Nb3Sn diffusion and grain growth behavior

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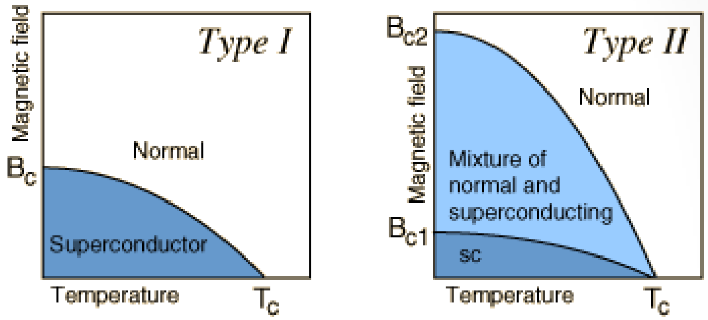
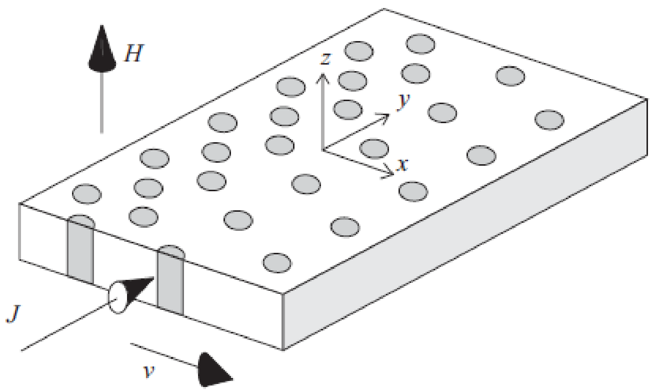
Introduction

- Nb_3Sn is a type-2 superconductor: when the magnetic field is higher than H_{c1}, magnetic vortex pass through the material, turning a region from superconductive to normal.

- Vortex feel the presence of the field generated from the supercurrent, and tend to migrate in the lower density region.

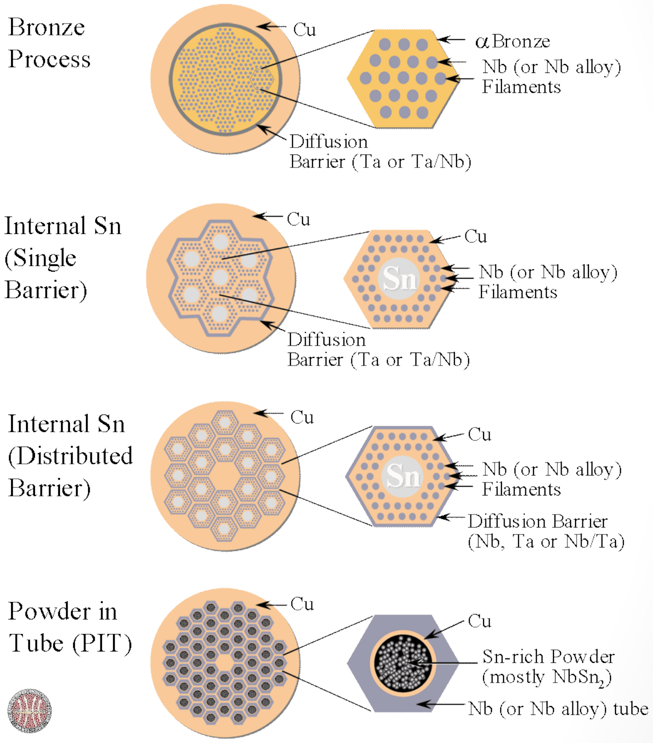
- To do not loose the superconductive state they must be pinned by material defects, like grain boundaries





Introduction

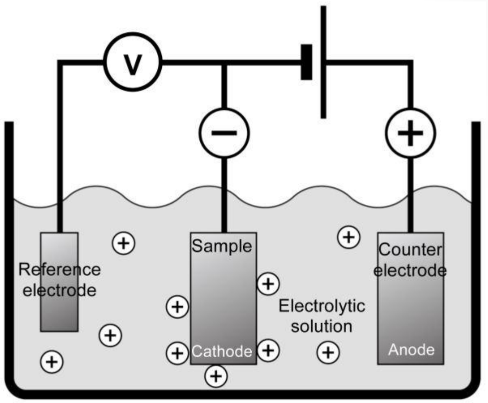
- Nb_3Sn phase is industrially produced by high temperature interdiffusion of Nb and Sn, with the addition of other metals.
- In the labs of Polytechnic of Milan I have been working to prepare electrodeposited layers of nanocrystalline – amorphous Nb-Sn alloy with the goal of verifying a number of flux-pinning models.
- One of the specific goals at Milan is to control grain size and shape growth.

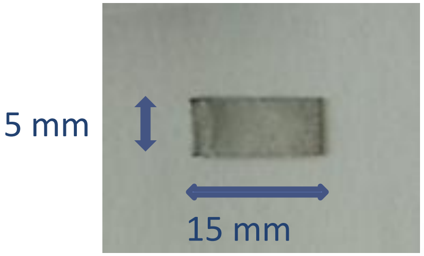


Introduction

- I have brought from Milan a number of different samples, consisting in a niobium tape substrate, with an electrodeposited Sn layer, or Cu-Sn layers of different thickness.

- The work at FNAL has been focused to study the diffusional behavior between pure Nb and Sn in these thin films, by performing different heat treatments. It was expected that heat treatment cycles would be much different than for Nb_3Sn wires [1].





[1] Kinetics of phase growth during the Cu-Sn diffusion process. Optimization of superconducting properties. Sara Mattafirri. FNAL

Experimental procedure

Position the niobium-tin covered tape in a sample holder, which has to be put in a tubular oven in an argon atmosphere to prevent oxidation of the sample, with subsequent performing of different heat treatments.

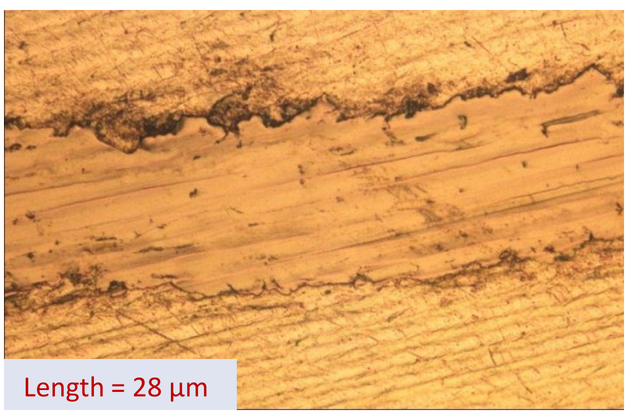
Experimental procedure

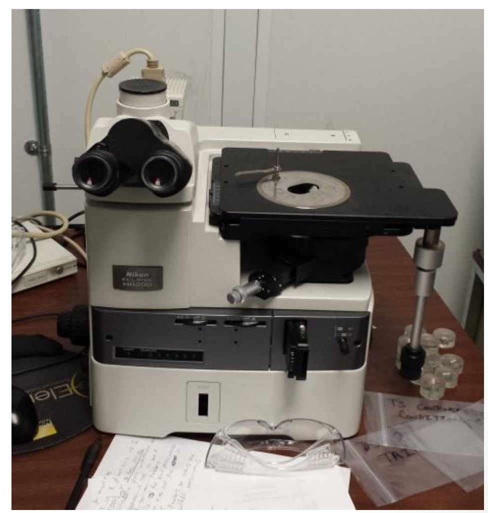
- Extraction of the sample from the oven and embedding in epoxy resin matrix.

- Polishing procedure of the sample, to reduce the average roughness of ~ 1µm.

Experimental procedure

- Optical microscopy and observation of the sample: measuring of the thickness of the new generated phase (10 data points measued for every sample).
- For the grain radius measurement a SEM is needed





Temperature and time effect on phase growth

- $L = \sqrt{2Dt}$
- L [µm] = thickness of the new phase
- t [s] = heat treatment time
- D [$\mu m^2 s^{-1}$] = Diffusion coefficient
- $D = D_0\, e^{-\frac{Q}{RT}}$
- Q [J] = activation energy
- T [K]= heat treatment temperature
- D_0 [$\mu m^2/s$] = diffusion frequency

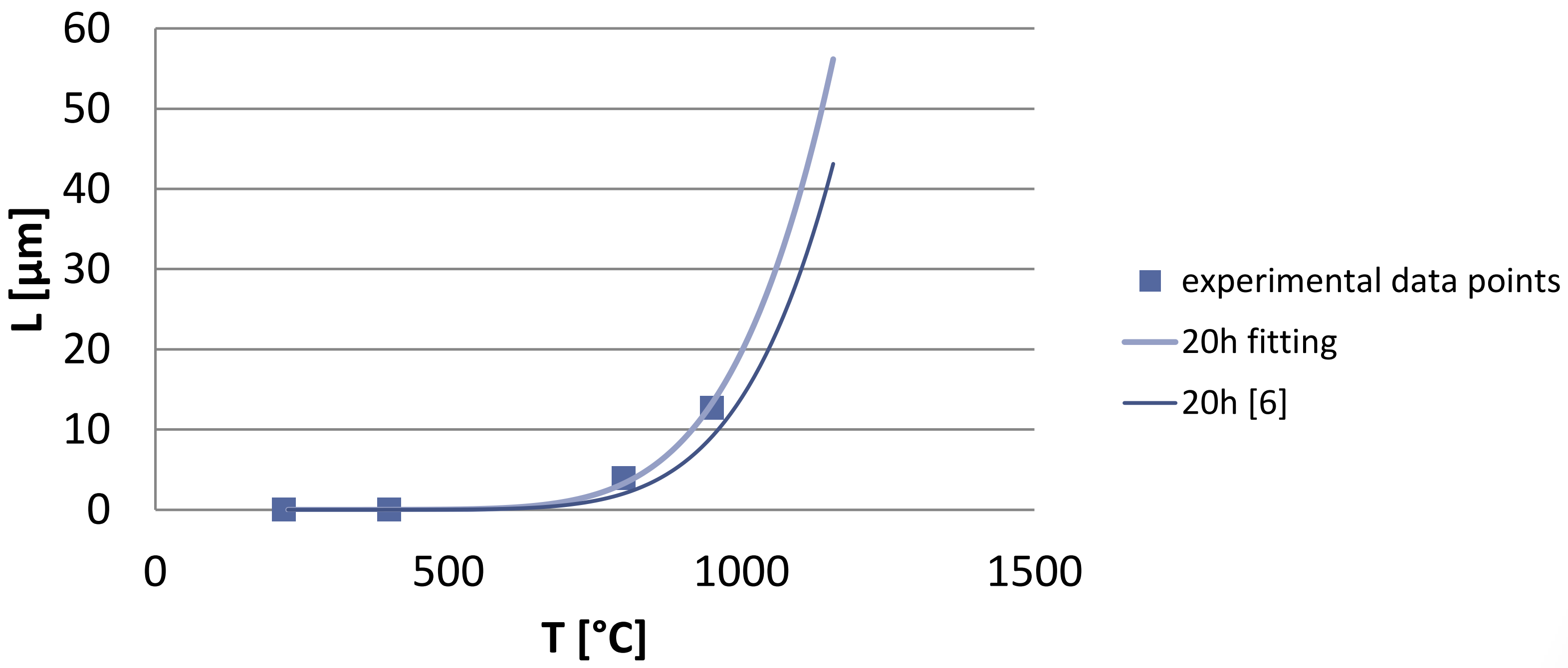
[2] *Journal of ELECTRONIC MATERIALS, Vol. 42, No. 8, 2013*
[3] Cryogenics 48 (2008) 323–330
[4] Shermon, P.G., Diffusion in Solids, McGraw-Hill
[5] *FERMILAB-Conf-02/175-E Nov. 2002*

Experimental results

- Literature data give values of Q = 218 KJ
- Experimental results give values of Q = 202 KJ and D_0 = 2*10^9 $\mu m^2/s$. In this case Q is lower, due to the high amount of dislocations that favor diffusive paths.

# sample	Temperature [°C]	Time [h]	Nb_3Sn mean phase thickness [µm]	Standard Deviation
1	220	100	-	-
2	400	40	-	-
3	800	40	4.2	0.36
4	800	20	3.9	0.44
5	950	20	12.7	0.48

Nb-Sn exponential diffusion evaluation



[6] Journal of ELECTRONIC MATERIALS, Vol. 42, No. 8, 2013

Comments and Conclusion

- The activation energy for Nb – Sn pure metals is lower to that calculated on IT and PIT wires.

- The diffusion length in an electrodeposited layer is of the order of nanometers (i.e. the dimension of the Nb – Sn metallic grains that have to be homogenized) instead of ~µm needed for diffusion in a wire.

Metal phase	Temperature range[°C]	Q [KJ/mol]
CuSn – η	150 - 227	102 [1]
IT	650 - 750	279 [1]
PIT	650 - 750	236 [1]
Nb - Sn	400 - 950	202

[1] Kinetics of phase growth during the Cu-Sn diffusion process. Optimization of superconducting properties. Sara Mattafirri. FNAL

Comments and Conclusion

- For these films the heat treatment for the formation of a stoichiometric A15 phase has to be performed at Temperatures higher than 650°C [7]. As an example, the time to obtain a thickness of 100 nm, using the calculated experimental values at 650°C, is less than an hour.

- Production of samples will continue at Milan Polytechnics. They will be heat treated according to the results of this work, before being evaluated for critical current.

[7] Performance boundaries in Nb_3Sn superconductors, Arno Godeke