

Effects of Element Addition into Cu matrix for IT-Processed Nb_3Sn Wires

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Background

J_c characteristics of Nb₃Sn : fully optimized?

M. B. Field, Y. Zhang, H. Miao, M. Gerace, and J.A. Parrell, “Optimizing conductors for high field applications,” *IEEE Trans. Appl. Supercond.*, vol. 24, 2014, Art. no. 6001105.

Potential Grain morphology?

X. Xu, M. D. Sumption, X. Peng, and E.W. Collings, “Refinement of Nb₃Sn grain size by the generation of ZrO₂ precipitates in Nb₃Sn wires,” *Appl. Phys. Lett.*, vol. 104, 2014, Art. no. 082602.

Compositional gradient (Stoichiometry of Nb₃Sn layer)?

P. J. Lee, and D. C. Larbalestier, “Microstructure, microchemistry and the development of very high Nb₃Sn layer critical current density,” *IEEE Trans. Appl. Supercond.*, vol. 15, pp. 3474-3477, 2005.

C. Senatore, and R. Flükiger, “Formation and upper critical fields of the two distinct A15 phases in the subelements of powder-in-tube Nb₃Sn wires,” *Appl. Phys. Lett.*, vol. 102, 2013, Art. no. 012601.

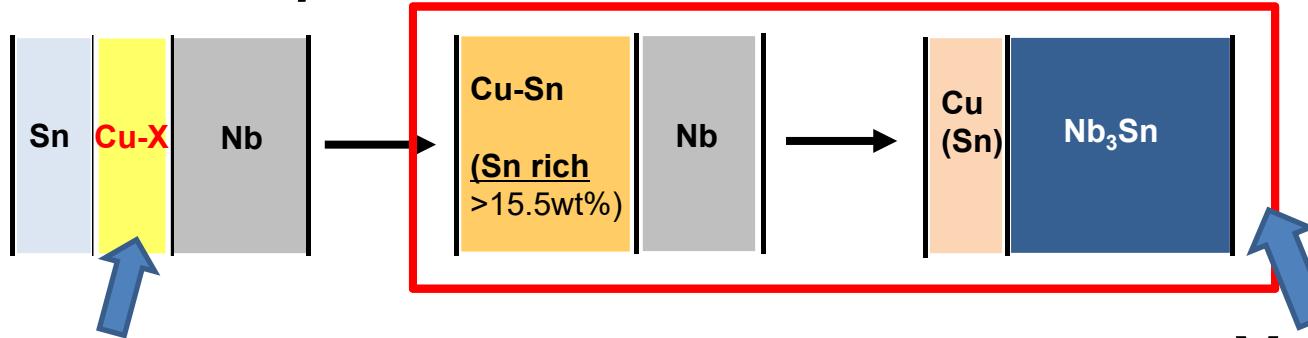
C. Tarantini, P. J. Lee, N. Craig, A. Ghosh, and D. C. Larbalestier, “Examination of the trade-off between intrinsic and extrinsic properties in the optimization of a modern internal tin Nb₃Sn conductor,” *Supercond. Sci. Technol.*, vol. 27, 2014, Art. no. 065013.



Motivation and objectives

Improvement of stoichiometry of Nb_3Sn layer with a different approach

Internal tin process



New approach: Element X addition

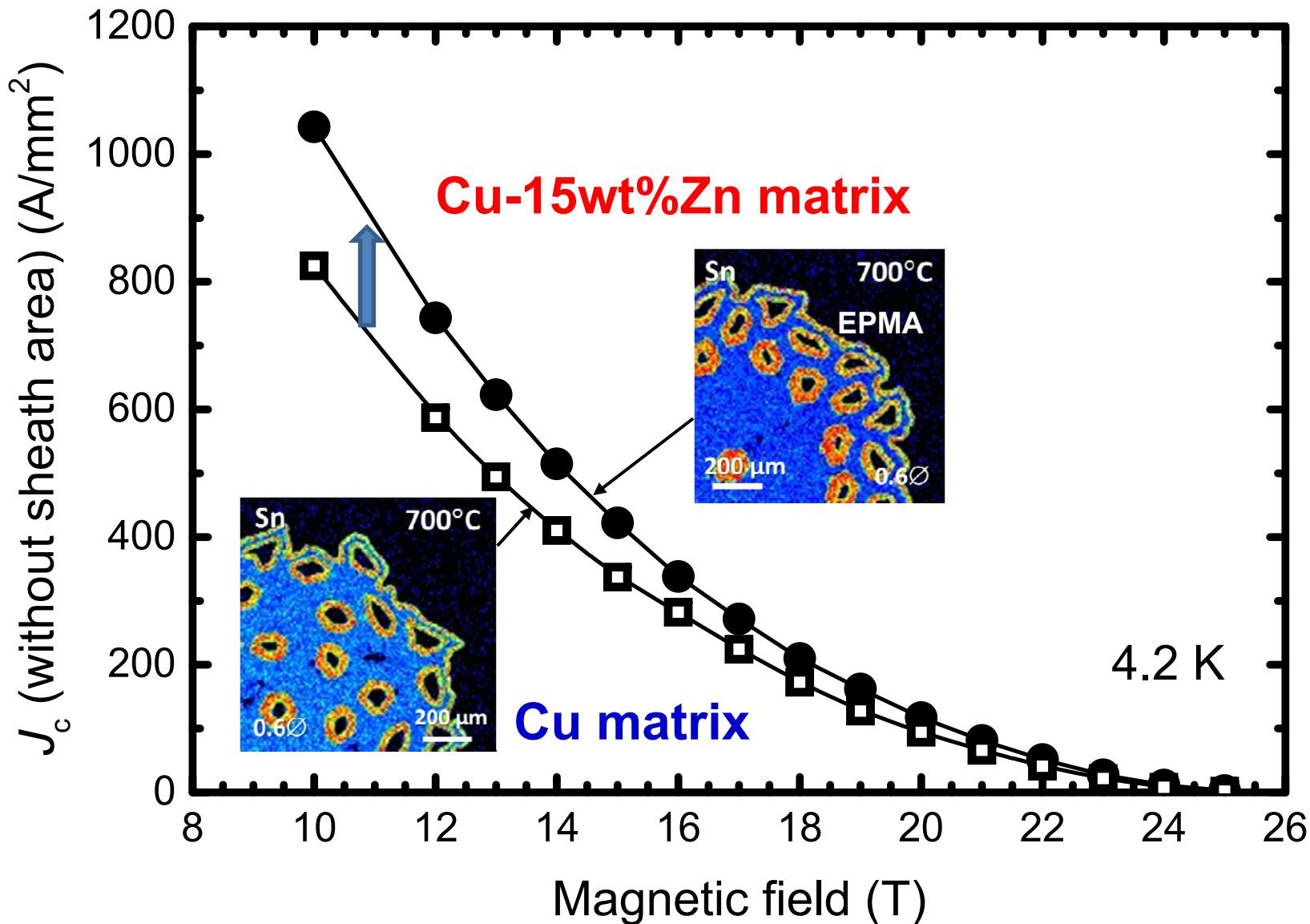
Variety of diffusion reaction

Zn addition : attractive in terms of growth kinetics

Thicker Nb_3Sn layer, smaller residual Sn content

N. Banno, Y. Miyamoto, and K. Tachikawa, *IEEE Trans. Appl. Supercond.*, vol. 26, 2016, Art. no. 6001504.

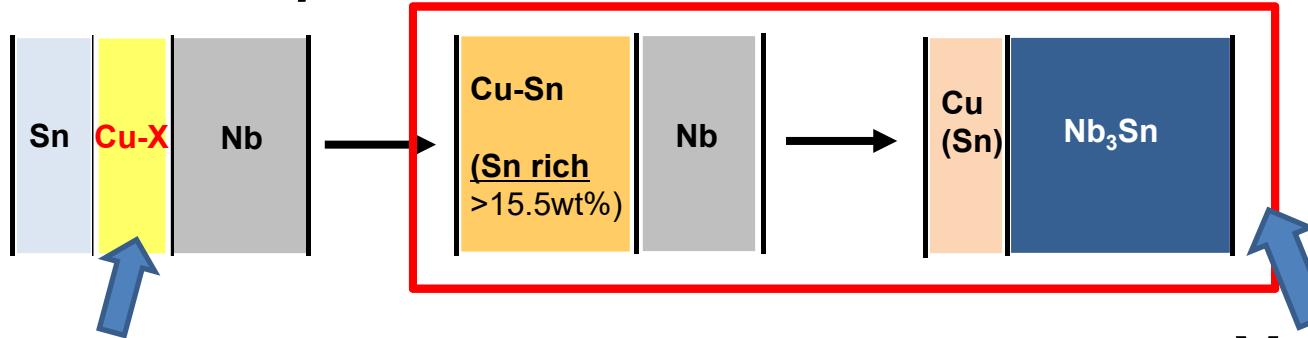
J_c comparison of laboratory-scale samples



Motivation and objectives

Improvement of Nb_3Sn layer stoichiometry with a different new approach

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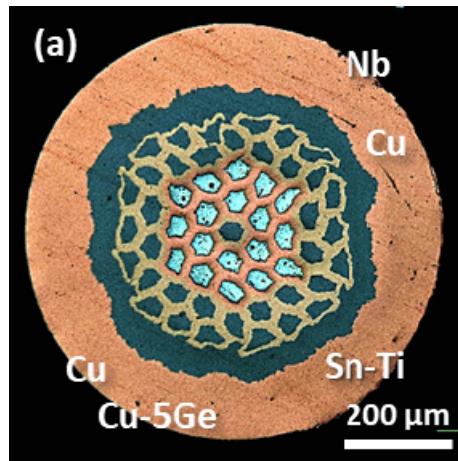
Thicker Nb_3Sn layer, smaller residual Sn content

N. Banno, Y. Miyamoto, and K. Tachikawa, *IEEE Trans. Appl. Supercond.*, vol. 26, 2016, Art. no. 6001504.

This work: Ge, Ga, Mg and simultaneous addition of Zn and Ge

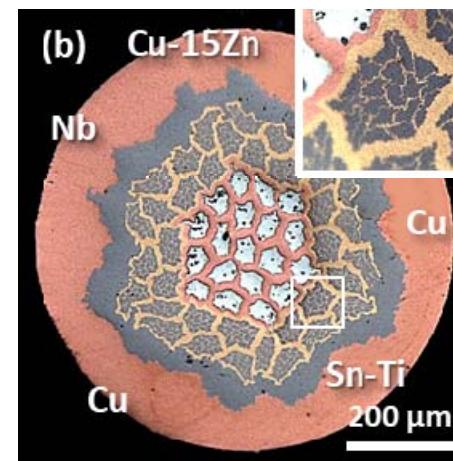
Laboratory-scale wires

Single Stack (SS) type



- Cu-5wt%Ge
- Cu-10wt%Ga
- Cu-1wt%Mg
- Gold brass (GB)
(Cu-15wt%Zn)
- Cu

Multifilamentary (MF684) type

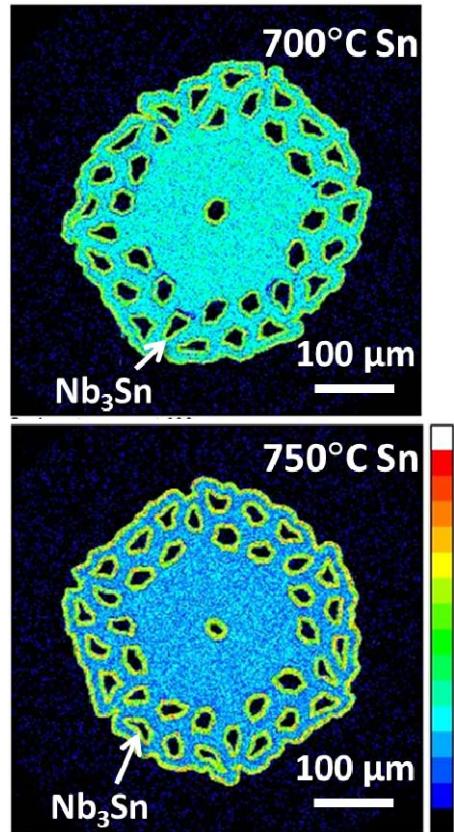


- Cu-14wt%Zn-5wt%Ge
- Gold brass (GB)
(Cu-15wt%Zn)

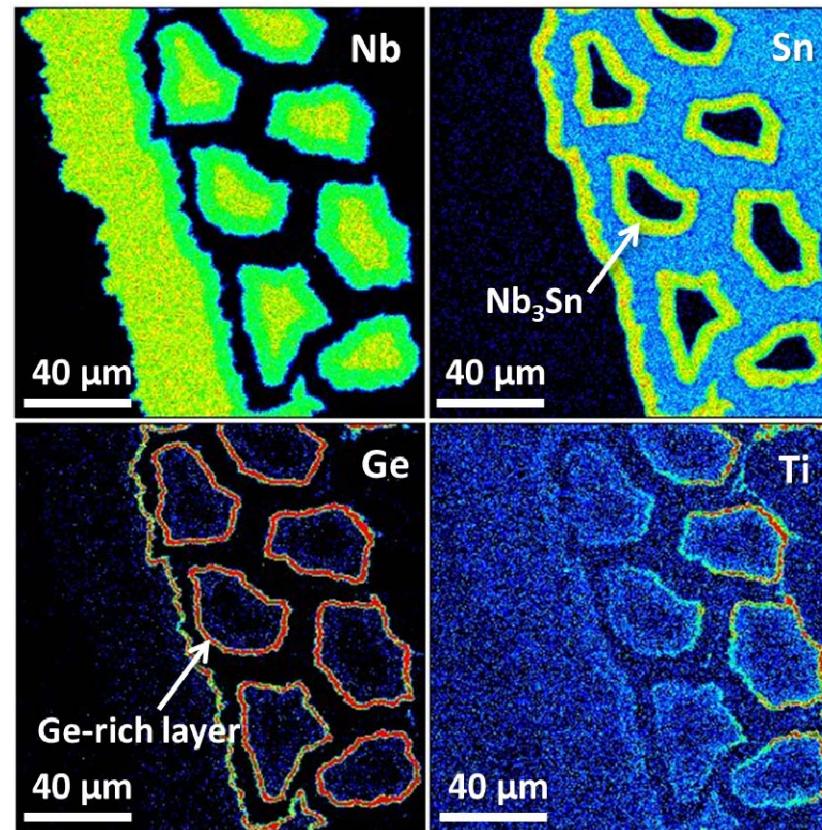
Sample name	SS-5Ge	SS-10Ga	SS-1Mg	MF684-14Zn1Ge
Wire diameter (mm)	0.6	0.81	0.6	0.6
Matrix material	Cu-5wt%Ge	Cu-10wt%Ga	Cu-1wt%Mg	Cu-14wt%Zn-1wt%Ge
No. of Nb filaments	37	37	37	684 (=19×36)
Filament diameter (μm)	31.9	43.2	31.9	8.18
Area fraction in filament region (%)				
Matrix	55.6	55.6	55.6	43.2
Nb cores	29.9	29.9	29.9	36.3
Sn-1.6wt%Ti cores	14.5	14.5	14.5	20.5

5Ge addition

EPMA Sn map



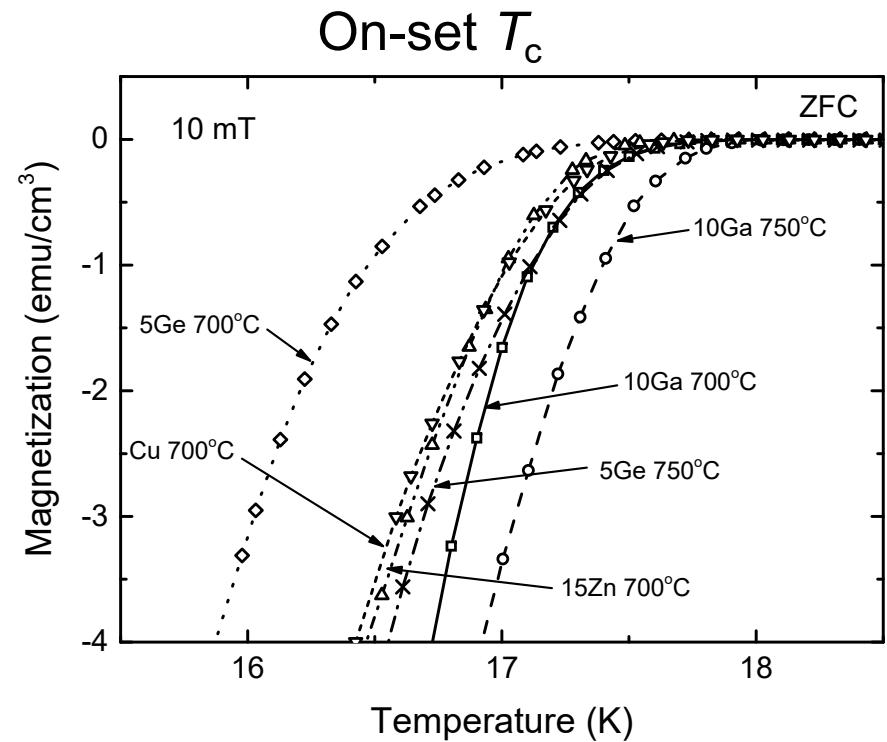
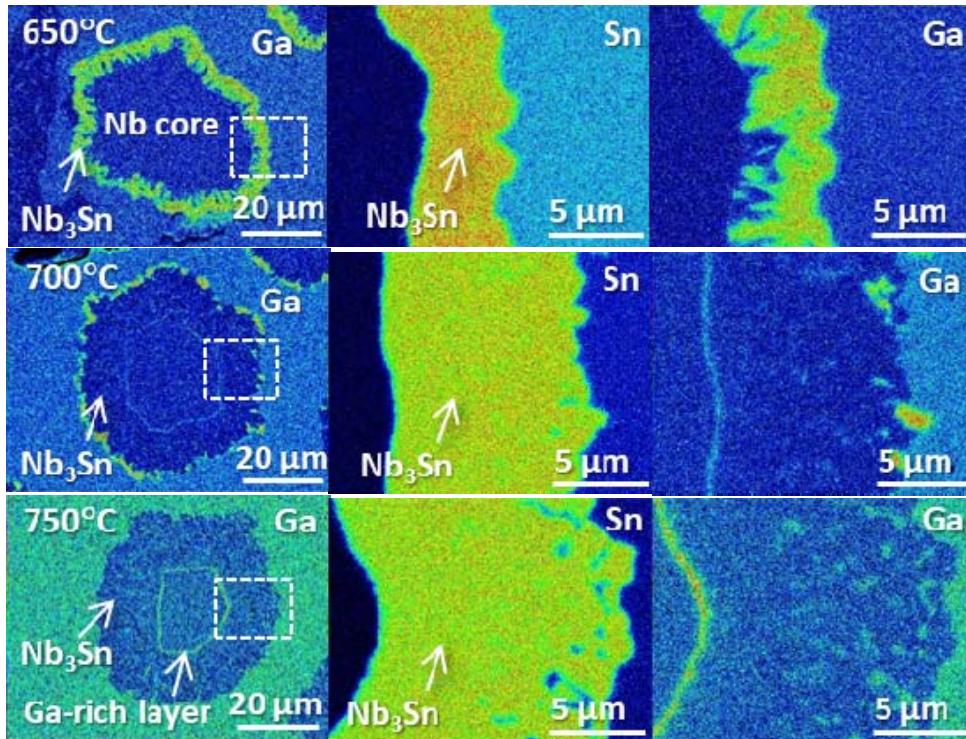
750 °C x 50 h



- Sn diffusion rate, Nb_3Sn layer growth rate : very slow
- Ge-rich layer : at the outer boundary of Nb_3Sn

10Ga addition

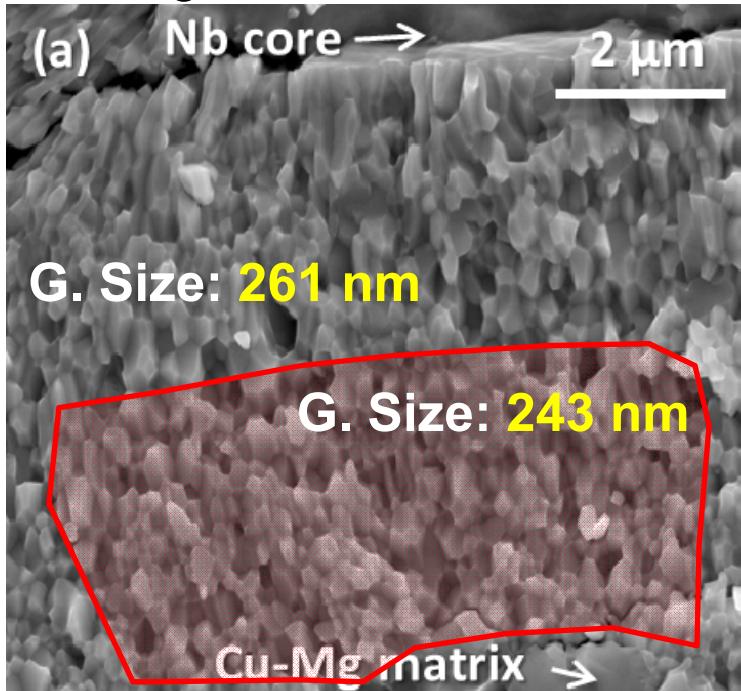
EDX Ga & Sn map



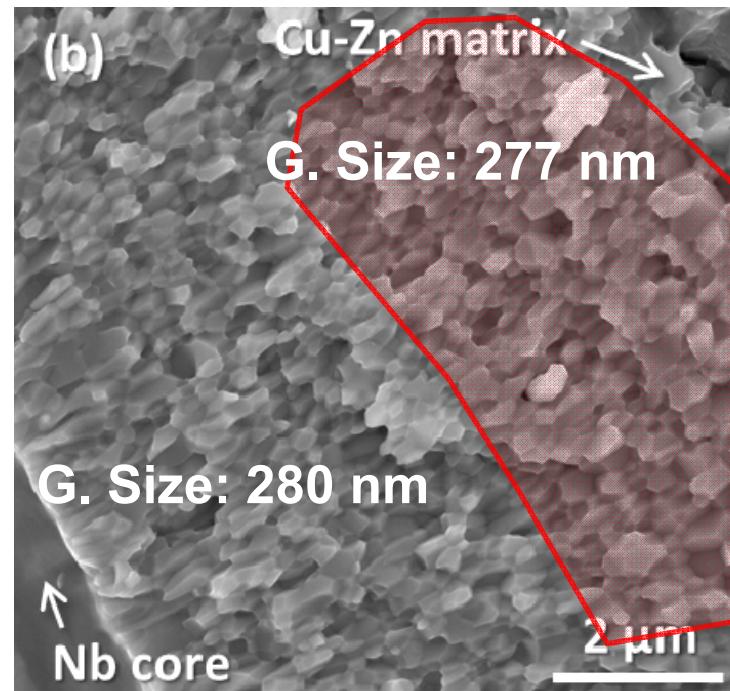
- Interesting reaction behavior : Ga diffuse into Nb_3Sn at 650 °C pushed out at 700 °C and form Ga-rich layer inside
- On-set T_c : improved

1Mg addition

Cu-1Mg

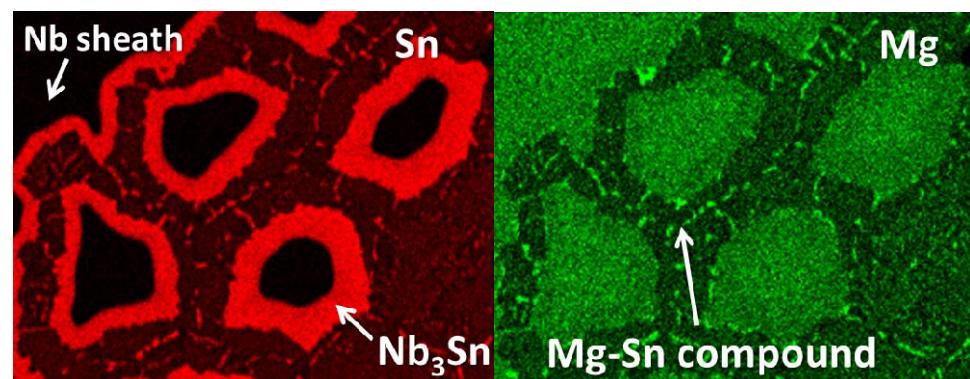


Cu-15Zn

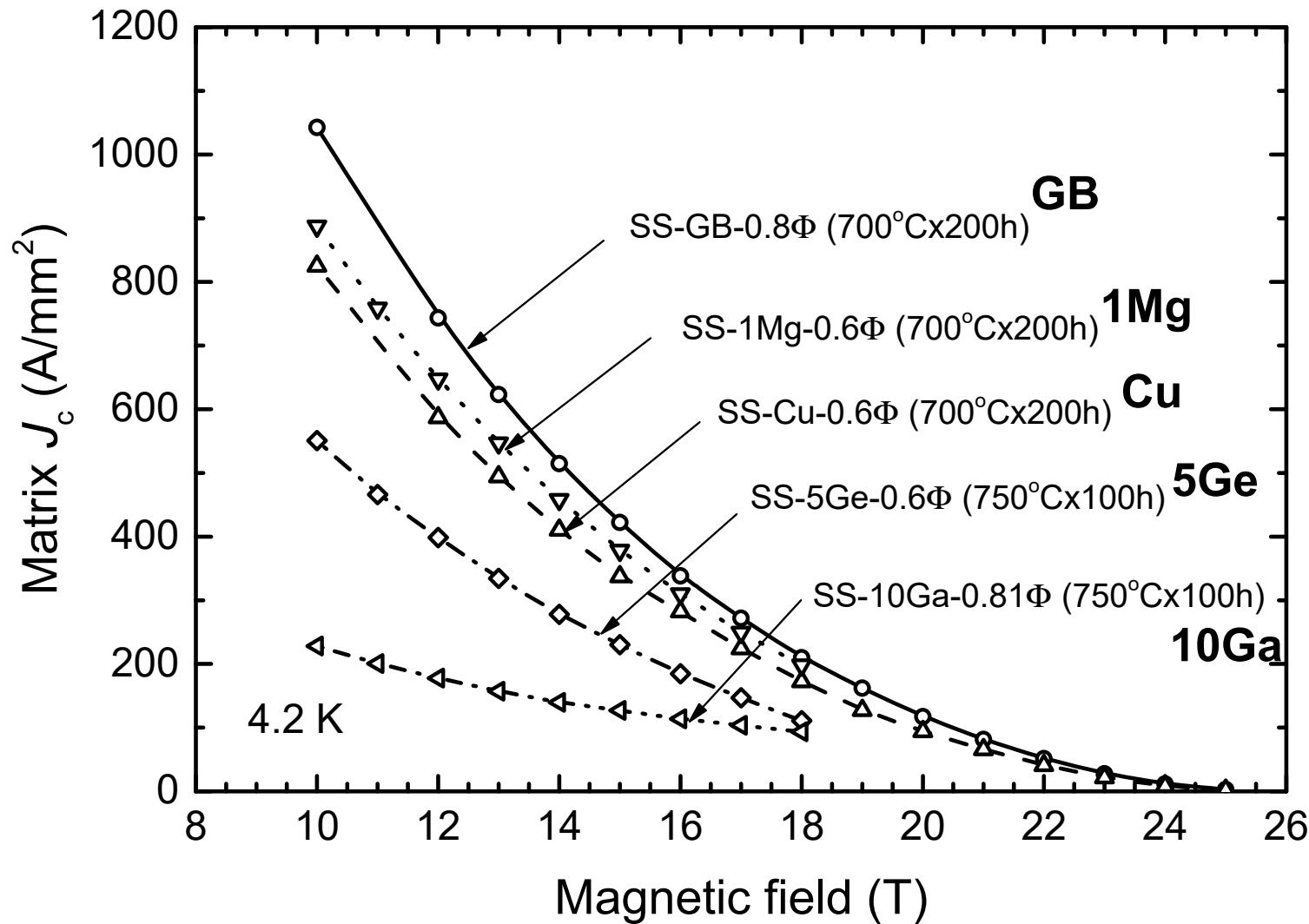


EDX

- Grain morphology : finer Columnar-like near Nb core
- Layer thickness : a little smaller
- Mg-Sn compound : present in the matrix

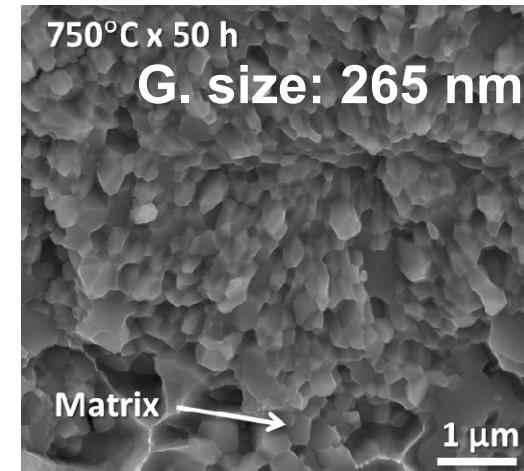
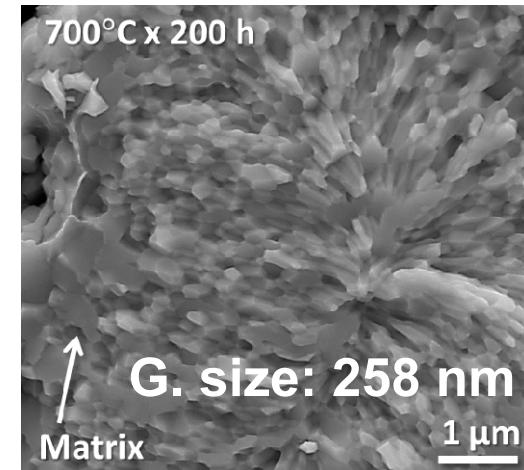
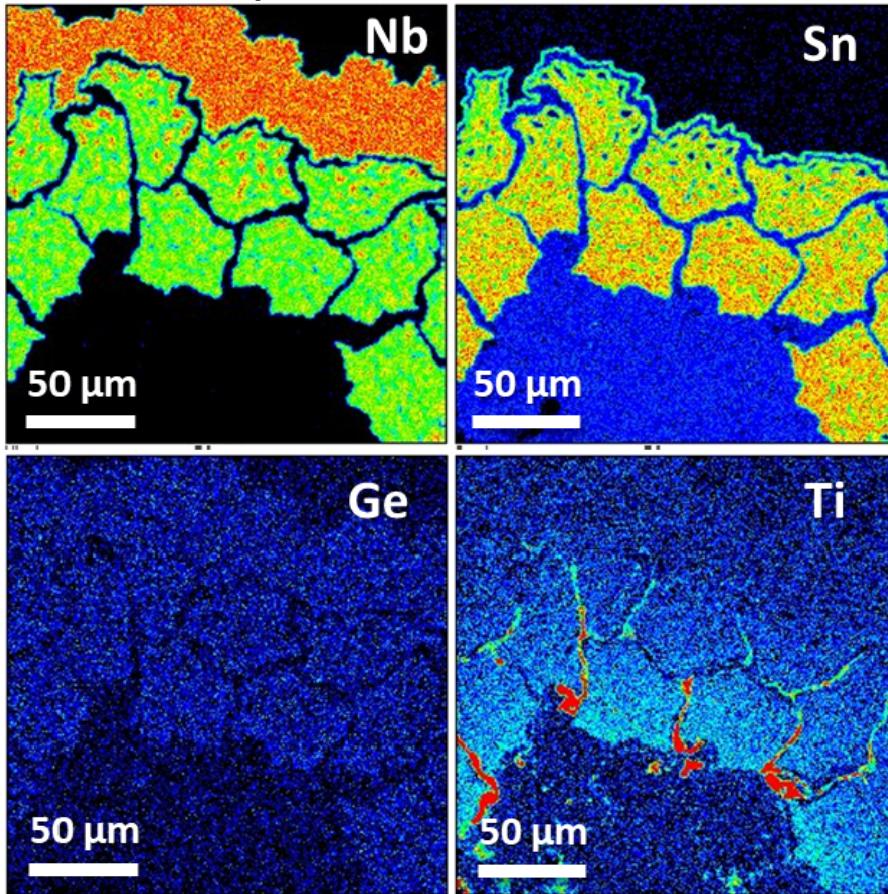


J_c for Ge, Ga, Mg addition



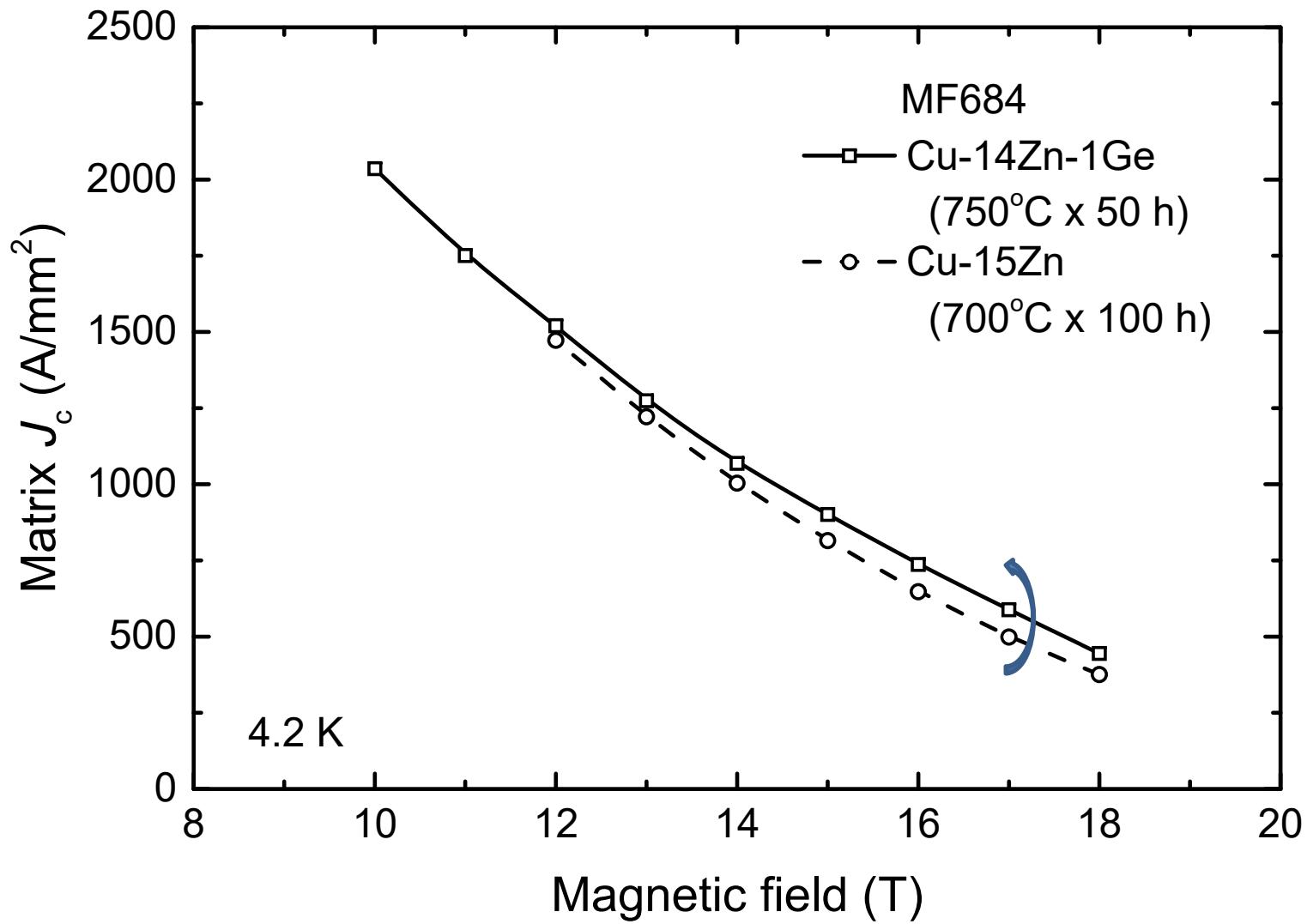
14Zn-1Ge addition

EPMA map : 750 °C x 50 h



- Ge-rich layer : No. Ge diffuse across the Nb core.
- Growth rate : good due to Zn addition
- Grain coarsening : suppressed even at 750 °C x 50 h

J_c for 14Zn-1Ge addition



Conclusion

- **Zn** addition : best in terms of growth kinetics.
- **Ge** addition : results in the formation of Ge-rich layer,
suppression of Nb_3Sn grain coarsening
- **Ga** : easily diffuse into Nb_3Sn layer. → Increase of T_c and B_{c2}
- **Mg** addition : brings about refinement of grain morphology
 J_c characteristics of **SS-1Mg** : comparable to **SS-Cu**
or relatively good. ← fine grain morphology
- **Zn + Ge** (a small amount) : Ge-rich layer was not found,
a small amount of **Ge** diffuse into Nb_3Sn layer.
 J_c characteristics of **14Zn+1Ge** increased slightly
in high fields.