§19. Development of New High Field and High Current Density Superconductors for Fusion Devices

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New Nb_3Sn superconductors with improved high-field performance have been prepared by the Jelly Roll (JR) process using Sn-Ta and Sn-Ti based sheet.[1] In this study, the diffusion mechanism and the origin of excellent performance obtained in present wires have been clarified.

Sn-Ta based alloy buttons of different compositions were prepared by the reaction among constituent metal powders at ~780℃. The buttons were then pressed into plates. Sn-Ti based alloy plates were sliced from the melt and cast ingot. Resulting Sn-based alloy plates were rolled into thin sheets, which were laminated with a Nb sheet and wound into a Jelly Roll (JR) composite. The composite was encased in a sheath, and fabricated into a thin wire followed by a heat treatment at 700~775℃ in vacuum.

In the Sn-Ta based sheet wires, non-Cu J_c's of 200~250A/mm^2 and 120~150A/mm^2 are obtained at 20T and 22T, respectively, at 4.2K. Fig.1 illustrates a typical upper critical field B_{c2} transition of the wire. A B_{c2} (4.2K) of 27.2T (on), 26.8T (mid) and 26.4 (off) is obtained which is the highest value so far reported in Nb_3Sn wires.

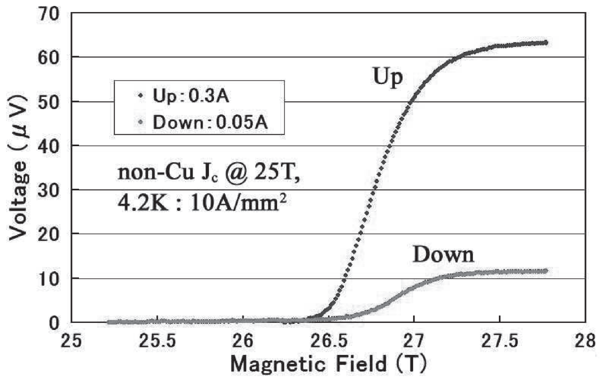

Fig.1 B_{c2} transition at 4.2K for 4/1(Sn/Ta)-4Ti+3Cu sheet wire reacted at 750℃ for 100h.

In the JR wire using Sn-Ta based sheet, thick Nb_3Sn layers with exactly stoichiometric Sn concentration are formed according to the EPMA analysis. Moreover, no composition gradient is observed in the Sn and Nb concentration throughout the Nb_3Sn layer. About 3at%Ta is substituted for Nb in the Nb_3Sn layer. These results yield intrinsically better performance in the present wires than in bronze processed Nb_3Sn wires currently being widely used.

The EPMA analysis on the present wires indicates that about 35at%Nb is incorporated into the Sn-Ta layer during the heat treatment. Fig.2 schematically illustrates the reaction in the Nb/Sn-Ta composite. Nb diffuses into the Sn-Ta layer, and Sn counter-diffuses into the Nb layer. Thus Nb_3Sn layers are formed by the mutual diffusion of Nb and Sn resulting no void formation in the Sn-Ta layer. In the bronze process, Nb does not diffuse into the bronze and Sn in the bronze diffuses into the Nb to form Nb_3Sn. Such one way diffusion causes considerable Sn concentration gradient in the Nb_3Sn, where the Sn concentration near the Nb core becomes appreciably poorer than the stoichiometry.

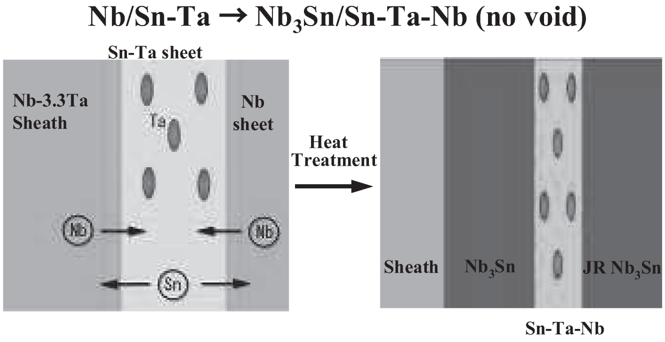

Fig.2 Schematic diffusion reaction in the Nb/Sn-Ta JR wire.

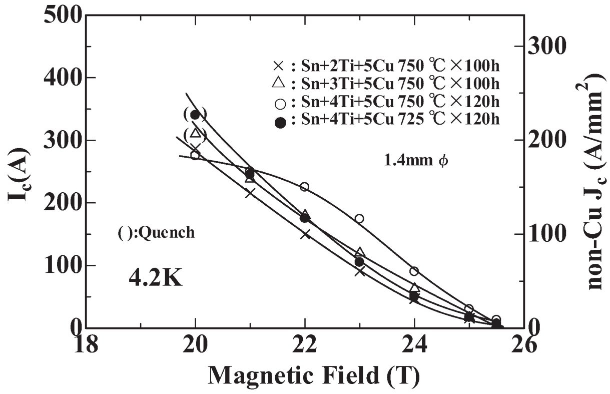

Fig.3 I_c(non-Cu J_c) versus magnetic field curves of different Sn-Ti based sheet wires.

Fig.3 is I_c (non-Cu J_c) versus magnetic field curves of Sn-Ti based sheet JR wires. J_c in high fields enhances with the Ti concentration in the sheet caused by the increase of Nb_3Sn layer thickness. The Sn+4wt%Ti+5wt%Cu sheet wire exhibits nearly the same high field performance as that of Sn-Ta based sheet wires. The EPMA analysis indicates that the Sn concentration in the Nb_3Sn layer is again stoichiometric A15 concentration. Nb diffuses into the Sn-Ti-Cu layer, and the Nb_3Sn layer is formed by the mutual diffusion of Nb and Sn as illustrated in Fig.2.

In summary, Nb_3Sn layers with stoichiometric A15 composition is synthesized through the new diffusion mechanism, which may be the origin of excellent high-field performance in present wires. Sn-Ta based sheet is somewhat more preferable than Sn-Ti based sheet with respect to the high-field performance of the wire. Meanwhile, Sn-Ti based sheet is attractive for mass production since it can be prepared by a conventional melt and cast procedure.

1) Tachikawa, K. Tsuyuki, T. Hayashi, Y. Nakata, K. and Takeuchi, T.: Adv. Cryogenic Engineering (Material), Vol 54(2008)pp244-251.