Development of superconducting joints between Bi-2212/Ag wires

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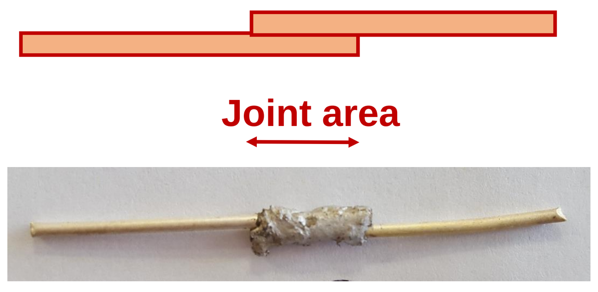
Introduction

Bi-2212 superconducting wires are being considered as key components for the development of high field magnets (up to 25 T), but it is recognised that a reliable joining process between these wires is a critical challenge for most high-field applications. This work focuses on the design and testing of jointing processes between Bi-2212 wires using different practically applicable techniques, including soldering and melt-processing, to make persistent mode joints. In the soldered joints, superconducting alloys from the PbBi, PbSn and SnInBi systems have been investigated. Several architectures of melt-processed joints have also been studied, with cold-pressing stages and the use of additional BSCCO powder to form superconducting paths between the filaments after a local melting process.

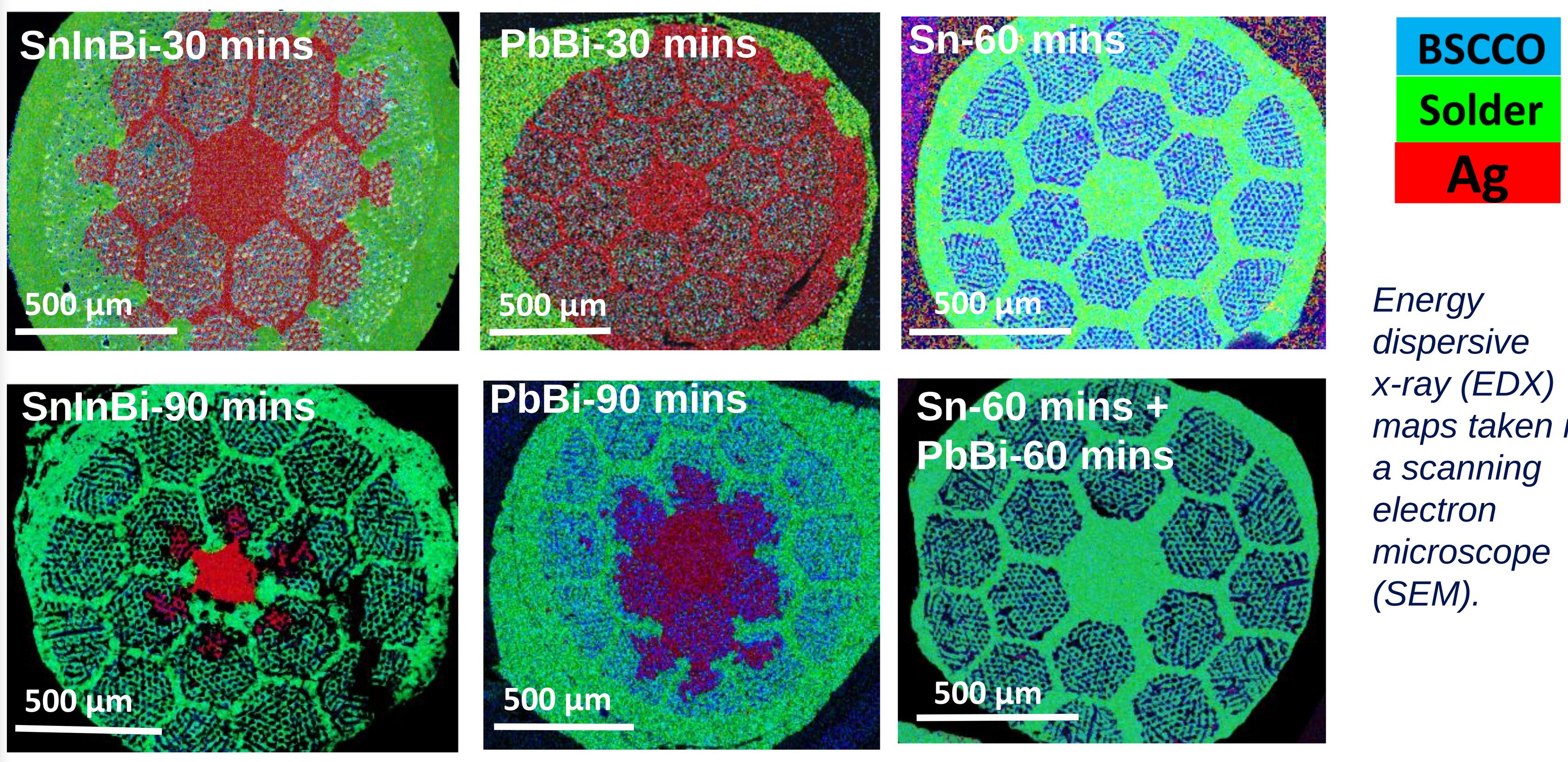
Soldered joints

- Ag matrix needs to be removed from reacted wires to produce direct bond between Bi-2212 filaments and superconducting solder.
- Bi-2212/Ag wires were dipped in various molten superconducting solder alloys (SnInBi and PbBi) at 400°C to investigate how effectively they remove the Ag matrix.
- Joints have also been fabricated using a two-stage process involving molten Sn followed by molten PbBi solder, as this is commonly used for soldering NbTi wires [1].



Typical soldered joint with lap joint architecture.

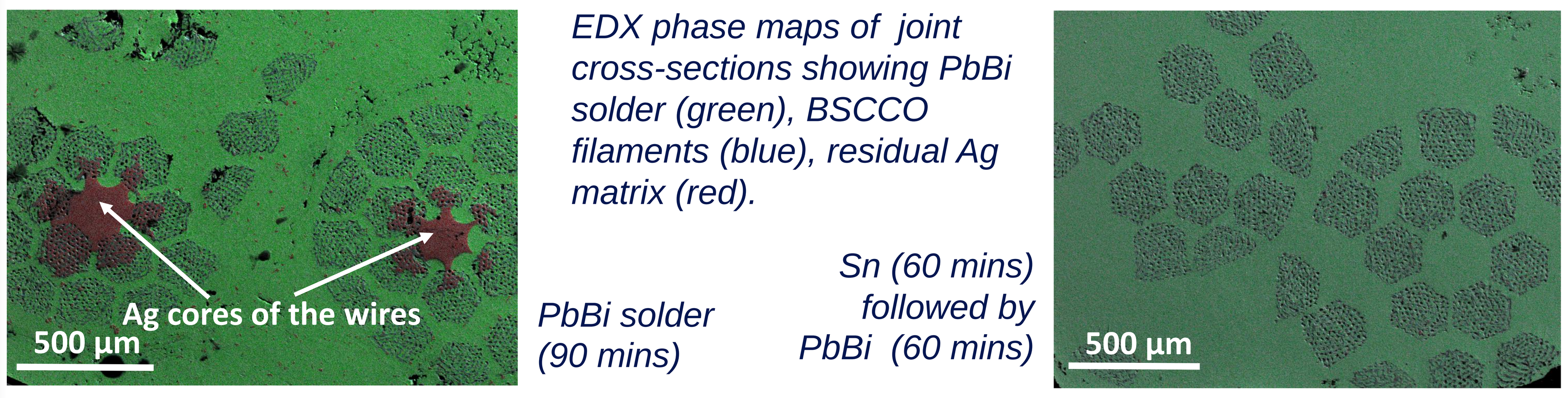
Ag etching with superconducting solder alloys



Energy dispersive x-ray (EDX) maps taken in a scanning electron microscope (SEM).

- Lead-free SnInBi solder removes Ag matrix in ~90 mins. Ag reacts with Sn and In and makes some small regions of In62Ag35Sn3 and some very small pure Ag regions. It also creates pores and cracks after 90 mins.
- PbBi solder also removes most of Ag in ~90 mins without damaging the filaments.
- Sn completely removes Ag more quickly (~60 mins) without damaging the filaments. The matrix consists of Sn and thin flakes of Sn-16wt%Ag.
- When Sn followed by PbBi are used, PbBi completely replaces the Sn matrix in ~60 mins.

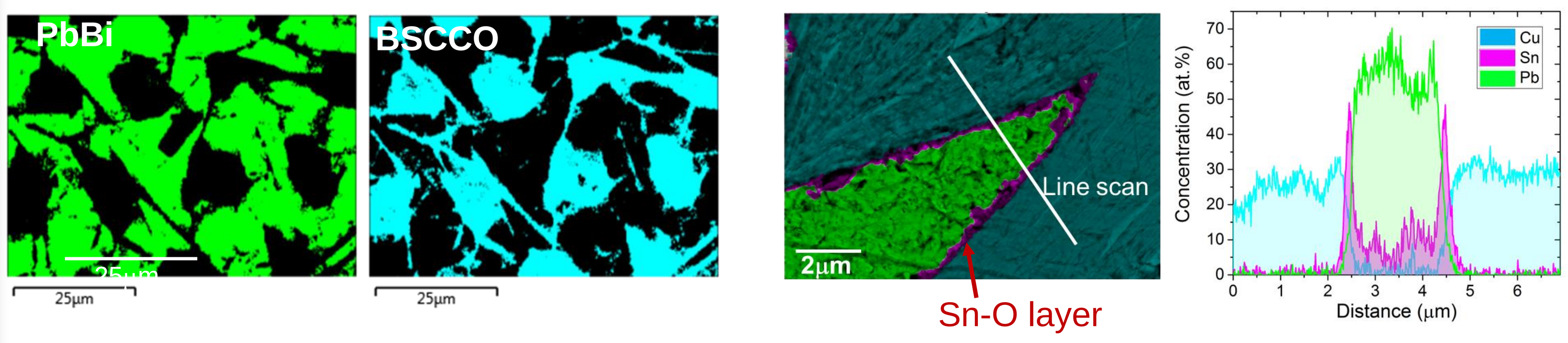
PbBi Joint / Sn+PbBi Joint



EDX phase maps of joint cross-sections showing PbBi solder (green), BSCCO filaments (blue), residual Ag matrix (red).

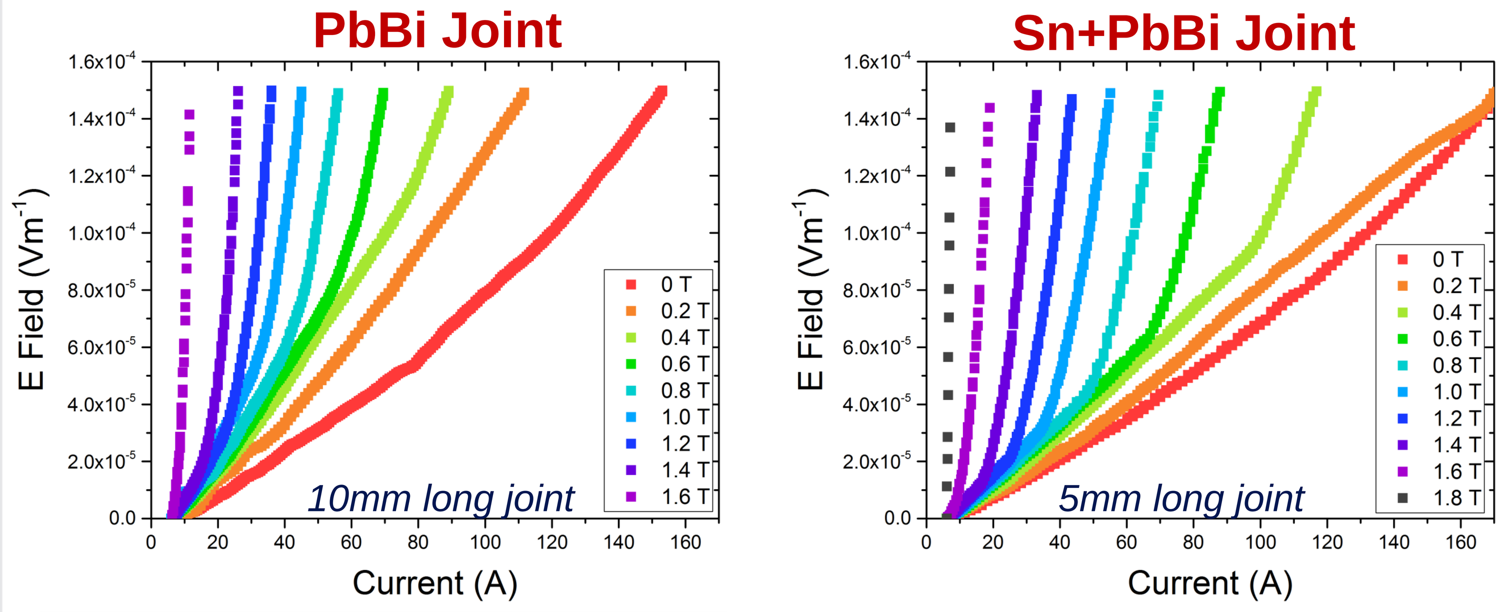
PbBi solder (90 mins)

Sn (60 mins) followed by PbBi (60 mins)



When PbBi is used to remove the Ag matrix it forms a good contact with the BSCCO filaments without appearing to damage them. However, 90 mins is not long enough to completely remove Ag from the core of the wires.

When Sn is used for the initial Ag matrix removal, a thin reaction layer of Sn-O is left around each filament. This layer may act as a barrier to supercurrent transfer from BSCCO filaments to the superconducting PbBi solder.

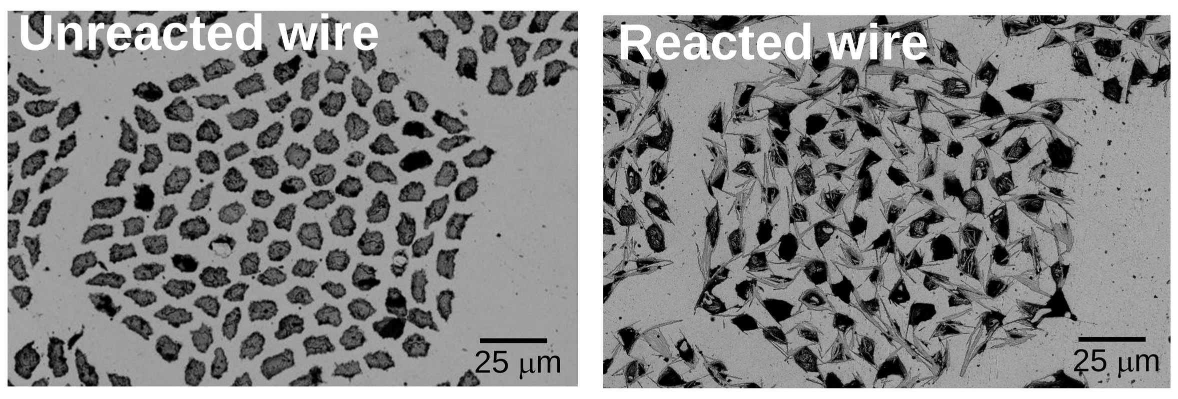


Transport measurements of soldered joints at 4.2K.

I_c (100 µVm-1)	Self-field	B = 1 T
PbBi	120 A	40 A
Sn+PbBi	133 A	49 A

The joint fabricated via a two-stage process using Sn followed by PbBi performed better than the joint fabricated using a single PbBi process despite the presence of a Sn-O interfacial layer.

Bi-2212 / Ag wire

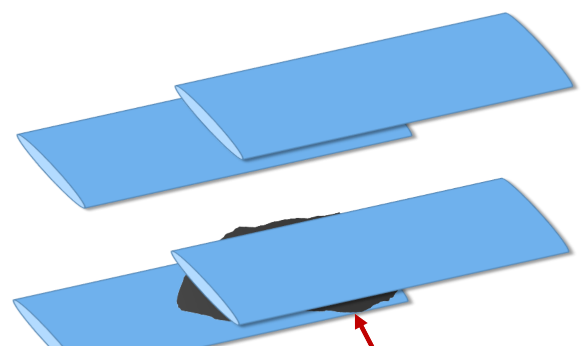


Bi-2212/Ag wires have been supplied by OST in both the unreacted and reacted forms. The unreacted wire requires melt-processing in O_2 to form interconnected filaments of superconductor [2,3].

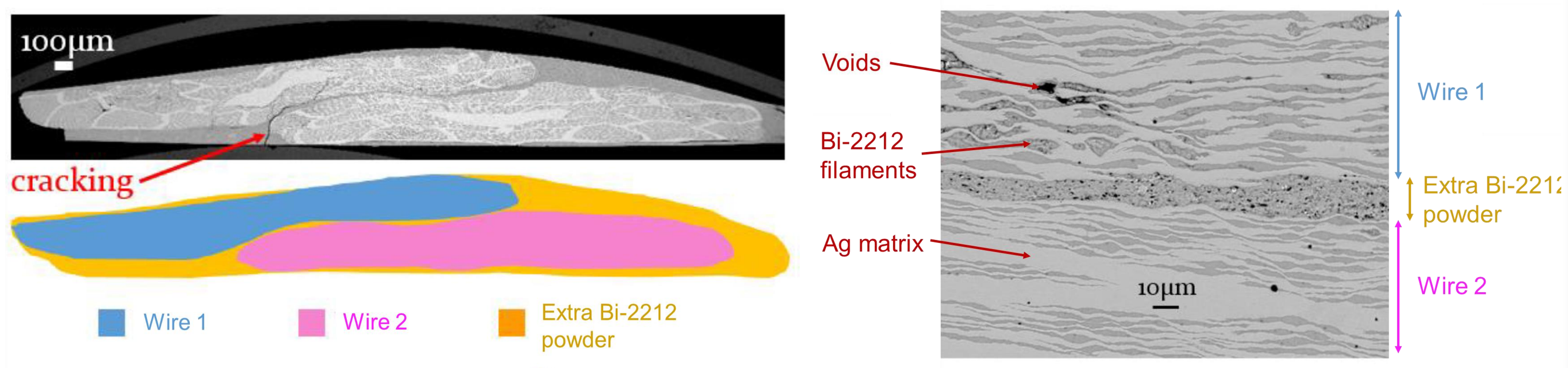
Melt-processed joints

Lap joints have been made between unreacted Bi-2212 wires by:

- Etching the outer silver layer using dilute nitric acid.
- Uniaxial pressing to flatten each wire.
- Assembling lap joint (with or without additional Bi-2212 powder in between) and cold pressing to fuse silver.
- Heat treating in flowing O_2 at melt temperatures T_m=880-889°C.



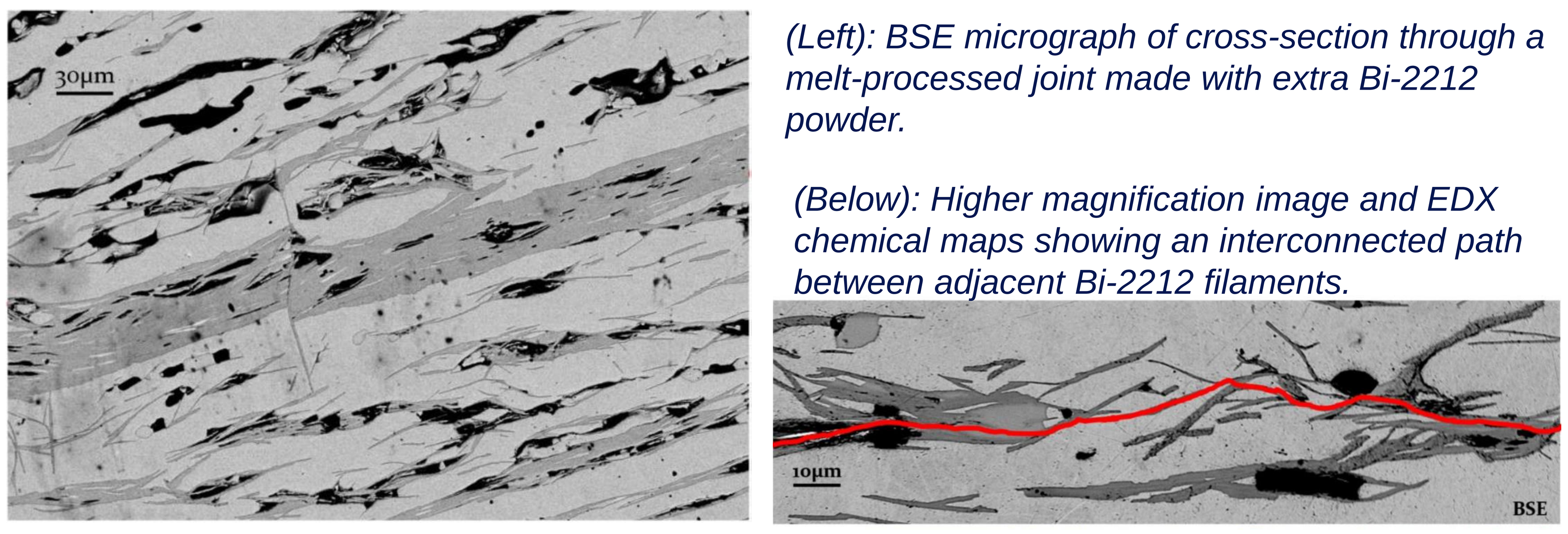
Before heat treatment



X-ray tomography cross section through a joint with extra Bi-2212 between the wires before heat treatment showing the BSCCO (dark grey) and Ag matrix (light grey).

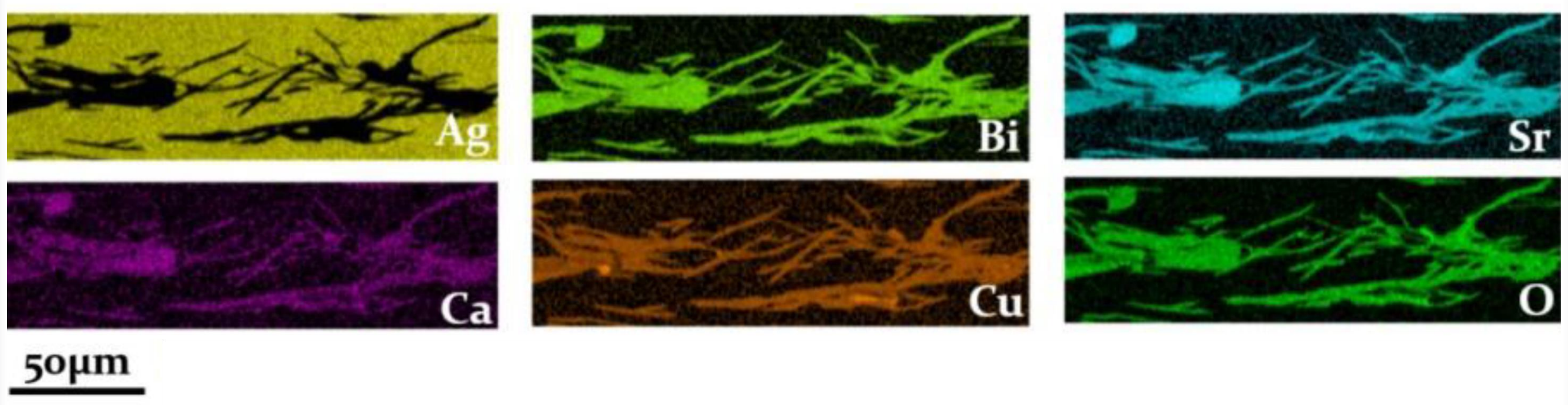
SEM backscattered electron (BSE) micrograph of the joint region at higher magnification.

After heat treatment

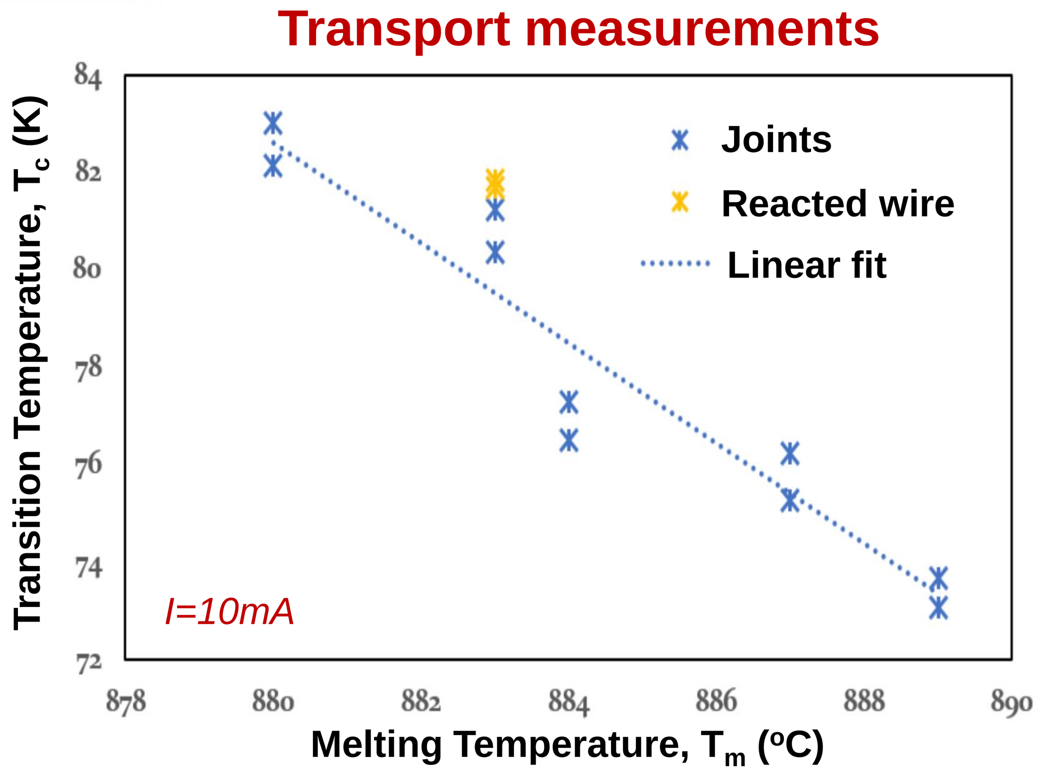


(Left): BSE micrograph of cross-section through a melt-processed joint made with extra Bi-2212 powder.

(Below): Higher magnification image and EDX chemical maps showing an interconnected path between adjacent Bi-2212 filaments.

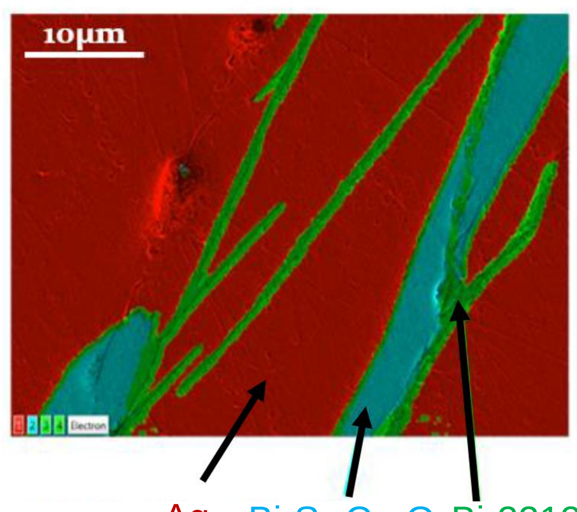


Transport measurements



(Left): 4-terminal transport T_c measurements from joints fabricated at a series of melting temperatures. T_c values of joints are consistent with the in-house reacted wire.

(Below): High magnification EDX phase map showing presence of non-superconducting Cu-free phase



- Preliminary critical currents measurements have been performed on some joints. The highest I_c~13 A at 4.2 K in self field was found for a joint melt-processed at 883 °C (estimated from transport data using 100 µV m^{-1} criterion).
- EDX mapping at high resolution shows that the BSCCO filaments contain a significant fraction of a non-superconducting, Cu-free oxide which may be responsible for the poor critical current values.
- Further optimisation of the heat treatment is required to promote formation of the superconducting Bi-2212 phase.

[1] Thornton US Patent 5410288 (1986) [2] Hellstrom et al, MRS Bull. 17 45 (1992) [3] Matsumoto et al, SUST 17 989 (2004)

Acknowledgements

Tim Davies (Oxford Materials) and Matt Bristow (Oxford Physics) for transport measurements on joints.