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ENHANCEMENT OF CRITICAL CURRENTS IN MULTIFILAMENTARY V₃Ga CONDUCTORS
BY ADDITION OF INDIUM

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Abstract - Results of enhancement of current density of technical V₃Ga conductors by deposition of indium prior to diffusion annealing are presented. The influence of indium on the V₃Ga structure is discussed.

Recently it has been demonstrated that for the construction of superconducting high-field magnets besides Nb₃Sn also bronze processed V₃Ga multifilamentary conductors may be successfully used /1,2,3/. The highest fields which have been reached up to now by means of V₃Ga-NbTi magnet systems are 12.4 Tesla in 80 mm /2/ and 13 Tesla in 30 mm free bore /3/. Higher fields can be produced economically only by improving the overall critical current density (J₀) of the conductors. One possibility to achieve this aim are third elements, added to the CuGa matrix /4,5/. As was demonstrated in former investigations with single core wires the current carrying capacity was most effectively improved by indium /6/. The present paper deals with the enhancement of J₀ of technical conductors by adding indium.

Experimental

The samples used throughout this investigation were either wires with 0.18 mm diameter containing 109 filaments or stranded cables consisting of six wires and a central tungsten wire with same diameter. Etching and electroplating of indium on to the sample surface was performed prior to thermal treatment essentially in the same way as described earlier /6/. The samples were annealed in vacuum or in helium atmosphere.

The field dependence of the critical current of cables was measured in a V₃Ga-NbTi magnet up to 10 Tesla at 4.2 K. For that purpose the annealed samples (length 18 cm) were wound on to a sample holder with 26 mm diameter. The critical current was defined according to 1 μV per 10 cm length of sample. Additionally, measurements of critical currents of multifilament wires have been performed in Bitter magnets of ILMT Wroclaw up to B₀2. By using pole pieces the field range was extended to 22.5 Tesla. Samples for this measurement were annealed in a hair-pin like geometry according to the shape of pole pieces to avoid undue bending of the material.
In some cases additionally to \( I_c \) and \( B_c \) further parameters have been measured as critical temperature, layer thickness of \( V_3Ga \) using optical microscopy and concentration of indium and gallium by means of X-ray microanalysis.

Results and discussion

In Fig. 1 the critical current of cables is represented as a function of thickness of deposited indium and of annealing conditions, where \( I_c \) values refer to a field of 10 Tesla. With rising thickness of indium layer the critical current increases up to 60 per cent for annealing temperatures in the range from 555 °C to 570 °C.

For temperatures above about 600 °C and comparatively thick indium layers a decrease of \( I_c \) occurs. But it cannot be excluded, that the bending diameter of 26 mm causes already a mechanical degradation of the samples considering the fact, that a combination of high annealing temperatures with large amounts of indium results in quite brittle material. Measurements are under way to clear this problem.

In Fig. 2 the critical current density of multifilamentary wires related to the overall cross section of the samples is plotted against magnetic field up to \( B_{c2} \). It is obvious that the deposition of 2.6 µm indium prior to thermal treatment leads to an increase of current density in the whole field range. The highest \( J_c \) of \( 3.3 \times 10^6 \) A/cm² at 15 Tesla was found after annealing at 570 °C.

Fig. 2 contains also the \( I_c(B) \) dependence of an indium-treated cable of 125 m length recalculated for one wire. A piece 1 m long was used for this measurement.

An essential cause for the improved critical current of samples containing indium is an accelerated \( V_3Ga \) layer growth rate, which was established for single core wires /6/ and also for multifilamentary conductors, see Fig. 3. Details of the influence of indium on the \( V_3Ga \) growth rate will be discussed elsewhere.

Fig. 4 shows the relative enhancement of critical current via reduced field \( B/B_{c2} \). A greater content of \( V_3Ga \) phase alone would only result in a field-independent enhanced \( \Delta I_c/I_c \). The rise of the curves in Fig. 4 towards higher fields therefore indicates a changed pinning in the \( V_3Ga \) layer of indium-treated samples which is especially favourable in the high field range.

The influence of low concentrations of indium on the intrinsic superconducting parameters of \( V_3Ga \) is small as is to be concluded from the small increase of critical temperature (≤ 0.2 K) and upper critical field (≤ 0.2 Tesla) of the investigated multifilamentary conductors.

The experimental evidence obtained by ESMA, that only a small amount of indium is contained in the \( V_3Ga \) layer is in accordance to the before-mentioned finding. Therefore, the changed pinning in indium-treated samples may be referred to the fact, that besides growthrate also the grain structure of the \( V_3Ga \) layer is influenced by indium. Investigations to settle this point are in progress.

Fig. 5 shows the comparison between the \( J_c(B) \) dependence of a \( V_3Ga \) sample annealed at 570 °C and commercially processed \( Nb_3Sn \) multifilamentary wires. It is obvious, that the \( J_c \) values of the indium-treated \( V_3Ga \) conductor in the high field range are comparable with those of the best \( Nb_3Sn \) conductors.
Fig. 1 - Critical current of cables at 10 Tesla as a function of indium deposition and annealing conditions
Fig. 2 - Influence of In on critical current density. 
full symbols: 2 \mu m In depos. 
empty symbols: without In 
\( \triangle 540^\circ C/425h \) \( \triangledown 570^\circ C/215h \) 
\( \bullet 570^\circ C/215h \) \( I_c/6 \) of cable 
\( \blacksquare 630^\circ C/70h \)

Fig. 3 - Influence of In on \( V_3Ga \) layer growth rate 
\( \bullet 2-3 \mu m \) In deposition 
\( \bigcirc \) without In

Fig. 4 - Relative enhancement of critical current vs. reduced magnetic field

Fig. 5 - Comparison of In-treated \( V_3Ga \) wire (curve) with commercial \( Nb_3Sn \) wires /7/ 
\( \bigtriangleup \) AERE \( \bigtriangledown \) Airco \( \bigstar \) IGC 
\( \bigcirc \) Airco \( \bigtriangleleft \) Vac. \( \bullet \) BNL/Airco 
\( \blacksquare \) Airco + IGC