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Nb_3Sn Artificial Pinning Microstructures

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Abstract—Extension of the APC approach to Nb_3Sn requires that a second phase be incorporated into the Nb_3Sn layer. The second phase would increase pinning strength by either reducing the grain size or by the second phase pinning the flux itself. The following criteria for elements to be candidates for the APC approach are: (1) they must form intermetallic compounds with Cu or Sn and (2) they must have negligible solubility in Cu and Nb or they must be strong oxide formers. Many of the rare earth elements satisfy these criteria. To circumvent the large strains required to produce wires with a fine distribution of the second phase, film deposition techniques have been used. Critical current densities for Nb films doped with Ti and Y are about 4,000 A/mm^2 at 6T and 4.2K.

I. Introduction

Since the requirements of an Artificial Pinning Center (APC) Nb_3Sn has been outlined previously [1] they will briefly be discussed here. One of the first applications of the APC approach was for Nb_3Sn tape conductor with ZrO_2 inclusions produced by internal oxidation of a Nb-1%Zr tape. The presence of these particles in the Nb tape inhibit grain growth during the Nb_3Sn formation at high temperature [2][3]. More recently attempts at applying the APC approach to "bronze-type" processes were made by adding Ta [4][5] and Cu [6] as distinct phases to the Nb core. These results were not conclusive. It is not clear if the increase in J_c for the Ta APC material was due to an increase in the upper critical field from doping of the Nb_3Sn or from an APC mechanism. The critical current densities of Cu APC wires were not significantly better than undoped wire. However, their observations show that the reaction rate is significantly increased by the addition of Cu [6].

To extend the APC approach to "bronze-type" processes one must add elements that do not alloy with Nb or Cu but form intermetallics with Sn or oxides. This would make most of the rare earth elements candidates (i.e. lanthanide period) plus elements of the second and third groups (i.e. Y and La). These elements readily form oxides but also form many intermetallics with Cu and Sn. To enhance the H_{c2} of the films and to determine if there are any interaction with other dopants Ti and Ta were also investagated. To test the APC concept for bronze type conductors the additions must have a very low solubility in Nb and should co-deform well with Nb. The later condition does not have to be met at this time since a thin film approach is being taken to avoid fabrication difficulties associated with the large wire reductions required to achieve a fine distribution of the addition in the Nb. Once perfected the film technique should permit the rapid screening of candidate elements. It should also produce a uniform fine scale distribution of the addition in the film prior to heat treatment which should act as artificial pinning center once the compounds are formed.

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II. Experimental Approach

Physical vapor deposition techniques (e-beam, sputtering and evaporation) were employed to produce films with layers of Nb, Cu, and Sn with thicknesses of about 200 to 400 nm. Additions of Ti, Ta, Y and La were incorporated in the Nb layer by e-beam co-evaporation. Since Sn is not permitted in the e-beam deposition system used for this work a Cu layer about 400 nm thick is added to prevent oxidation of the Nb layer before the films are removed from the e-beam chamber. The e-beam system permitted the co-depostion of up to three elements simultaneously. The Nb and Cu deposition rates were 1-3 Å/s and 5-20 Å/s, respectively. The deposition rate for Ti, La, and Y was about 0.1-0.2 Å/s to produce a composition of about 5 volume percent of each addition. This could be higher or lower depending on the sample. The base pressure for the system was usually 1×10^{-7} Torr. With such high base pressure it is possible that some oxygen was incorporated into the Nb alloy layer during deposition.

A Sn layer about 100-200 nm thick is then applied by either sputtering or evaporation. The wafer processing is listed in Table I. By monitoring the deposition rate with crystal monitors the thicknesses were usually within 20% of the values stated above. To avoid photolithography and its associated dry or wet

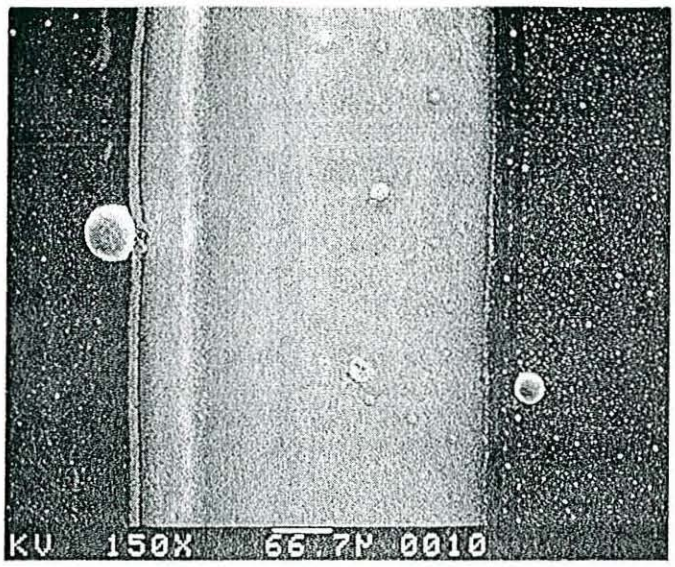

Fig. 3. SEM image of the line of film 17 after heat treament. Note balls of Sn on the line and surface of Sc_2O_3.

The critical current of the best films can be seen in Fig. 5. There are two main points in the figure. One is that Ti and Y doped samples have the highest J_c's of about 4,000 A/mm^2 at 6T. This is about twice that of the undoped sample, number 13. The second is that the films with highest J_c's (17 and 18) are obtained on Y_2O_3 or Sc_2O_3 buffer layers. The J_c's of samples 2 and 10, and to some extent 3, have a very steep drop between zero field and 2T. This drop may be due to excessive doping since these three samples each have two dopants.

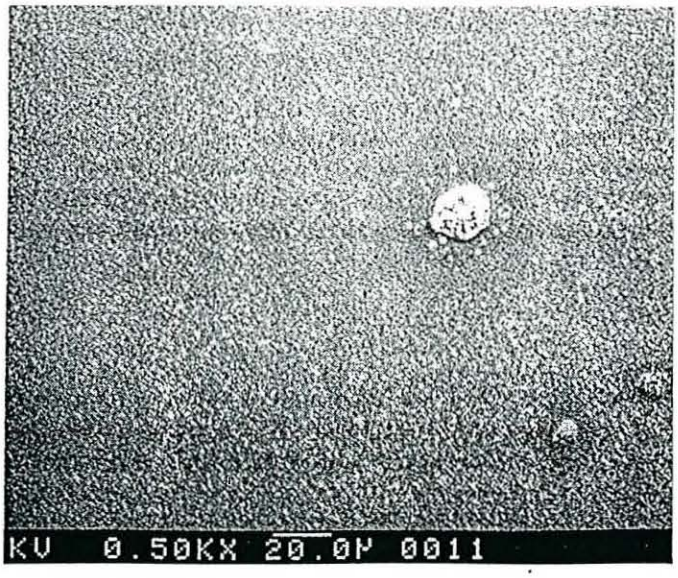

Fig. 4. SEM image at higher magnification of the line of Fig. 3. Notice that the film is uniform and crack-free.

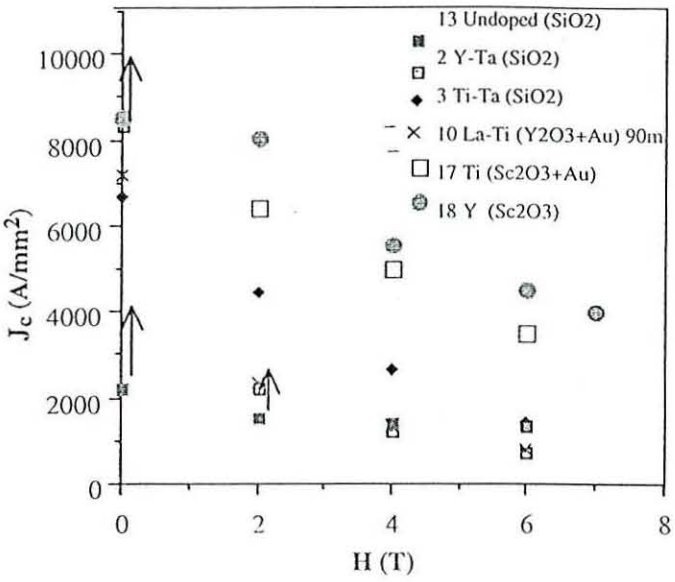

Fig. 5. Critical current density at 4.2 K of best films. All of the samples had the same heat treatment of 700°C for 30 minutes except 10 which was heat treated for 90 minutes.

Some preliminary TEM observations of sample 3 show that the Nb_3Sn grain size may be about 20-40 nm. The observations also revealed regions of light contrast perpendicular to the substrate (i.e. the films growth direction). At this time it is not known if these regions formed during the Nb-Ti-Ta deposition or during the reaction to form the Nb_3Sn and what they are.

IV. Conclusions

The highest J_c's (3,500-4,500 A/mm^2 at 6T and 4.2K) are obtained in films doped with Ti and Y. At this time it is not known if the Ti and Y have formed oxide particles in the Nb_3Sn film. Buffer layers of Y_2O_3 or Sc_2O_3 produced the highest J_c's. A thin layer of Au on the oxide promotes adhesion of the Nb layer.

Acknowledgment

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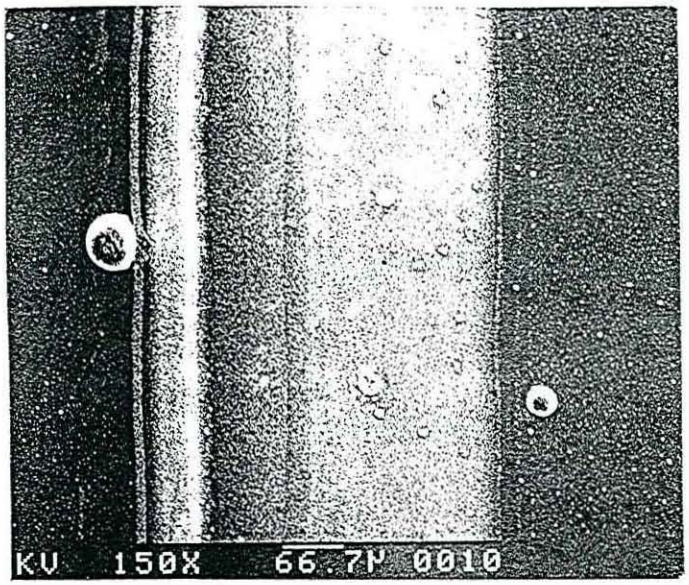
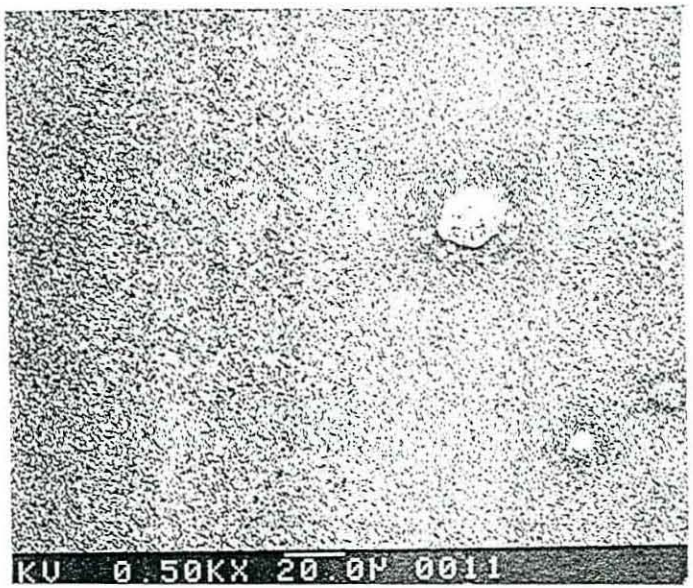

KV 150X 66.7µ 0010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