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Nondestructive x-ray Scattering Characterization of High Temperature Superconducting Wires

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Importance of solving the problem addressed by the research performed:

The superconducting wires characterized in this CRADA can be used in a number of devices such as magnets, generators, transformers, current limiters, and transmission cables. Prototypes of these and other devices made with high-T_c superconducting wires are just beginning to be built. A reference which gives an overview of the recent progress made in this field is "Power Applications of High-Temperature Superconductors" by G.B. Lubkin, *Physics Today* March 1996, page 48.

Regardless of the application, wires with higher current carrying capacities (at higher temperatures and magnetic field strengths) are more useful. Unfortunately, there are a variety of effects that can limit the current carrying capacity of these wires, with the consequence that today's best Bi-2223 wires typically have capacities at least ~5 times smaller than the maximum theoretical capacity. The purpose of this CRADA was to characterize the structural properties of the superconductor material within the wires in order to determine which processing procedures produce the best superconductor texture and phase development, and hence the best ultimate current carrying capacity.

Major research activities:

3/95 to 6/95: Hard x-ray spectrometer construction.

An absolute necessity for the success of this CRADA was to have routine access to a hard x-ray diffraction beam line at the National Synchrotron Light Source (NSLS). Fortunately, the NSLS beam line R&D group initially provided generous amounts of time on a white light beam line suitable for this work, but which lacked a diffraction spectrometer. Construction of apparatus for performing diffraction experiments therefore occurred during the first three months of the CRADA. An important innovation implemented at this time was the use of a bent Laue Si(111) monochromator crystal. This device was originally designed for angiography work by the NSLS medical group, but it was found that it provides a very good combination of flux and resolution for hard x-ray diffraction experiments as well.

DISCLAIMER

7/95 to 10/95: Texture and composition measurements of fully processed Bi-2223 wires.

The first set of experiments performed in this CRADA were done on wire samples which had been fully processed at Intermagnetics General Corporation. Techniques for characterizing the texture and phase development with hard x-rays were developed at this time, and the correlations that exist between the texture and composition of a sample and its superconducting current carrying capacity (at 77K) were determined. As had been expected, samples with better texture and Bi-2223 phase development systematically had better current carrying capacities. A detailed exposition of this work is given in the article, "Synchrotron x-ray scattering measurements of bulk structural properties in superconducting $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10}$-Ag tapes", Journal of Applied Physics **79**, 3122 (1996).

11/95 to 5/97: *In situ* studies of texture and phase development of Bi-2223 wires.

The experiments performed from 6/95 to 10/95 showed that the transport properties of Bi-2223 wires are correlated with structural characteristics easily measured using synchrotron x-ray diffraction techniques. Monitoring structural properties under different processing conditions was the main CRADA activity from 11/95 to 7/96. These studies were time consuming because Bi-2223 phase development itself takes several days, and because there were so many variables that can be adjusted when making these wires, such as heating temperatures and rates, initial compositions, times when intermediate pressings are performed, physical dimensions of the wires *etc*. On the other hand, with so many different parameters that can be varied, the utility of real time phase and texture development information for making reasoned modifications of the processing conditions was clear.

In order to perform *in situ* studies at elevated temperatures, CRADA personnel constructed an x-ray compatible furnace which was stable to ±0.2°C at typical processing temperatures, ~830°C. The phase and texture development of approximately 30 samples were monitored in this furnace. A major discovery has been that texture starts developing at temperatures as low as ~750°C, a temperature too low for Bi-2223 phase development to occur. Thus, much of the texture development occurs before essentially any of the initial Bi-2212 starting material has converted into Bi-2223. The process by which Bi-2212 converts into Bi-2223 then proceeds over a period of days. By examining samples which have been heat treated once and then rerolled, it was also discovered that the intermediate rolling procedure can actually worsen the texture of a sample under some conditions. On the other hand, these rerollings appear to be necessary to complete Bi-2223 phase development and to densify the superconductor material. It was also shown that the rate at which a wire is cooled from its processing temperature affects the sample phase content. Bi-2212 typically precipitates out as the temperature is lowered, and other phases can also precipitate out under some conditions. These three results illustrate the type of information that has been obtained from these *in situ* experiments. A detailed description of the *in situ* work performed from 11/95 to 8/96 is given in "*In situ* measurements of texture and phase development in $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10}$-Ag tapes", J. Mat. Res. **12**, 891 (1997).

Publications:

"Effects of Axial Tensile and Bending Strains on Critical Currents of Mono- and Multicored $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10}$-Ag Tapes", M. Suenaga, Y. Fukumoto, P. Haldar, T.R. Thurston, and U. Wildgruber, Applied Physics Letters **67**, 3025 (1995).

"Synchrotron X-ray Scattering Measurements of Bulk Structural Properties in Superconducting $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10}$-Ag Tapes", T. R. Thurston, U. Wildgruber, N. Jisrawi, P. Haldar, M. Suenaga, and Y.L. Wang, Journal of Applied Physics **79**, 3122 (1996).

"A kinetic mechanism for the formation of aligned $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10}$ in a powder-in-tube processed tape, Y.L. Wang, W. Bian, Y. Zhu, Z.X. Cai, D.O. Welch, R.L. Sabatini, M. Suenaga, and T.R. Thurston, Applied Physics Letters **69**, 580 (1996).

"*In situ* Measurements of Texture and Phase Development in $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10}$-Ag Tapes", T.R. Thurston, P. Haldar, Y.L. Wang, M. Suenaga, N.M. Jisrawi, and U. Wildgruber, Journal of Materials Research **12**, 891 (1997).

"Kinetics of the alignment and the formation of the Bi(2223) platelets in the powder-in-tube processed Bi(2223)/Ag composite tapes", Li-jun Wu, Y.-L. Wang, Weimin Bian, Yimei Zhu, T. R. Thurston, R.L. Sabatini, P. Haldar, and M. Suenaga, submitted to Journal of Materials Research.