Filamentary A15 Superconductors

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PREFACE

Compound superconductors with the A15 structure carry the promise of the second generation in practical superconductivity. They will provide higher operating magnetic fields at higher temperatures than the preceding alloy superconductors. To fulfill this promise, their brittle nature must be accommodated in a filamentary structure. Achieving this has been no simple task and imaginative research and clever production techniques have led to many usable conductor configurations. In addition, several new and exciting possibilities are being proposed; for example, in situ processing promises easier production with improved strain tolerance. It is timely, therefore, to take measure of what we have achieved and to assess our understanding so that we may choose, with some confidence, paths for future research and potential applications.

To meet these needs, the International Cryogenic Materials Conference Board has sponsored this special topic conference on Filamentary A15 Superconductors bringing together superconductivity researchers, superconducting wire producers, and high field magnet users to discuss current research problems. That the information exchange was intensive and successful is evidenced by the excellent papers in this volume. In order to capture some of the synergistic wisdom generated in discussions at the conference several people were asked to assemble and interpret the comments and concerns of the fusion, high energy physics, solid state physics, and metallurgy groups. These reports and a conference summary are also included in the proceedings in an attempt to preserve at least a small part of the invaluable "back hall" component of any successful conference. These reports are particularly helpful in identifying research needs. We feel that all present contributed to the commitment of successful applications of filamentary A15 superconductors based on solid understanding and added insights to the potential, not only of these conductors, but to the future of all superconductivity as well.

The editors wish to express their sincere appreciation to L. C. Arns who worked hard to produce a uniform and exceptional proceedings to this conference.

M. Suenaga
A. F. Clark

CONFERENCE SUMMARY

FILAMENTARY A15 SUPERCONDUCTORS

J. E. Evetts

Cambridge University
Cambridge, UK

This conference is exceedingly timely: the first generation multifilamentary A15 conductors have successfully proved themselves in the market place and attention is now turning with confidence to the future. Renewed consideration is being given to every aspect of conductor design. The immediate objectives are on the one hand to develop large volume production of conductor for medium field applications (8-12 T), and on the other hand, to explore systematically the exciting and unique prospects A15 materials offer for the technological exploitation of superconductivity at high fields (14-18 T and higher). The design of a five or six component composite turns on an extravagant blend of electrodynamic, mechanical and metallurgical considerations, it is hardly surprising therefore that conductor development has tended to proceed on semi-empirical lines. The explicit aim of this meeting was to bring together producers, users and academics concerned with multifilamentary A15 conductors in the expectation that the exchange of information and ideas would highlight important issues and stimulate a more concerted cross-disciplinary approach to understanding complex materials. This objective was reinforced by devoting the fourth session of the meeting to reports by chairmen of specialist groups appointed by the Organizing Committee to monitor the previous three sessions.

The first of the sessions comprised national and company overviews and briefly surveyed all current research and development work. The range of experimental conductors receiving serious attention gave emphasis to the conflicting requirements of different applications. As the demand for conductor increases there is likely to be a proliferation of conductor types to suit specific requirements. The trend towards more complex alloys with ternary and quaternary additions seems irresistible; as a consequence the metallurgical effects observed become more intricate and their quantitative interpretation more difficult.

The theme of the second session, mechanical properties, reflects the great effort that has gone into understanding the variation of superconducting properties with strain. Since in certain field regimes intrinsic conductor strain can lead to a fourfold degradation in critical current, a quantitative description of the effect of strain is a prerequisite to the development of accurate models for flux pinning in these materials. The observation that the shape of the critical current versus reduced field curves scales directly with strain leads to the conclusion that the various different shaped critical current curves commonly observed do not depend directly on the strain sensitivity of the particular composite components and conductor geometry.

The session on multiply connected conductors was valuable for two reasons. Firstly, it served to emphasize the wide range of conductor routes that merit serious investigation. Secondly, the remarkable microstructures exhibited by in-situ materials raise fundamental questions for the interpretation of their properties. Furthermore on reflection it is clear that many of the same questions should also be raised in the case of more conventional conductors. The practice of carrying over concepts and ideas developed for bulk superconductors must be questioned. For instance the concept of a critical current density becomes difficult to justify on a scale less than the pinning penetration depth. Also in the case of sub-micron filaments the surface pinning contribution can be appreciable, and the bulk pinning summation, involving only a few pinning sites, cannot be treated using a conventional statistical theory.

Before the final session, a small poster session (9 papers) was provided to cover pertinent subjects to the conference but could not be included in the oral sessions. These papers discussed, for example, composition profiles in Nb_3Sn layers, ac losses in in-situ processed Nb_3Sn wires, flux pinning in bronze processed Nb_3Sn, etc.

In the final session the group chairmen reported to the Conference, describing those aspects of the subject that had appeared of particular interest or importance to their specialist groups. Both specific and general problems were discussed with emphasis on gaps in our present understanding and on the likely future requirements for conductors for different applications. (These reports are included in this volume.)

These proceedings represent a critical overview of the subject at a crucial stage in the development of a new generation of materials. The interaction between disciplines was particularly valuable. When research on a project involves progress in a very broad front there is a tendency for each specialist area to make local progress on premises that derive from the stage before last in related areas. Presented with this situation in the development of multifilamentary A15 conductors this meeting has enabled the different disciplines to cross relate and set a new common level of understanding.

Full recognition must be extended to the Organizing Committee, firstly, for its appreciation of the need for a topical conference in this area and, secondly, for the clarity and balance of the program which, without doubt, contributed greatly to the success of the conference.

CONTENTS

MULTIPLY CONNECTED SUPERCONDUCTORS

GROUP COMMENTS

INDEXES

DEVELOPMENTS OF A15 FILAMENTARY COMPOSITE SUPERCONDUCTORS IN JAPAN

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INTRODUCTION

At the National Research Institute for Metals, the so-called surface diffusion process (SDP) to produce V_3Ga tape was invented in 1967.[1] In this process, a vanadium substrate is passed continuously through a molten gallium bath in which some copper is added. The copper acts as a catalyst for enhancing the diffusion reaction between the vanadium substrate and the gallium to form V_3Ga phase.[2] The critical current density versus magnetic field, J_c-H, curve of V_3Ga is convex upward in fields above 10 T, and the V_3Ga exhibits a higher J_c at fields above 13 T than any other practical superconductors. The V_3Ga tape was used to construct the 17.5 T superconducting magnet, which established the highest field record in the world in the superconducting state.[3] The invention of the surface diffusion process led to the following success of the so-called composite diffusion process, which enables the fabrication of multifilamentary type-V_3Ga superconductors.[4] The multifilamentary V_3Ga wires were expected to be much more stable than the tapes and to be useful for applications in time varying fields.

FABRICATION OF MULTIFILAMENTARY V_3Ga WIRES AND THEIR SUPERCONDUCTING PROPERTIES

In the composite diffusion process (CDP) to fabricate multifilamentary V_3Ga wires, a composite of a Cu-Ga solid solution alloy matrix containing 15-20 at.% Ga and vanadium cores is fabricated into a thin wire, and then heat treated at a temperature between 600-700°C. In the heat treatment, gallium in the Cu-Ga alloy matrix selectively diffuses with vanadium, and only V_3Ga layers are formed around the vanadium cores. When the gallium concentration in the Cu-Ga alloy exceeds about 40%, the compounds richer in gallium appear. Figure 1 shows an X-ray microanalysis line scanning chart taken on the cross-section of the CDP V_3Ga tape.[5] Very little copper (< 0.2 at.%) is incorporated within the V_3Ga layer. The copper acts as a mother metal of gallium and enhanced the formation of V_3Ga. The effects of metallurgical variables on superconducting properties and workability of the CDP V_3Ga have been reported in detail in references 6-8.

The higher transition temperature, T_c is obtained after the heat treatment for the specimen with higher gallium concentration in the matrix as shown in Fig. 2. However, the maximum gallium concentration in the Cu-Ga matrix workable at room temperature is limited up to about 21 at.%. The highest T_c is obtained in the V/Cu-20 at.% Ga composite after the heat treatment at 625-650°C for 100-200 h.[7] The dependences of the upper critical field, H_{c2} on the matrix composition and on the heat treatment condition are similar to those of T_c. The CDP V_3Ga shows about the same T_c, but

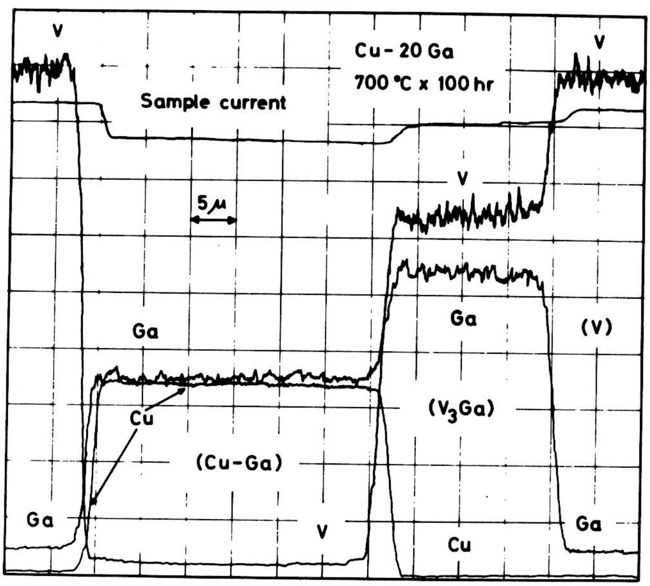

Fig. 1. An XMA line scanning chart taken on the cross-section of the CDP V_3Ga, which shows the concentration profiles of vanadium, gallium and copper in the vanadium core, in the Cu-Ga matrix and in the V_3Ga.[5]