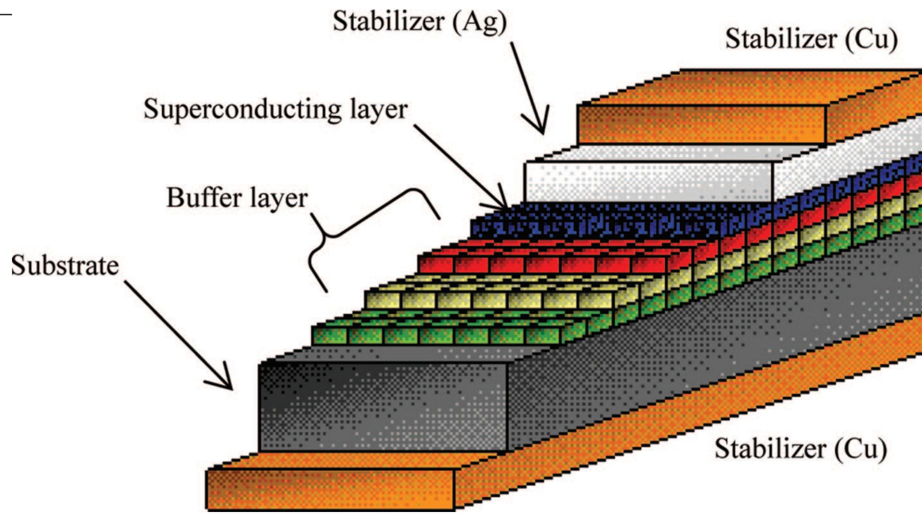

Figure 2. Inner structure of the developed HTSC.

by Y. Ohki

Development of a RE-Ba-Cu-O Superconducting Current Lead

Today, superconductivity technology is attracting much attention, because it can realize zero electrical resistance and very strong magnetic fields. Although research and development work has been carried out to fabricate superconducting cables and various machines, e.g., rotating machines and transformers, the most successful industrial application so far is to the manufacture of electromagnets generating very strong magnetic fields. By using such electromagnets, the sensitivity of nuclear magnetic resonance (NMR) for pure scientific research, and of magnetic resonance imaging (MRI) for medical diagnosis, has been greatly increased.

Presently, in most NMR and MRI apparatus, metal-based superconducting wires which become superconducting only at temperatures below approximately 10K (−263°C) are being used. A magnet using metal-based wires must therefore be cooled using liquid helium, which has a boiling point of 4K at atmospheric pressure, and in many cases the exterior of the magnet is cooled by liquid nitrogen (boiling point = 77K at atmospheric pressure). In order to minimize the evaporation of coolant, ingress of heat from the outer ambient environment must be minimized. Furthermore, in order to generate high magnetic fields, a large current must be supplied to the magnet. It follows that the current leads connecting the external power supply to the first and second cooling stages (Figure 1) must be highly conducting electrically but also highly insulating thermally.

These two apparently conflicting requirements can be satisfied by the high-T_c superconductors (HTSCs) discovered in the late 1980s, which have critical temperatures (T_c) above 77K, i.e., they remain superconducting up to T_c. Two particular HTSCs have received much attention. The first is BSCCO, consisting

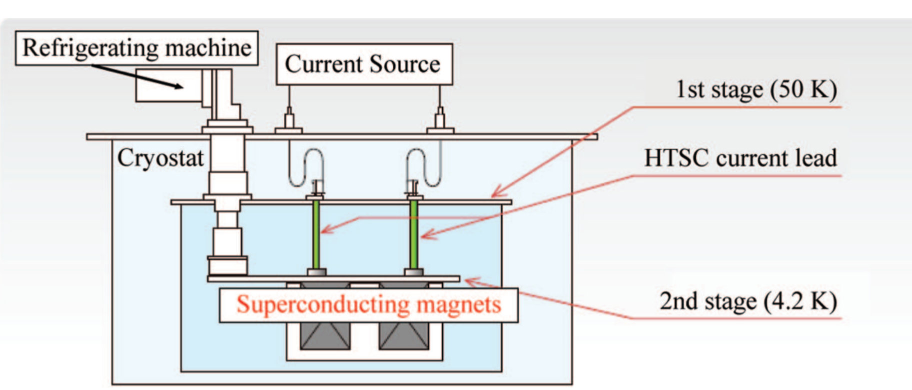

Figure 1. HTSC current leads attached to the first and second cooling stages of a superconducting magnet.

Table 1. Specifications of the 1-kA HTSC Current Lead.

Rated current (A)	1000
Current lead length (mm)	340
Distance between electrodes (mm)	200
Number of YBCO tapes	30
Operating temperature range (K)	77 to 4.2
Applied magnetic field (T)	0.5
Heat leakage from 77K to 4.2K (W)	≦0.3

Figure 3. A 1.0-kA HTSC current lead.

of bismuth (Bi), strontium (Sr), calcium (Ca), copper (Cu), and oxygen (O), and a kilometer-long practical HTSC wire based on this material was developed in the 1990s. BSCCO is called a first-generation HTSC [1]. The second is RE123, consisting of a rare earth metal [RE = Y (yttrium), Yb (ytterbium), Gd (gadolinium), Sm (samarium), etc.], barium (Ba), copper, and oxygen, with the formula $RE_xBa_2Cu_3O_{7-x}$ (x = 0.5 to 1.0). At present, of all the known HTSCs, RE123 has the largest critical current density, i.e., the current density required to destroy the superconducting state. RE123 is a second-generation HTSC. Because little silver is needed to make wires based on RE123, it is expected that more compact electric apparatus with higher performance could be realized more cheaply using RE123 [2], [3].

If a magnetic field exists in the vicinity of the wire, the critical current is lowered because of the partial penetration of the magnetic flux into the wire. Because current leads to strong electromagnets are inevitably exposed to strong magnetic fields, prevention or limitation of the partial penetration is important. For this purpose, material which fixes (or pins) the ends of the magnetic flux lines within the superconductor are usually incorporated in HTSCs. Such materials are called pinning centers.

Recently, SWCC Showa Cable System Co. Ltd, Tokyo, developed HTSC current leads using RE123 as core material. In order to realize high performance in magnetic fields, inorganic particles with a size less than 1.0 µm were uniformly incorporated as pinning centers in the RE123, using a technique developed in joint research work with the International Superconductivity Technology Center (ISTEC), Tokyo.

Figure 2 shows the inner structure of the developed HTSC. The HTSC layer is composed mainly of RE123 incorporating pinning centers as described above, deposited on a Hastelloy (a highly corrosion-resistant metal alloy) substrate. Stabilizing silver and copper layers and MgO buffer layers (Figure 2) are also important components. The width of the conductor layer is 5 mm; its thickness is 130 µm, of which 1.5 µm is the RE123 layer, 100 µm is the substrate, and 24 µm is the silver layer. Ten such conductors, consisting of five conductor pairs connected in parallel, make up a 350-A current lead. A 1.0-kA lead consists of three 350-A leads connected in parallel. Two copper electrodes are soldered to the two common ends of the three units, which are covered by glass-fiber reinforced plastic (Figure 3). Table 1 shows the specifications of the 1.0-kA current lead.

Figure 4 shows the result of a continuous current test, carried out on a 1.0-kA HTSC current lead at 77K in the absence of an externally applied magnetic field, i.e., the lead was exposed only to the mag-

Table 2. End-to-End Heat Leakage Through HTSC Current Leads.

Item	Total length (mm)	Heat leakage (W) (77K to 4.2K, 0.5 T)
REBCO with APCs	340	0.27
REBCO tapes	340	0.41

APCs = artificial pinning centers.

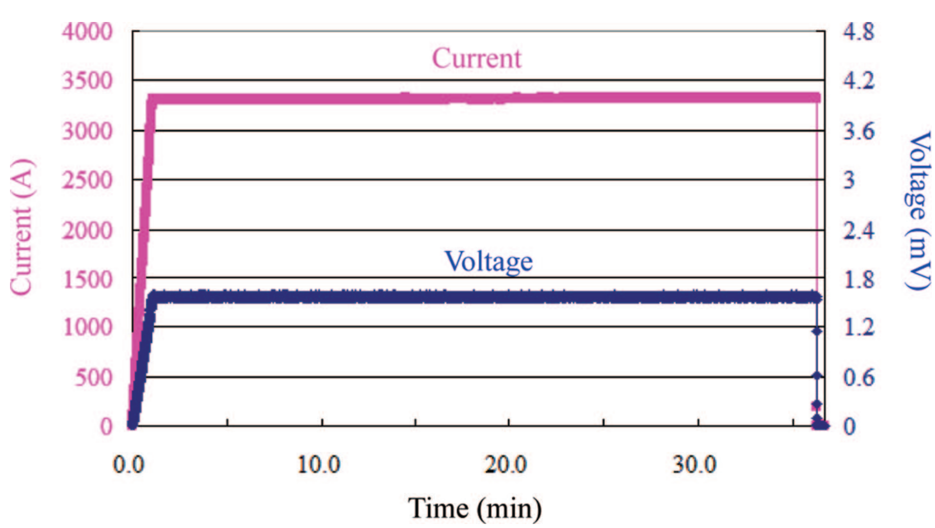

Figure 4. Result of a continuous current test.

netic field induced by the current flowing in the lead. The voltage applied across the current lead was increased until the voltage across the HTSC component reached 20 μV. Note that the voltage across the lead including the two end electrodes was around 1.6 mV, as shown in Figure 4. It will be seen that a stable continuous current of about 3400 A was passed for 37 minutes.

The heat transmitted end-to-end through each of two HTSC current leads based on RE123, with and without artificial pinning centers, is shown in Table 2. The ends of each lead were held at 77K and 4.2K, and the strength of the externally applied magnetic field was 0.5 T. The pinning centers reduce the heat leakage by about 30%. SWCC Showa Cable System has designed HTSC current leads with various current-carrying capacities. The specifications of 250-, 500-, and 1500-A leads are shown in Table 3. Figure 5 shows external views of the developed 500-A-class HTSC current leads. It is expected that these leads will soon be commercially available.

Figure 5. External view of the developed 500-A-class HTSC current leads.

This article was written with the help of Ms. Kyo Takahashi of SWCC Showa Cable Systems Co., Ltd.

Table 3. HTSC Current Lead Specifications.

Specification	250-A class	500-A class	1500-A class
Operating temperature range	77K to 4.2K		
Heat leakage	≦0.03 W	≦0.06 W	≦0.15 W
Size (mm)	220 L × 14 W × 14 T	220 L × 14 W × 14 T	220 L × 23 W × 16 T

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