§16. Research and Development of New Intermetallic Compound Superconductors

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Generation of high magnetic field is indispensable for the progress of fusion facilities. However, the generation of magnetic field over 20T has not yet been realized in superconducting state at 4.2K. Present authors recently fabricated a new high-field (Nb, Ta)$_3$Sn conductors using a composite of Ta-Sn core and Nb (Nb-Ta) sheath. In the present study, the mechanism of the thick (Nb, Ta)$_3$Sn layer synthesis has been clarified, and a more simple fabrication process has been developed.

1. Mechanism of the Thick (Nb, Ta)$_3$Sn Layer Synthesis

Pure Sn, Ta-Sn reacted powder or Ta+Sn mixed powder was encased in a Nb tube with bottom and heat treated at 900℃ for 80h. For the preparation of Ta-Sn reacted powder, a mixed powder of Ta and Sn was reacted at 950℃ for 10h in an alumina crucible in vacuum, the powder size of Ta and Sn being under 350 mesh. The atomic ratio of Ta/Sn in the mixed powder was 6/5. For the peparation of Ta+Sn mixed powder, Ta and Sn powders were pestled in an alumina bowl.

In the Sn/Nb composite specimen, a very thin layer of Nb_3Sn is formed along the Nb sheath, and an intermediate compound richer in Sn is formed at the Sn core side. Meanwhile, in the Ta-Sn /Nb or Ta+Sn/Nb composite specimens, the diffusion structure exhibits a drastic change where a thick Nb_3Sn layer, 70μm-80μm in thickness, is formed along the Nb sheath. A district feature of the reaction is that the Nb in the sheath diffuses into the core, which may enhance the diffusion of Sn from the core to the sheath. This may be a probable origin of the synthesis of the thick Nb_3Sn layer. The Ta in the Ta-Sn core is incorporated into the Nb_3Sn layer, and improve the high-field performance of Nb_3Sn. No difference is found in the structure between Ta-Sn/Nb and Ta+Sn/Nb composite specimens. Fig.1 illustrates schematically the migration of Nb, Sn and Ta during the diffusion reaction in the Ta-Sn/Nb or Ta+Sn/Nb composites.

2. Studies on Simplified Process

The Ta-Sn reacted powder or Ta+Sn mixed powder was encased in a Nb-4at%Ta tube, the outer and inner diameter of the tube being 8mm and 5mm, respectively. By using Ta+Sn mixed powder as a core material, the melt diffusion process preparing Ta-Sn reacted powder can be saved, which yields considerable simplification in the fabrication procedure. The core/sheath composites were fabricated into a tape of 4mm-wide and 0.6mm-thick by grooved rolling and subsequent flat rolling. The tapes were heat treated at temperatures between 750℃ and 925℃ in vacuum to from a (Nb,Ta)$_3$Sn layer between the sheath and the core.

T_c(midpoint)'s of tapes with Ta-Sn reacted core and Ta+Sn mixed core tapes are~18.1K which is higher than that of bronze-processed Nb_3Sn conductors by ~0.5K. Fig.2 summarizes the I_c and non-Cu J_c versus magnetic field curves of different specimens. In the specimen denoted as MD, Ta-Sn powder prepared by the melt diffusion is used as the core. In the specimen denoted as NM(no MD),Ta+Sn mixed powder is used as the core. In the specimen NM6/6-3Cu, 3wt%Cu powder is added to the Ta+Sn powder with Ta/Sn ratio of 6/6. In the core of the specimen denoted as 6/7(3/1+Sn), MD powder with Ta/Sn ratio of 3/1 is mixed with Sn powder to increase the Ta/Sn ratio to 6/7. Since the 3/1 powder is easily crushed into a fine powder, a finer dispersion of Ta is achieved than in the 6/7 core. The NM6/7 tape shows a similar I_c(non-Cu J_c)-magnetic field curve as that of MD 6/5 tape. The 6/7(3/1+Sn) tape shows appreciably larger Jc in fields below 23T compared to the 6/7 tape, which may originate from the finer dispersion of Ta in the core described above. The 6/7(3/1+Sn) tape shows a large non-Cu J_c of 1.5×10^4A/cm^2 at 22T and 4.2K. The 3wt% Cu addition reduces the reaction temperature, and produces a more rapid increase in I_c in fields below 20T.

In the present study, the mechanism of the thick (Nb,Ta)$_3$Sn layer synthesis using the Ta-Sn core has been clarified. Referring the result, the melt diffusion required to prepare Ta-Sn reacted powder has been omitted, and a nearly the same I_c versus magnetic field performance is obtained even if Ta+Sn mixed powder is used as the core. When fine Ta/Sn=3/1 powder is used and mixed with Sn powder, which is easier in the preparation, an improved non-Cu J_c at 22T has been obtained.

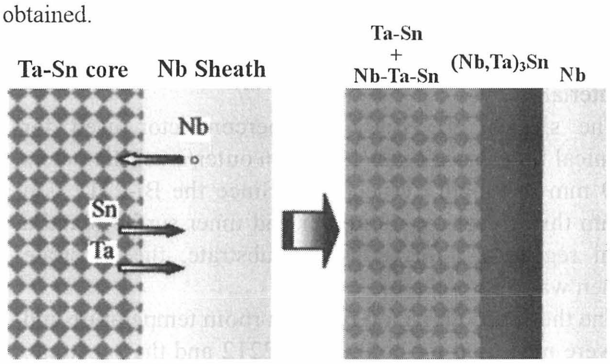

Fig.1 Diffusion reaction in Ta-Sn/Nb or Ta+Sn/Nb composite.

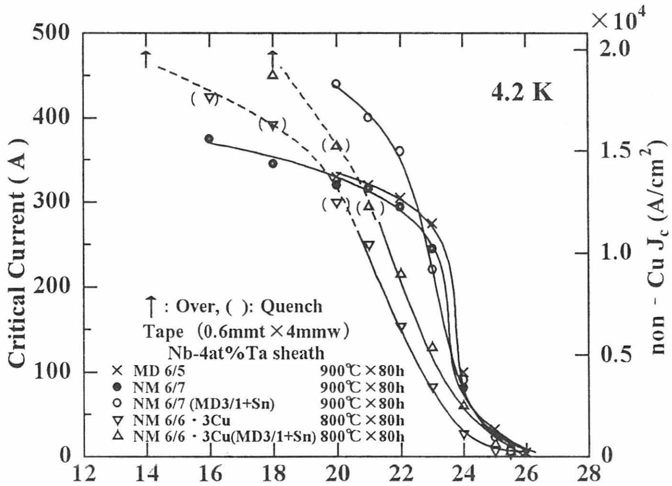

Fig.2 I_c and non-Cu J_c versus magnetic field performance of different tape specimens.