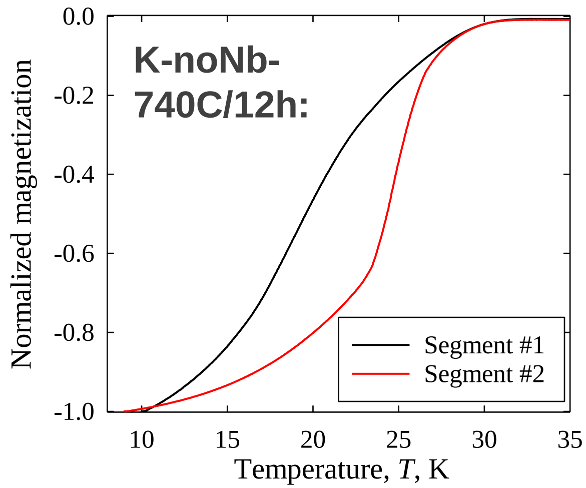
Future work

T_c results for Co-noTa and K-noNb wires:





- The transitions are very broad.
- Neighboring segments from the same heat treated wire had quite different T_c values.
- These indicate that there is serious inhomogeneity issue with the IBS powders.

Potential causes of the problem:

- Powders?
- Oxidation during transportation?

Future work:

- Work with TUAT to improve the powder quality and solve the transportation issue.
- Test to see if this design really improves IBS performance.