SYNTHESIS REPORT

FOR PUBLICATION

Contract n° : BRE2-CT92-0229

Project no : BE-5479

Title : Development of high critical current Bi (2223) Tapes

Project coordinator : Forschungszentrum Karlsruhe
Institut für Technische Physik

Partners : **University Geneva, DPMC**
Imperial College London
INFM **Genus**
CNRS **Grenoble**

Reference period : from 1.4.93 **to 31.3.96**

Starting date : 1.4.1993 **Duration : 36 months**

Date of issue of this report : **18.3.** 1997

Project funded by the European Community under the Industrial & Materials Technologies: Programme (Brite-EuRam III

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2. Summary

Keywords: Superconductor, BSCCO, High transport current s

The main goal of the project was the development of mechanically reinforced high transport current carrying BSCCO (2223) tapes. This challenge required developments of the superconductor precursor powder processing, the study of the thermodynamics of the formation of the superconducting phase and most important the investigation of the multiparameter set of the tape deformation and production. Very detailed physical investigations of the superconductor properties by' means of magnetic and transport current characterization applying partly new developed experimental methods the important feedback for the progress in tape quality.

The finally achieved critical current densities in BSCCO (2223) tapes were J_c = 45000 Acr^{-2} for Ag sheathed- monofilarnentary tapes and J_c = 25000 A cm^{-2} in 0.5 m samples of 37 filament tapes. We developed a successful method to reinforce the soft Ag sheath with dispersion hardened AgMg sheaths, thus enhancing the tolerable stress values by a factor of five to yield strengths of 250 Mpa, with a comparable content of superconductor material and nearly the same level of transport current. The analytical work gave new results about the subsequent processes during phase fo 'mation, information about the current distribution in the tape and the consequences for the preparation and last not least a quantitative evaluation of the achieved grain alignment in the superconductor which correlates with the transport current. The sum of the results has a strong impact on the reliable industrial processing of mechanical stable, high current long length BSCCO tapes, which presently appear to be applied in first devices and prototypes of energy technique like the power cable, transformer, magnetic energy storage, NMR imaging and motor. Further specialized follow up actions like low AC loss tape development and tape modifications for current leads benefit from the experience and success of this project.

3. The consortium

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3.2 Consortium description

FZK

The Forschungszentrum Karlsruhe, Institut **fur** Technische Physik **has a long tradition in the development and characterization o', superconductors from** NbTi, Nb_3Sn **over** chevrel **phase to HTC materials** coverir g-the **range from small** short **length prototype conductors to large cables being ap** plied **in superconducting coils. The research is strongly focused on application** since **in parallel superconducting coils for, fusion reactors NMR, SMES and magnetic separation are developed as prototypes. Furtheron innovative cryogenic systems as pulse tube coolers are investigated:**

UNIGE

The University of Geneva, Department de la Physique du Matière Condensée **is well** known **as developer and investigator** of **mostly all high temperature superconductors of possible technical interest as** YBCO, TISSCO **and BSCCO as single crystal, bulk** and **wire or tape. Special** expertize **is provided in general metallurgy, thermodynamics and fundamental** physica **I characterization.**

IMPCO

The Imperical **College,** Blackett **Laboratory,** Superconductor **Group is especially expertized in magnetic methods for the characterization of superconductors combining the both important aspects the development of new innovative experimental methods and the theoretical** interpretation **of the experimental results.**

I N F M

The INFM Genus is specialized on fundamental inv estimation of superconducting properties investigating bulk and tape materials by means of different magnetic methods. Additional physical properties of technical interest "as the thermal conductivity of modified, superconductors are under im'estimation.

CNRS

The CNRS Grenoble, Laboratoire de Cristallografie is highly expertized in crystal structure determination and evaluation. Of special interest are texture investigation by means of pole figures which gives a quantitative evaluation of the grain alignment in the superconductor.

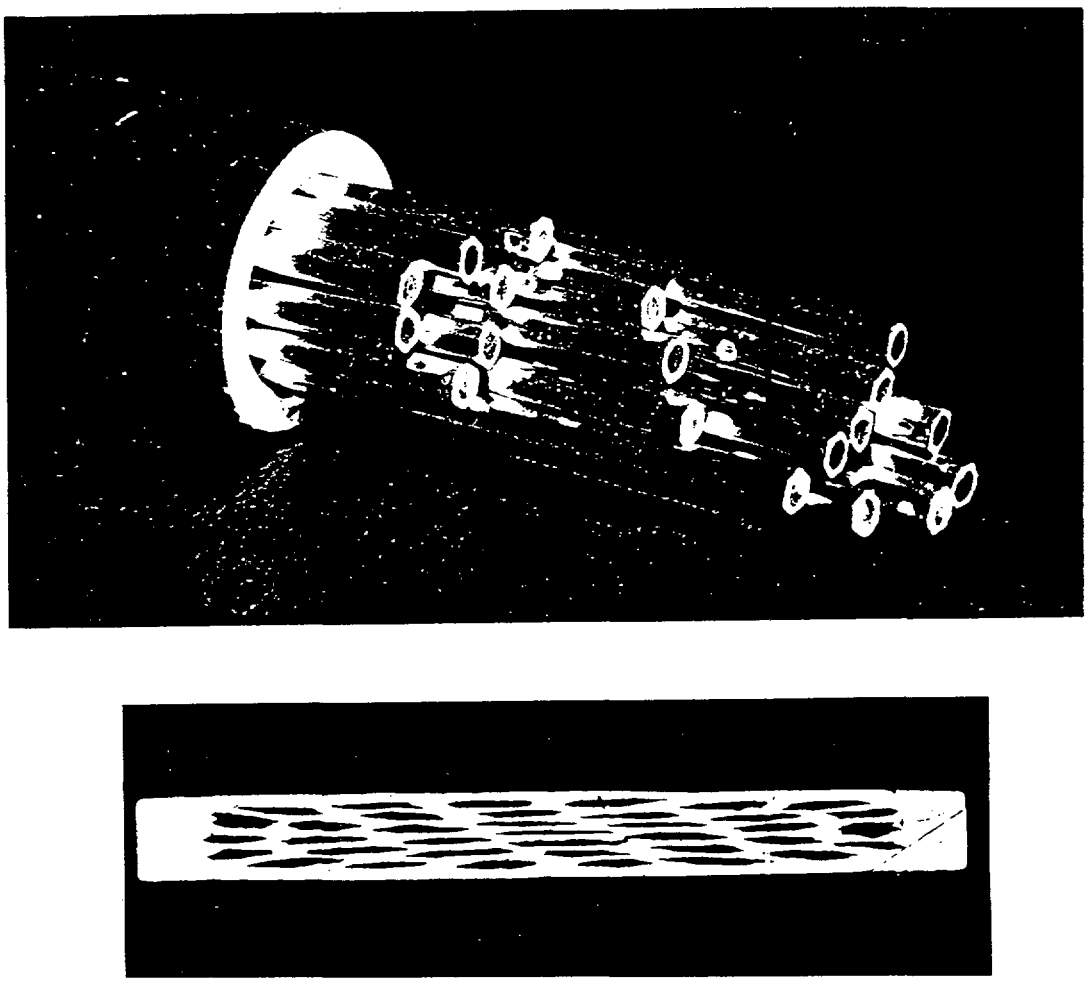

Fig. 1
Bundling of hexagonal monocore conductors into a Ag rod, below the final tape cross section (2.5 x 0.2 mm) after drawing and rolling.

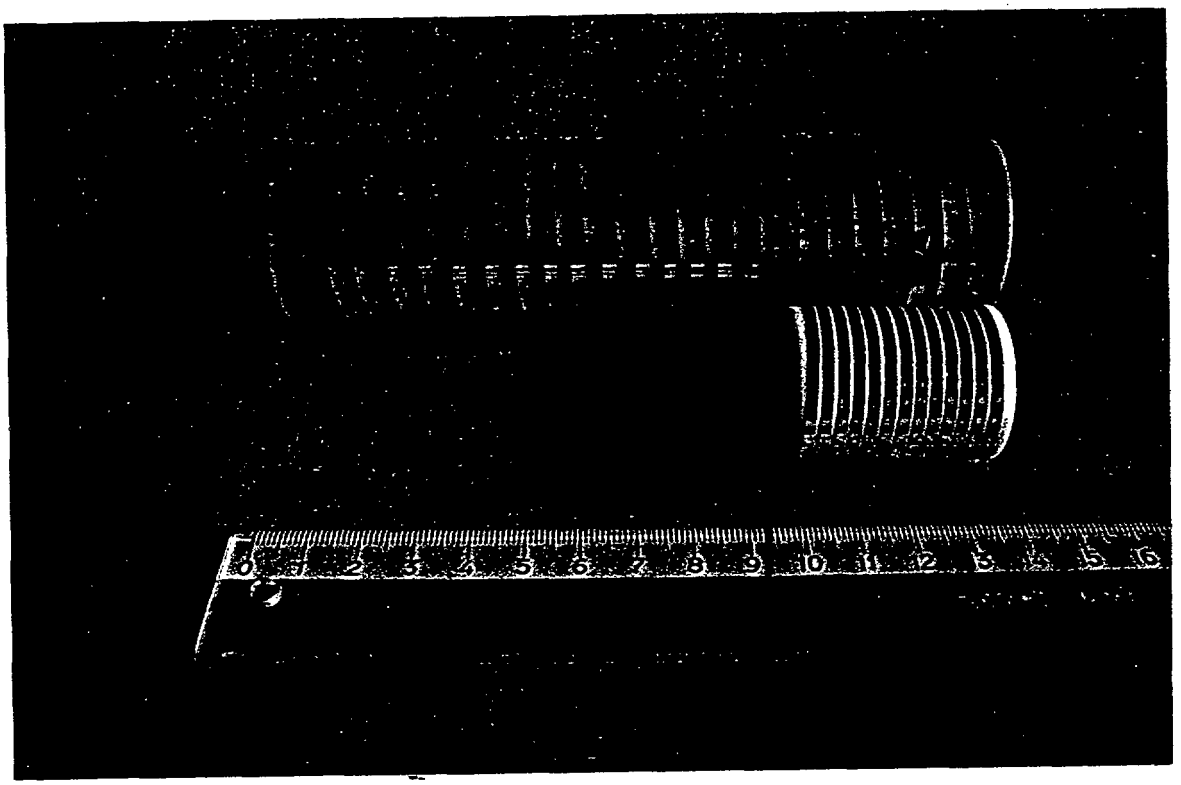

Fig. 2
BASSCO **tape "wound on alumina rods for the heat treatment**

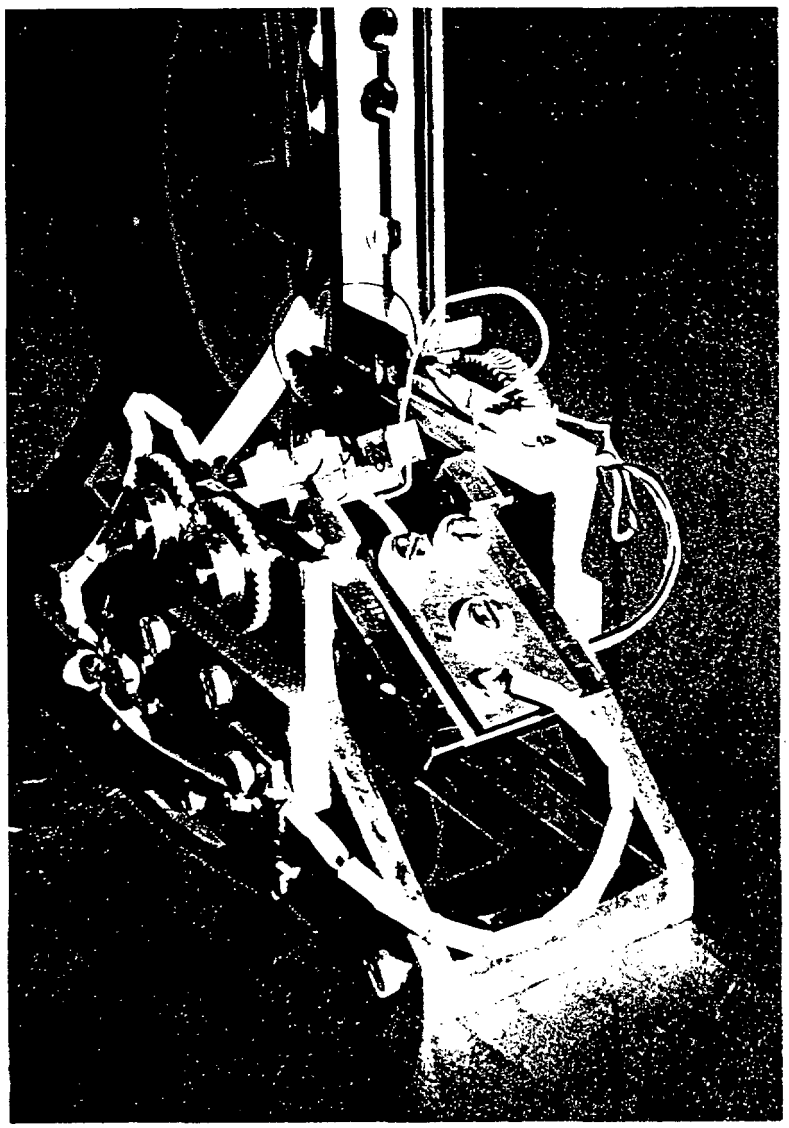

Fig. 3
Bending test **rig for 77 K operation** to **investigate** the mechanical **properties of** BSCCO **tapes**

4. Technical achievements

The Challenge of this project was the development of superconducting Bi(2223) tapes with high transport currents, using a reliable technique with the potential of extension to industrial scale and using conductor concepts, which insure a mechanical reinforcement. The consortium strategy is expressed through the combination of two groups focused on the preparation work and three groups which contribute to improved superconductor quality through fundamental physical investigations. The tasks included the following scientific questions.

a) **Improvement of the superconductor power handling**
b) **Studies of the formation mechanism of the superconducting phase**
c) **Development of an optimized tape deformation technique by means of innovative methods**
d) **Applying mechanically reinforced sheath materials**
e) **Characterization and improvement of the current carrying properties as function of temperature and magnetic field, applying new magnetic method and transport current measurements.**
f) **Improvement and analysis of the grain alignment and grain connection in the superconductor.**
g) **Improving the tape transport currents in long tape lengths**

The achieved results were in detail:

The treatment of the precursor powder of the superconductor was one of the basic problems since several parameters had to be improved. First the calcination process parameters were optimized with respect to low carbon content and a suitable phase composition of the precursor powders both being related to phase formation conditions of the superconductor-in the tape and the resulting transport currents.

Studies of the phase formation process resulted in a more detailed knowledge about the distinct steps in the chemistry of the phase formation, investigated by means of DTA, X-ray diffraction and SEM/EDX spectroscopy. The formation of the lead doped Bi(2212) phase was confirmed. A change of the Ca/Sr ratio destabilizes the (2212) phase which leads to liquid second phases which favours the formation of BI(2223) with good intergrain contact. Using an annealing atmosphere with reduced oxygen content for the final tape annealing bradenes the reaction temperature range significantly and shortens the annealing time to about 30 % being important for the large scale industrial process. The tape deformation process performed by rolling a round wire out of silver and superconductor which was reduced by drawing before needs too very accurately fixed parameters since otherwise this metal-oxide composite shows a strong tendency to can irregular geometry after deformation. The parameter studies gave a reliable parameter set which allowed reproducible tape preparation with high transport current. Controlling the rolling process by an innovative side limited rolling process allowed the realization of improved tape cross section, especially with respect to multifilamentary tapes.

The quality of grain alignment (texture) in the superconducting filaments of the tapes is of crucial importance for high final transport currents due to the anisotropic current carrying properties of the Bi(2223) phase. X-ray pole figure techniques were improved to allow a quantitative description of the phase texture. A correlation of these results with field dependent transport current measurement proofed that predominantly the highly textured fraction of the grains carries the supercurrent. SEM investigations of the microstructure, measurement of the current anisotropy and theoretical models came to the result that two current paths, a small angle in plane grain connection and a distinct contribution from out of plane grain contact exist.

For technical application, reinforced sheaths are necessary. We applied alloyed AgMg sheaths in the Ag matrix of the tapes which form during the tape heat treatments dispersed MgO particles called an internal oxidation process with the effect of a significant sheath hardening. The tolerable mechanical stress values were improved from 50 Mpa to > 250 Mpa which satisfies the requirements of all applications. We produced successfully a length of 110 m AgMg sheathed tape demonstrating the possibility of long length production.

For the improvement of the current carrying capability of the tapes, detailed magnetic and transport measurements partly using new methods were applied, which resulted in a much deeper understanding of the superconducting properties, the inter- and intra grain current path and the dissipation behaviour always correlated to the different sample qualities and the evaluation of quality progress.

The final most important result of the project was the improvement of the transport critical currents in the Bi(2223) tapes up to the level of international state of the art. In monofilamentary Ag-sheathed tapes we achieved values up to J_c = 45000 Acm^{-2} (77 K, OT) and with reinforced sheaths up to J_c = 26000 Acr^{-2}. In multifilamentary tapes with typically 7, 19, 37, 61 and 385 filaments the best values were obtained in 37 and 61 filament tapes being J_c = 25000 Acr^{-2} (Ag sheath), reproducibly obtained in 0,5 m pieces (length furnace restricted) In mechanically reinforced multifilamentary AgMg sheathed tapes J_c values of the order of 20 kA were realized.

Achieving the state of the art level for Bi(2223) tapes the consortium has achieved the supposition to continue in the development of specialized tapes as for AC application or tapes with reduced thermal losses for current lead application.

5. Exploitation plans and follow up actions

The character of this project was of preindustrial focused fundamental nature with the challenge to establish a technical level of the research being in competition to the leading groups in USA and Japan. This enables the partners of this consortium to follow-up this, project on one hand with specialized actions as the development of low AC loss tape modification in a very similar consortium of project partners or in a project dealing with Tl based tapes.. On the other hand industrial or preindustrial cooperation followed which focus on the application of BSCCO-tapes in first prototype devices. The FZK contributes to a national industrial project which constructs and test a power cable based on BSCCO tapes. In a second project, current leads for large magnets with currents of 1 -20 kA are developed. The UNIGE participates in a project which challenge is the superconducting transformer, which needs for economical operation low AC loss BSCCO tapes.

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TECHNOLOGY DESCRIPTION

Title ⌫

Development of high critical current Bi(2223) Tapes

Subject descriptors *Please look at the enclosed appendix 1 and specify up to five codes Codes should be allocated in order of priority* ⌫

C 42 | A 10 | B 42 | D 25 | E 33

Innovative aspects *Please give a short description of the innovative characteristic of the result*

Development of mechanically reinforced, high current carrying Bi(2223) superconducting tapes, applying innovative rolling processes. Characterization of chemistry and physical properties.

Current stage of development

Preliminary design, feasibility study	☐ (m&3)*	Available for testing or assessment	☐ (code 6)"
Intermediate design, research phase	☐ (code 4)	**Tested,** available for demonstration	☒ (W&7)
Development phase ,	☐ (m.25)	Other *(Please specify)*	•*1* (code 8)"

Details: Prototype superconductor ar availlable in medium lengths ready for technological ransfe int th industrial production.

* These codes are for internal use only

FINANCIAL SUPPORT FOR THE RESEARCH

Sources of support *Source(s) of funding support for the research*

CEC	☒ (code 1)	Industry	☐ (code 5)
International non-CEC	☐ (code 2)	Education, research	☐ (m&6)
National	☒ (code 3)	Other	☐ (Co&7)
Regional	☐ (code 4)		

Details of any CEC funding support

Programme acronym *(e.g. BRITE/EURAM 2)*: BRITE EURAM 2

Project **reference** (e.g. *BRE20375)*: BRE20229

Project title : Developinentofhigh,, critical . . currert . . Bi(2223) . . . Tapes . . . . . .

EXPLOITATION

Property **rights** *With regard to property rights, which of the following are currently applicable to the result? (more than one option can be selected)*

Patent(s) applied for but not yet granted	☐ (code 1)	License agreement(s) reached	•1 (code 4)
Patent(s) granted	☐ (Co&2)	Partnership/other contractual agreement(s)	☒ (code 5)
Copyright(s) registered	n (CO&3)	Exclusive rights	☐ (code 6)

Market applications *Please look at the enclosed appendix 2 and specify up to five codes for market areas in which your findings could be applied*

11	220	430	107	

Type of collaboration sought *(more than one option can be selected)*

Further research and/or development support	☒ (code 2)	Manufacturing agreement	☐ (w&6)
Joint Venture agreement	☐ (code 3)	Financial resources	☐ (m&7)
Licence agreement	☐ (m&4)	Information exchange	☐ (code 8)
Marketing agreement	☐ (code 5)		

Details: Development of special superconductors for "specific applications. Application in ptototypes of devices like cables, coil stransformers and motors

Consultancy *Please specify whether your exploitation offer includes consultant'*

☒ *Yes* Details: Consultance with respect to the application of those superconductors

CONTACT PERSON DETAILS

Title *(e.g. Mr, Mrs, Dr, ...)*	First name(s)	Family name
Dr	Wilfried	Goldacker

Position in organization
Group Leader

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* Cartermill International Ltd works as external contractor on behalf of the European Commission DG XIII, Telecommunications, Information Market and Exploitation of Research.