

DAPNIA/STCM 98-09

September 1998

**DEVELOPMENT OF CURRENT LEADS USING  
ELECTROLYTICALLY DEPOSITED BSCCO 2212 TAPES**

**J. Le Bars, T. Dechambre, P. Regnier**

# DAPNIA

*Talk given at the Applied Superconductivity Conference (ASC '98),  
Palm Desert, California (U.S.A.), September 13-18, 1998*

**COMMISSARIAT A L'ENERGIE ATOMIQUE**

**DSM/DAPNIA/STCM**

**Rapport n° 9**  
le 15 septembre 1998

**J. LE BARS**

**DEVELOPMENT OF CURRENT LEADS USING**  
**ELECTROLYTICALLY DEPOSITED BSCCO 2212 TAPES**

ASC' 98 Palm Desert - California  
13/09/1998 au 18/09/1998

# Development of Current Leads Using Electrolytically Deposited BSCCO 2212 Tapes

J. LE BARS, T. DECHAMBRE

Commissariat à l'Énergie Atomique Saclay, DSM/DAPNIA/STCM, 91191 GIF-SUR-YVETTE CEDEX, France

P. REGNIER

Commissariat à l'Énergie Atomique Saclay, CEREM/SRMP, 91191 GIF-SUR-YVETTE CEDEX, France

K. GAGNANT

Ecole Nationale Supérieure de Chimie de Lille, France

**Abstract** - Prototype current leads of BSCCO 2212 are being developed using the sequential electrolytic deposition of precursors on a silver or a silver alloy tape and heat treatments. The tapes are made using a continuous industrial process. This method of deposition, gives great flexibility in minimizing the mechanical stresses, the thermal conductivity and in ensuring the quench protection. Functional models were tested at 4.2 K in magnetic fields up to 7 T and in self field at 77 K. The maximum currents reached were 1000 A at 4.2 K and 100 A at 77 K.

## I. INTRODUCTION

Bi 2212 superconducting tapes prepared using electrolytic deposits on a silver tape are used to produce the superconducting part of hybrid current leads.

As is widely described, hybrid current leads are composed from a normal part carrying the current from room temperature to an intermediate temperature (77 K or less  $\sim$  60 K) and a superconducting part.

The major attraction of such a current lead is to reduce the heat load due to the current transport in the HTS part and to develop a marketable, low price, zero resistance application.

Next to the ohmic losses, the thermal losses are a very important concern but will not be treated in this work. However, we will mention the way to reduce the thermal conductivity of the substrate without introducing any problems in the electrolytic deposition of Bi 2212.

We report on the way to make such a current lead and the electrical properties of different stacks of tapes, at 4 K ( $0 < B < 7$  T) and at 77 K.

## II. TAPE PREPARATION

The high temperature superconducting tapes were prepared from a nominal composition of  $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$  (BSCCO 2212) by an electrolytic process.

The 4 precursors were continuously electrodeposited (Fig. 1) on a 50  $\mu\text{m}$  thick silver tape, using the following baths: an aqueous solution of  $\text{SO}_4\text{Cu}$  for Cu,  $\text{Bi}(\text{NO}_3)_3$  into dimethyl sulfoxide (DMSO) for Bi,  $\text{SrCl}_2$  dissolved into a mixture of DMSO + acetonitrile for Sr and  $\text{CaCl}_2$  dissolved into DMSO for Ca. To improve the adhesion of these precursors and to benefit of the homogenisation brought about by the presence of liquid phases, short heat treatments were alternated with electrodepositions.

The final thickness of the Bi 2212 layers was 3.5  $\mu\text{m}$ . At this stage, the tape was annealed for a few minutes at 860 C, subsequently quenched down to room temperature and finally re-annealed for 1 hour at 840 C [1].



Fig. 1 View of a Bi 2212 tape in production

## III. SAMPLE PREPARATION AND EXPERIMENTAL SETUP

The samples used for electrical measurements were 130 mm long, 10 or 20 mm wide and 50  $\mu\text{m}$  thick coated on both sides with a 3.5  $\mu\text{m}$  thick layer of Bi-2212.

To obtain a module, silver tapes of 50  $\mu\text{m}$  thickness were attached either side of the Bi-2212 coated tape. Electrical contact between the HTS and the silver tape was ensured by using silver paint to join them. Braided copper (or LTS) wires were then soldered on to the silver tape using a lead-tin solder. This provides a strong physical connection between the silver and the copper (or LTS). Stacks with 4, 5 and 10 modulus were fabricated (Fig.2).

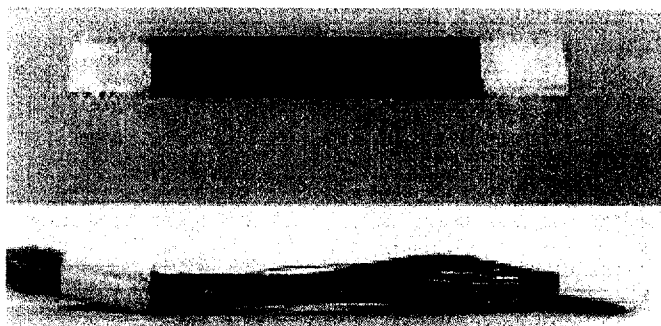


Fig. 2. Bi 2212 sample and stack (10 samples)

Voltage taps were attached along the modules to measure the critical current. The sample was then installed in the test facility.

#### IV ELECTRICAL CHARACTERIZATION

The transport  $J_c$  of our samples was measured as a function of the applied magnetic field, up to 7 T for specimens tested at 4.2K and in self field conditions for those tested at 77 K. The voltage criterion is as  $1 \mu\text{V}/\text{cm}$ :

The samples were cutted from the first 200 m of tape made in the aim of helping the manufacturer optimize their production process. Though this first tape was not homogeneous, it was found that the transport  $J_c$  of the two central modules of a stack of 4 tapes was as high  $1\,500 \text{ A}/\text{mm}^2$  (0T, 4.2K) over 10 cm. This result highlights the relevance of the technique and since the best  $J_c$  value measured over 2 cm produced at the laboratory scale is  $2\,350 \text{ A}/\text{mm}^2$  in the same conditions [2], there is room for large improvements.

Figure 3 shows the field dependence of the transport  $J_c$  at 4.2 K of a specimen 20 mm in width, 130 mm in length and equipped with potential probes separated by 60 mm. The presented values account for the edge effects which reduce  $J_c$  by about 20 % of the specimens.

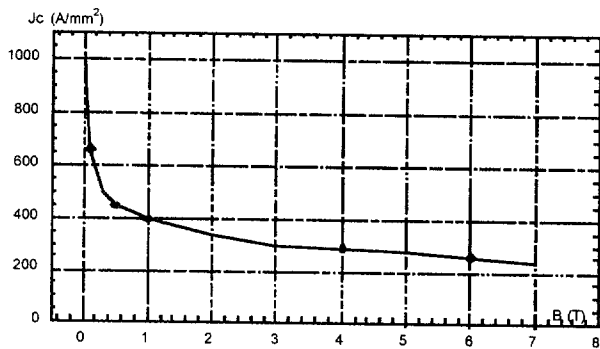


Fig. 3.  $J_c$  versus magnetic field for a strip at 4.2 K

These effects are mainly due to the preferential deposition of some of the precursors in the vicinity of the sample edges which gives rise to dewetting and to cuprate excess (Fig.4).

In another set of experiments, 5 modules of 10 mm width were stacked and joined as described in section II, three of them were equipped with potential probes: the central one labelled 2 and the outer on each side labelled 1 and 3. The measured values are reported in Table 1. The whole width of the samples is assumed to be good since the edges were cut off. Hence  $J_c = 879 \text{ A}/\text{mm}^2$  is calculated in dividing  $I_c = 246 \text{ A}$ , the current injected in the stack which generates a voltage drop of  $1 \mu\text{V}/\text{cm}$  in the weakest tested module (the one labelled 3), by the whole cross section of the five modules ( $5 \times 8 \text{ mm} \times 0.007 \text{ mm} = 0.28 \text{ mm}^2$ ).

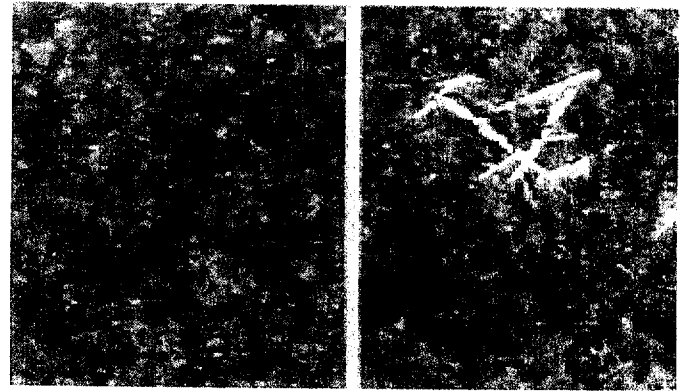


Fig. 4 Micrographs of good (A) and bad (B) parts of Bi 2212

Table I

Module	$J_c$ ( $\text{A}/\text{mm}^2$ )	$I_c$ total (A)
1		270
2	879	246
3		336

Following the same line, 270 and 336 A are the currents which generate  $1 \mu\text{V}/\text{cm}$  between the potential probes of modulus 1 and 3, respectively. However the genuine current capability of this current lead is of course 246 A at 4.2 K despite the fact 2 modules are still far under their critical current density (Fig. 5).

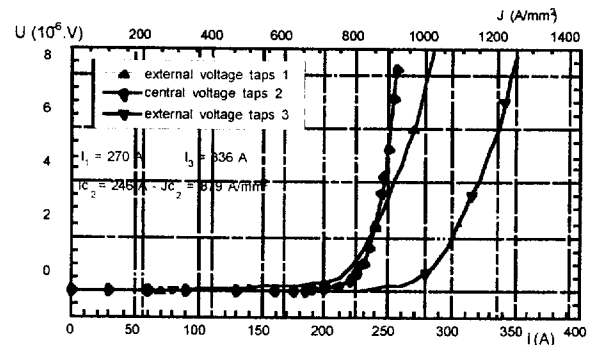


Fig. 5. I-V curves of a functional 5 strip modulus (4.2 K - 0T)

$I_c$  is reduced to about 25 A at 77 K. The current distribution into the five slabs is also controlled by the contact resistance's not yet measured.

Because we could not test a stack of 10 modules of 20 mm in width with our equipment, 10 modules of 20 mm in width were cut exactly into two pieces of 10 mm in

width and the parts assembled to build 2 stacks of 10 modules.

We label the modules of the stack from bottom to top (Fig. 6).

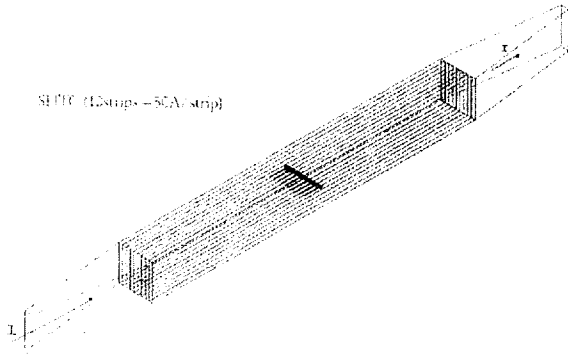


Fig. 6 Schematic view of a stack - 10 modules

Module number 2, 4, 6, 8 and 10 were equipped with potential probes and the performances of the stack estimated in the same way as those of the 5 modules stack (Table II). The total cross section of the superconducting assemblage was 0.56 mm<sup>2</sup> for 1 stack.

Table II

Module	$J_c$ (A/mm <sup>2</sup> )	I total (A)
2	884	495
4		565
6		bad contact
8		bad contact
10	884	1 395

We have also tested a second stack of 10 modules. The lower critical current in the module labelled 2 in this stack was 504 A. (this module was the second half part of the same piece originally 20 mm).

Finally the two stacks of 10 modules were joined together and the critical current of the set was measured as before. The critical current was about 1 000 A at 4.2 K and 105 A at 77 K, both values measured in the sample self field.

To get more information on the behaviour of such current leads, the applied magnetic field was increased in a sawtooth way in a stack of 4 modules. The results are shown in figs. 7 and 8. Curves M1 - direct and M2 - direct which are plots of  $J_c$  versus the applied magnetic field respectively correspond to the 2 central modules. The maximum field was 7 T. The  $J_c$  (0 T) appears as a function of the applied field. Some explanations in terms of the vortex lattice have been given elsewhere [3].

After this first experiment, the 4 modules stack was warmed over in the He gas and re-cooled. Another sawtooth cycle was applied and the current transport was reversed. The results are shown in figs. 7 and 8 (curves M1 - reverse and M2 -

reverse). Surprisingly, the sawtooth profile corresponding to the reverse current is above that of the direct current for the module M1 and under for the module M2.

From these experiments it can be concluded that  $J_c$  at 4.2 K and 0 T is sensitive to the history of the applied field, to the temperature cycle and to the direction of the transport current flowing through the modules.

A/mm<sup>2</sup>

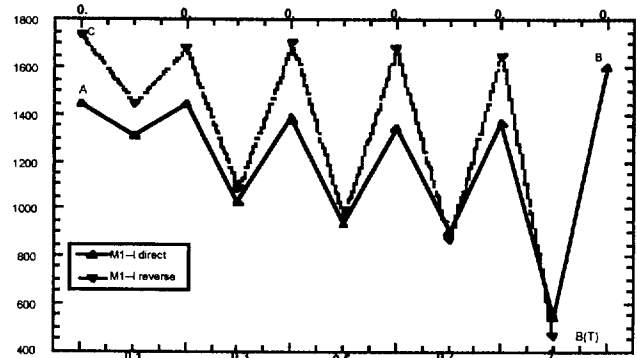


Fig. 7 module 1

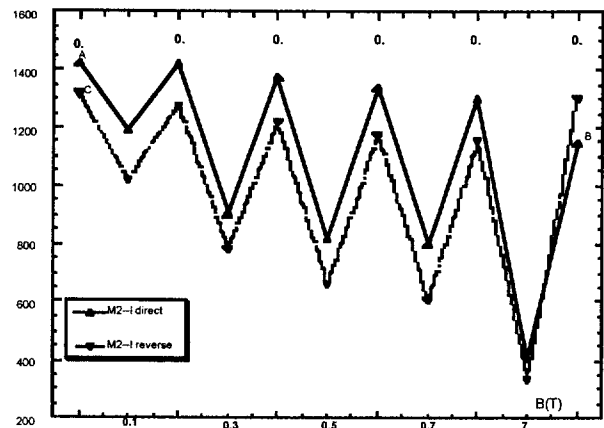


Fig. 8 module 2

Fig. 7 and 8 : Sawtooth  $J_c = f(B)$  at 4.2 K for 2 modules as a function of the direction of the transport current and the temperature cycle (the bold 0. of the B axis corresponds to  $B = 0$  T for one of the two extrem values of the sawtooth cycle).

## V. CONCLUSIONS

These early results reported here are our first encouraging step in the realization of current leads able to carry 1 000 A at 77 K. To achieve this goal, we have to

- use a specific design to assemble more adapted modules into a more appropriate stack
- take into account the self field distribution
- increase the mechanical strength of the substrate
- pay special attention to minimize the contact resistance of current injection
- use silver-gold alloys as substrate to strongly decrease the thermal conductivity [4]
- increase the overall  $J_c$  of the tapes.

All this points are now in progress.

## ACKNOWLEDGMENT

The authors would like to thank gratefully :  
S. Verneyre, University Paris-Sud XI Fiupso, France,  
J.J. Bigot CEA Saclay, Dsm/Dapnia/Sgpi 91191  
Gif-Sur-Yvette Cedex, France  
A. Dauba CEA Saclay, Dsm/Dapnia/Sgpi 91191  
Gif-Sur-Yvette Cedex, France  
S. Klioukhine, IHEP, Protvino, Russia,  
for their contribution to these results.

## REFERENCES

- [1] Fabrice Legendre, Philippe Gendre, Lelia Schmirgeld-Mignot and Pierre Regnier, Bi 2212 tapes prepared by alternating electro-deposition and heat treatments Applied Superconductivity 97, Institut of Physics Conference - series number 158, 2, p. 1347.
- [2] L. Zani, M. Menget, P. Regnier, J. Le Bars, T. Dechambre, P. Nicolas Transport critical current at 4.2 K of pure and MgO - doped Bi 2212 IEEE Trans. on Appl. Supercond. 7 (2) 1997 pp. 1683-6.
- [3] Louis Zani, thesis in physics of Ecole Polytechnique, 23 july 1998.
- [4] S.M. Ting, K.R. Marken Jr., L. Cowey, W. Dai, S. Hong and S. Nelson, Development of current leads using Dip-Coated tapes BSCCO - 2212, IEEE Trans. on Appl. Supercond. 7 (2) 1997 pp. 700-2.