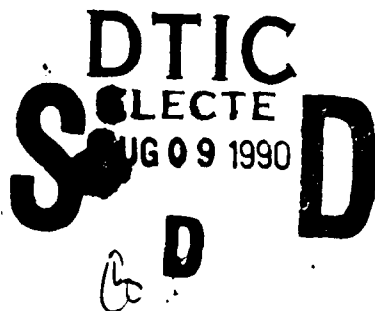


AD-A224 971



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**DEVELOPMENT OF ELEMENTS OF A HIGH  $T_c$   
SUPERCONDUCTING CABLE**

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## PROGRAM SUMMARY

Further effort on the YBCO system will not be likely to result in a polycrystalline conductor with the desired critical current. A realignment of the program has been undertaken with the effort redirected to the use of a bismuth strontium calcium cuprate (BSCCO) conductor at 20K. This was done because of the abundant evidence for the much greater critical currents possible in polycrystalline BSCCO. The overall goal of the program, the development of materials and processes for the fabrication of a composite high  $T_c$  superconductor element, remains unchanged.

The progress and plans portion of this report will be divided into two parts. First the final status of the discontinued YBCO effort will be covered. Progress and plans on silver clad BSCCO will then be covered.

## YBCO STATUS

The goal of the program was the development of materials and processes for the fabrication of a composite YBCO element made of a superconducting coating on a supporting fiber. The proposed application was a DC transmission line operating at 77K. At mid-program a decision was to be made on the feasibility of fabricating a long-length conductor of polycrystalline YBCO. At this time there is no solution in sight for the weak-link low  $J_c$  problem in long polycrystalline YBCO wires. No further effort is planned on YBCO. This program status section will summarize the progress over the past year and the present status of the YBCO effort on the major tasks aimed at increased  $J_c$ .

### Task I-1 Quantify the effects of crystallographic orientation on $J_c$

The effects of materials system, processing conditions and crystal alignment on  $J_c$  have been determined on magnetically aligned bulk samples. This alignment results in the c-axes of the crystals in alignment with a random alignment of the a- and b-axes in the ab-plane. The results can be explained by flux penetration into grain boundaries parallel to the magnetic field. Although the absolute values are low, about  $300\text{A}/\text{cm}^2$  at 77K, there is a very little change in  $J_c$  at applied magnetic fields up to a few tesla. It seems the current is carried by a percolative path across only a small fraction of the grain boundaries. This percolative path is maintained at high magnetic fields. These few boundaries do not show weak link behavior. It seems that high currents can only be carried across small-angle, non-basal-plane YBCO grain boundaries. The best aligned samples we could make with the magnetic alignment technique showed (005)

rocking curves of about  $6^\circ$ . If there is a misorientation of a few degrees between the c-axes of two adjacent grains, only small misorientations in the ab-plane are allowed if appreciable currents are to be carried across the grain boundary. This is the best explanation of the small but non-zero critical currents in the aligned bulk samples.

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## Task I-2 Demonstrate improvements in critical current density

A study of process parameters during fabrication of magnetically aligned samples was done: (1) Low calcining temperatures and carbon contamination are both to be avoided. Low calcining temperatures gives particles which cannot be aligned in a magnetic field. Carbon contamination results in liquid phase assisted growth of large grains which are not easily made superconducting. (2) Doping YBCO with excess BaO and CuO, on the other hand, gave samples intentionally containing a small amount of liquid phase. This resulted in some the highest  $J_c$  samples. Large grains are acceptable in c-axis aligned samples. The small amount of CuO and  $BaCuO_2$  impurity phase does not coat the low-angle grain boundaries which are believed to carry the current. (3) A study of various oxidation cycles did not show any appreciable effect on the critical current as long as the sample is fully oxidized.

Two different concepts were tried to see if the critical currents in aligned samples could be increased. These were based on either increasing the number of "good" grain boundaries or improving the current carrying capacity of the "good" boundaries. The former idea was tested by making  $CaLaBaCu_3O_7$ . It was hoped this material might show conduction through the basal plane boundaries. The concept did not work. The compound cannot be magnetically aligned, apparently because of  $90^\circ$  twin boundaries in the starting powder. The latter idea was based on doping with a variety of materials which should show intragranular flux pinning. Perhaps increased intragranular pinning might increase the current across low angle grain boundaries if these boundaries are made up of well-matched regions between the two grains separated by dislocations. No increase in transport critical current was seen with any of the samples.

In summary, studies of a variety of process parameters showed that our well-aligned bulk materials had critical currents of the order of 75 to 200A/cm<sup>2</sup> at 77K and 0.3T with little degradation at higher fields. The state of the situation for aligned YBCO can be summarized in Figures 1 and 2. Figure 1 shows a comparison between different materials which are all believed to have similar alignments. Figure 2 shows the effect of temperature on our aligned YBCO. There seems to be an intrinsic difference in YBCO as contrasted with the Bismuth- and Thallium-based materials. YBCO seems to have a much worse weak link problem in c-axis aligned materials in comparison with the other two materials.

## **BSCCO STATUS**

The realigned program is aimed at the development of long lengths of silver-clad BSCCO. A variation on the powder in tube technique will be used to make silver-clad BSCCO tapes. BSCCO-2223 will be the material of choice with 20K the operating temperature goal. Such a tape conductor ultimately could be used in a pancake wound magnetic coil.

A key element of the program is the development of processes with the potential of fabrication of very long conductors. A novel process for making silver clad tapes (SCT) which starts with extruded BSCCO which is then wrapped with silver foil will be studied. This technique has the potential for fabrication of continuous lengths and also avoids the extensive size reduction and attending potential for non-homogeneity involved with the more conventional powder-in-tube (PIT) process. We will also carry on a parallel PIT study to use for comparison purposes and as a back-up process to the SCT process.

### TASK 1 -- POWDER PRODUCTION

The goal of this task is the production of reproducible large powder batches of BSCCO-2223 to be used in the tape development effort. We anticipate using a lead-doped, slightly calcium- and copper-rich composition which has been found to optimize the formation of the high-Tc 2223 compound from 2212 which forms first.

The initial composition we have chosen has cation contents of Bi/Pb/Sr/Ca/Cu of 1.7/0.3/2/2.05/3.05. We have started calcination tests of the mixed starting oxides and carbonates. We will then make a large batch of powder, several hundred grams, to be used for PIT wire fabrication, and SCT extrusions.

### TASK 2 -- TAPE FABRICATION USING POWDER-IN TUBE

Deformation processing of BSCCO-filled silver tubes will be done by sequential swaging, drawing, and rolling. The tapes will then be subjected to rolling and heat-treatment cycles under task 5 to optimize properties, especially Jc. The aim of this task is two-fold. The tapes will be used for comparison with the task 3 tapes and, if the new process is not successful, the PIT process will be available as a back-up process.

Preliminary swaging and drawing experiments on BSCCO-filled silver tubes have already been done using equipment available in our Metals Processing Facility. A problem identified in the initial runs is breakage of the composite rod at the interface between the BSCCO powder and the silver end-plug. A modified method of plugging the end of the powder packed tube will be used in the next experiments. A small bench-top rolling mill which will be used for the high-Tc program has been located and installed and will be used to roll tapes from the drawn or swaged rods.

### TASK 3 -- EXTRUDED TAPE FABRICATION

A new process for the fabrication of high-Tc conductor silver-clad tape is proposed. The first step is to extrude a thin 0.005" tape containing BSCCO and organic binder. The tape is then placed in silver foil bent around the extruded tape but not sealed. A heat-treatment in oxygen or air will be used to remove the organics from the composite tape. This task will be aimed at the optimization of the extrusion and binder removal steps.

We have already demonstrated the ability to extrude 0.015" thick BSCCO tapes using a binder system previously developed at GE for ceramic extrusion. This process has been used to make 0.005" diameter filaments of a variety of ceramics in programs in the Ceramics Laboratory. The equipment available for use on the high T<sub>c</sub> program includes a high-shear mixer, extruder, and an automated filament take-up system. The screw-driven extruder has the capability to make tape continuously of any desired length. The tape die has just been modified to make thinner tape.

#### TASK 4 -- SILVER FOIL PRESSURE WELDING

The second step in the new tape process is the sealing of the edge of the silver foil wrapped around the BSCCO tape. We propose to do this using pressure welding. Silver is quite ductile and should be an ideal material for deformation welding. We hope to be able to weld shut the silver-BSCCO tape by rolling the overlapped silver ends. After the tape package is sealed it would be rolled and heat-treated under task 5.

Pressing experiments using two 0.005" thick silver foil pieces has shown that a reduction in thickness of about 70% will result in good welds. This value of optimum reduction in thickness agrees with literature data for ductile metals. Final weld thicknesses of about 0.003" would be obtained at the edge of a tape made from 0.005" silver foil. Initial sealing experiments will be done by pressing the edges of short sections of composite tape between a flat platen and one side of a thin long bar. When an optimum punch shape has been found, a special roll will be made for the bench-top rolling mill so that continuous welds can be made on the edge of tape packages.

#### TASK 5 -- SUPERCONDUCTOR OPTIMIZATION

The optimization of silver-clad BSCCO superconductors requires the correct deformation of the tape as well as optimized heat-treatment times and temperatures. These will be studied in this task for both PIT and SCT tapes. Properties to be measured will be J<sub>c</sub> (using both transport and magnetic hysteresis measurements), flux creep, grain alignment, and microstructure. Particular attention will be given to J<sub>c</sub> as a function of temperature and applied magnetic field. We expect that the heat treatments for the 2223 material will involve temperatures below the melting temperature, in contrast to 2212 which seems to be optimized by melting.

Equipment and techniques for the characterization of the superconductor properties of short sections (about 1 to 2 inches) of tape are available.

#### TASK 6 -- LONG LENGTH AND SINGLE COIL PROPERTIES

The properties of long lengths of tape will be studied when the material becomes available. The uniformity of properties along the tape are particularly important. The effect of winding the tape into a pancake coil configuration will also be studied.

Equipment and techniques are available for the characterization of single layer or multilayer small coils as a function of both temperature and applied magnetic field.

### **TALKS AND PAPERS**

J E Tkaczyk, K W Lay, and H R Hart, "Anisotropic Critical Currents in Aligned Sintered Compacts in  $\text{YBa}_2\text{Cu}_3\text{O}_y$ ," talk given at New York State Institute on Superconductivity Conference, Sept. '89, Buffalo, NY To Appear in Superconductivity and Applications, Plenum Publ., Ed. Hoi S. Kwok, 1990

K W Lay, "Oxygen Partial Pressure Effects on Formation, Sintering and Melting of  $\text{YBa}_2\text{Cu}_3\text{O}_y$ ," invited talk given at the Metallurgical Society Symposium on High-Tc Superconductors, Oct. '89, Indianapolis, IN

J E Tkaczyk and K W Lay, "Critical Current and Processing Temperature in Aligned Sintered Compacts of  $\text{YBa}_2\text{Cu}_3\text{O}_y$ ," poster session at MRS Meeting, Nov 29, Boston, MA

K W Lay, "Progress Toward a High-Temperature Superconducting Wire," talk given at SC GLOBAL 90, Jan. '90, Long Beach, CA

J E Tkaczyk, R H Arendt, J A DeLuca, M F Garbauskis, P L Karas, K W Lay, A Mogro-Campero, L G Turner, "Improved Magnetic Field Dependence of  $J_c$  in c-axis Aligned Polycrystalline High Temperature Superconductor," talk given at Am. Phys. Soc. meeting Mar. Anaheim, CA

J E Tkaczyk, R H Arendt, and K W Lay, "Critical Current in Aligned Sintered Compacts of Y and Bi Based High Temperature Superconductors," talk given at 1990 Spring Meeting of the Mater. Research Soc., San Francisco, CA

### **GOALS FOR NEXT QUARTER**

Preparation of large powder batch of BSCCO-2223.

Fabrication of short PIT tape segments.

Extrude and remove binder from 0.005" extruded tape.

Pressure weld short sections of SCT BSCCO-Ag composite

All values are cost plus fixed fee total costs.

**TOTAL FUNDING REQUIRED FOR EFFORT**      \$2,424,530  
01Sept88 through 31Aug91 (36 months)

CURRENT AUTHORIZATION 1,668,000  
01Sept88 through 31Jan91 (29 months)

FUNDING EXPENDED TO-DATE 1,114,451  
01Sept88 through 30Jun90 (22 months)

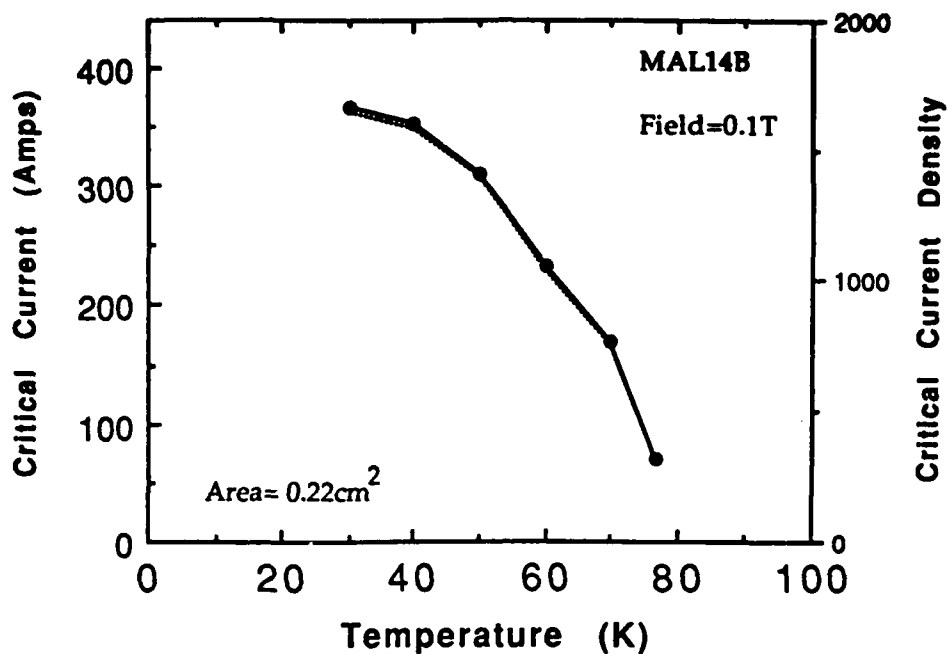


Fig. 1 Critical Current of a magnetically aligned sintered bar of 98.3% by weight of  $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$  plus 1.7% of a mixture of Ba and Cu oxides with a cation mole ratio of Ba:Cu=3:5. The magnetic field was applied perpendicular to the current and the c-direction of the aligned grains.

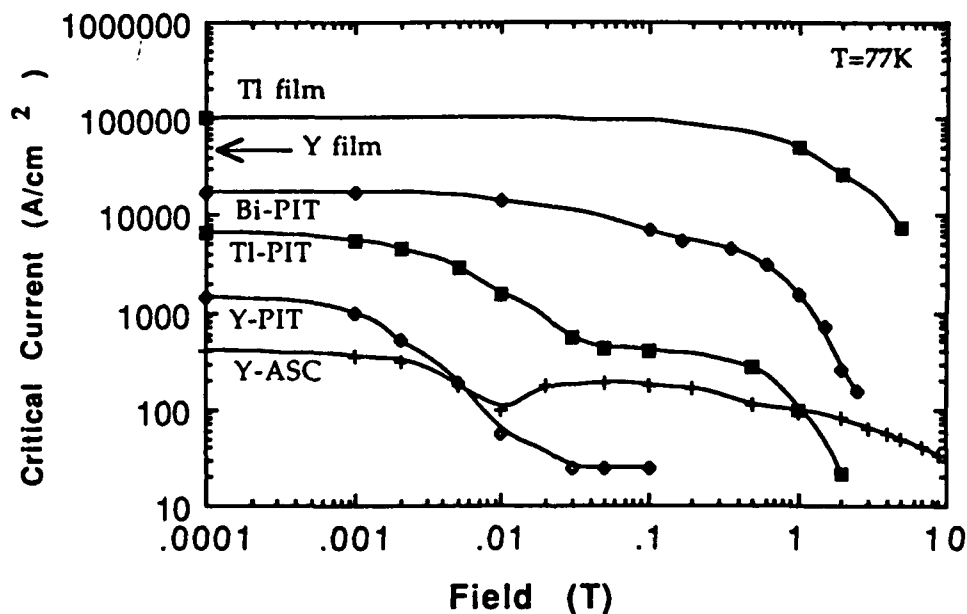


Fig. 2 Literature values for the critical current of aligned polycrystalline samples. The magnetic field was perpendicular to the current and the c-direction of the aligned grains. The initials ASC refer to aligned sintered compacts fabricated at GE-CRD. The initials PIT refers to powder in silver tube. The origin of the data above is Sandia National Labs. for the polycrystalline Tl-high temperature superconducting film, Cornell University for the Y based film, Sumitomo Electric for the Bi-PIT, Hitachi for the Y- and Tl- PIT, and measurements at NIST, Bolder on Y-ASC.