유럽의 Coated Conductors 개발 동향

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We review the status of research and development of coated conductors and related power application systems using high temperature superconductors in European countries. Processing methods of coated conductors and critical currents characterization of the quality of the conductors are reviewed. The research goals in European countries for coated conductors is to realize longer tha 500 meter-tapes with Ic = 250 A/cm-w at 77K. By controlling of pinning structure or fabrication of twisting or transposition, Jc and AC losses can be reduced. As a result, power applications of superconductors will be available in the near future.

I. Introduction

As the high-Temperature superconducting (HTS) coated conductors (CC) have been studied and developed over the last twenty years, many industrialized countries have tried to achieve HTS applications such as conventional systems (cables, transformers, motors, and generators) and novel systems (flywheels, superconducting magnetic energy storages (SMES), and fault current limiters (FCL)). This paper will review the recent results of research and development in coated conductors in European countries, which are mostly presented by Dr. Freyhardt during the workshop of Coated Conductors Applications 2007 held in Jeju, South Korea.

II. Coated conductor development in Europe

1. Processing Technology

The research groups and institutions in Europe carry out their projects to get the results in application of HTS CC and efficient superconducting power systems. Processing methods for producing textured substrates and HTS layers and power applications are shown in table1. The current status and future goals of the CC are explained briefly in the followings.

Table I. Coated conductor processing and power applications in Europe
[1)] European High Temperature Superconductors GmbH & Co. KG (EHTS)

CC Processing	
Substrates	Evico; IFW
IBAD, ABAD, ISD	EHTS[1)],(ZFW),Theva,IFW
RABiTS	Edison, Evico, NSC;
Vacuum Depos.	Edison, Evico, NSC, IFW, U. Linz,U.Geneva,U.Cambridge
MOD, MOCVD	NSC(MOD), PerCoTech(MOCVD), Trithor(MOD); ICMAB IFW, U. Ghent,LMPG/MINATEC,INPG/CNRS
Characterization	U. Cambridge,FZK,U.Geneva,U.Goettingen, ZFW,ICMAB,IFW,TU.Wien,IEE/SAS
Pinning	ICMAB, IFW, TU. Wien
CC Applications	
Cables	Super3C (NSC, EHTS, ZFW, IEEE/SAS)
FCL	EHTS, Siemens, Theva; CNRS/Grenoble, FZK
Motor, Generator	Oswarld, Siemens
Coils, Current Leads	Trithor, Theva

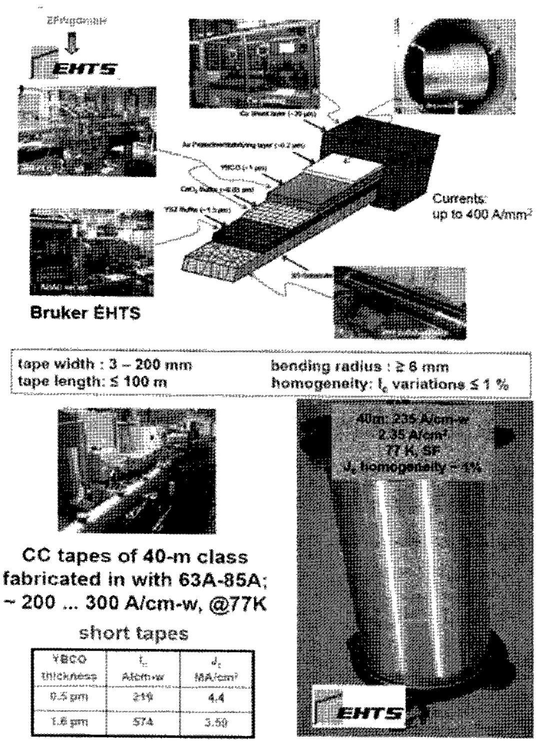

Fig. 1. High-Jc SS/IBAD-YSZ/PLD -YBCO at EHTS.

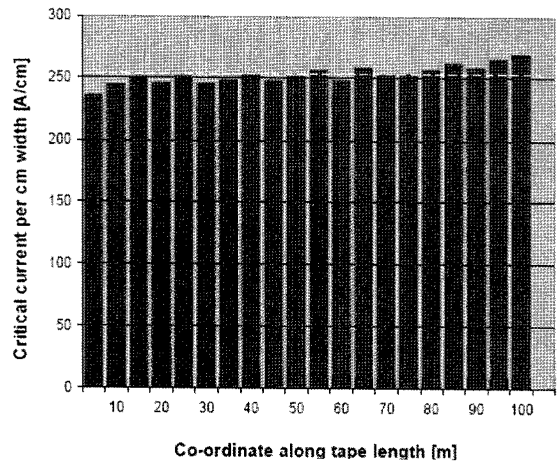

Fig. 2. Histogram (Critical current measured in sections of 100m long YBCO coated conductor. Measurements performed at 77K in self field.)

Fig. 1 shows the development of $YBa_2Cu_3O_{7-\delta}$(YBCO) coatedconductor (CC) at European High Temperature Superconductors GmbH & Co. KG(EHTS). EHTS continuously scaled up the YBCO tape from 40m to 100m. And also, by continuing development, they obtained an average critical current of 253 A per cm width in selffield. The measurement of the critical current, Ic, has been performed on 5m-sections, demonstrating the very high homogeneity of the product with a standard deviation of approximately 2.5% only (see histogram of Fig. 2). Their next goal is fabrication of 300m unit lengths carrying a critical current of 350Amps per cm width [1].

1) THEVA

In case of THEVA, Inclined-Substrate Deposition (ISD) process has been applied to deposit MgO buffer layer. Based on the ISD technique, they fabricated 2.5μm thick DyBCO film which was deposited on optimized MgO buffer layer with 400A. As a result, the standard deviation has dropped to a much lower value of about ±10% to ±4%

2) EDISON

To reduce the deposition costs, EDISON utilize the Pulsed electron deposition(PED) method. This method allows them to have low cost, high flexibility, excellent stoichiometry transfer from target to substrate, electrical efficiency, clean system, and stability of working conditions during long periods. Inaddition, because of manufacturing cost of the coated conductor, they investigated doped-CeO_2(PED) as a single buffer layer. This route exhibits a high potential for lowering production costs of HTS coated conductors. As a result, 1μm thick YBCO films which were deposited on CeO_2/Ni-Wshowed120A/cm-wat77K, self field.

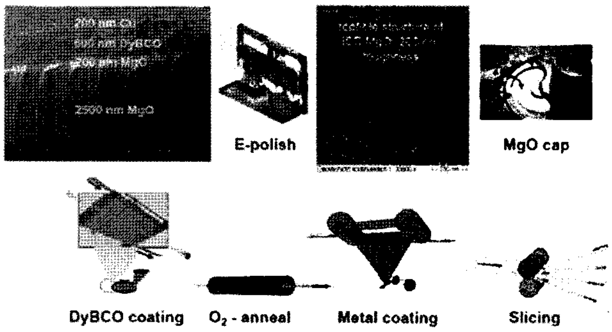

Fig. 3. ISD / TCE coated conductor architecture

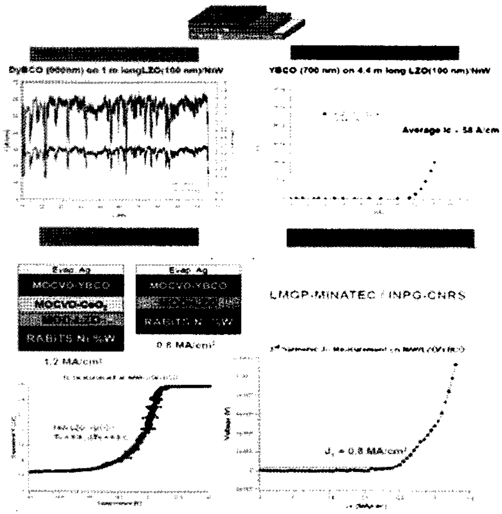

Fig. 4. The result of long length REBCO by NSC

3) Nexans Super Conductors (NSC)

NSC strategy on coated conductor (CC) is fabrication of the CC by simplest architecture and all chemical solution deposition process. To fabricate CC, NSC cooperates with some institution. The process for producing NiW RABiTS textured metallic substrates was developed by evico(Dresden) and INPG(Grenoble), and fabrication for MOD-LZO($La_2Zr_2O_7$) by ISC(Würzburg) and IFW(Dresden) and YBCO processes by ICMAB, UCAM, Univ. of Augsburg, Theva, and IOT/PerCoTec were accomplished. Fig. 3, 4 shows the method of coated conductors fabrication and the result of long length REBCO by NSC.

2. Pinning and Jc optimization

1) $BaZrO_3$(BZO)nanodots

To use power applications of superconductors, conductors with high pinning forces at high temperature is required. According to the research results of J.Gutiéffez et al(nano materials, they reported that $BaZrO_3$(BZO) play primary role in[2] efficient vortex pinning center. These dots which are arrayed in YBCO matrix help angle-dependent critical current value to be high at high temperatures and high magnetic fields.

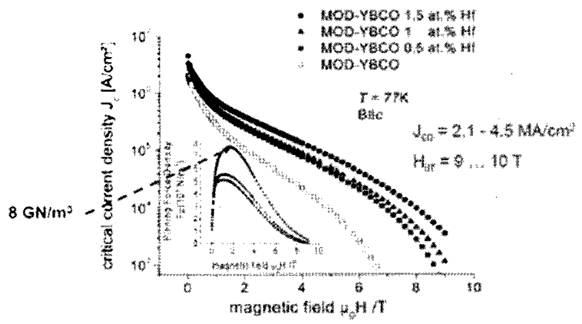

Fig. 5. Field dependence of the normalized Jc(H)/Jc(0) at 77K for standard and nanocomposite films and pinning force

The first graph in Fig. 5 shows the magnetic field dependence, Jc (H//c) at 77K measured through transport measurements for a nanocomposite and a standard YBCO-TFA film. When Jc (H) decreases by a factor of ~13 in standard YBCO-TFA films at 1T and 77K, Jc(H) decreases by a factor of only ~3 in the nanocomposite films. And also, the second graph in Fig. 5 shows magnetic field dependence of the pinning force curves of a nanocomposite film at 65 and 77K. When it is compared to a standard YBCO-TFA film at 65K and NbTi wires at 4.2 K, nanocomposite film has enormous pinning force. For instance, pinning force of ~78GN/m^3 in nanocomposite film at 65K is 5 times higher than that in NbTi wires at

4.2K. According to the this article, because of quasi-isotropic defects by BZO nanodots, YBCO/BZO nanocomposite films fabricated by chemical solutions allow to have gigantic flux pinning and YBCO films show a reduced effective anisotropy. As a result, it is possible for them to beused in practical applications at high temperatures and high magnetic fields.

2) $BaHfO_3$ precipitates using chemical deposition method

To enhance intragrain pinning, $BaHfO_3$ nanosized in clusion was investigated by S.Engeletal.(APL,90,102505,2007[3]) research group. In this work, they used chemical solution deposition(CSD) techniques based on the trifluoroacetic acid(TFA) process. This process makes possible to scale up easily and to reduce cost fabrication. The magnetic field dependence of the critical current density Jcinthe YBCO films with different amounts of $BaHfO_3$ particles are

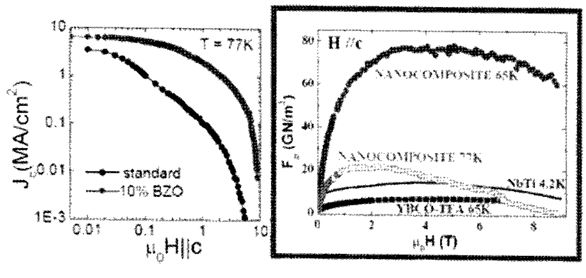

Fig. 6. Jc vs magnetic field for B//c at 77K in the YBCO films with different amounts of $BaHfO_3$ particles

shown in fig. 6. The pinning force density up to $8GN/m^3$and the irreversibility field H_{irr} values between 9 and 10T were observed. And J_{C0} was bserved between 2.1 and $4.5MA/cm^2$. As amount of $BaHfO_3$ precipitates are increased, pinning properties are enhanced. Hence, stronger critical current density is observed.

3) Vortex pinning in YBCO grown by hybrid liquid phase epitaxy

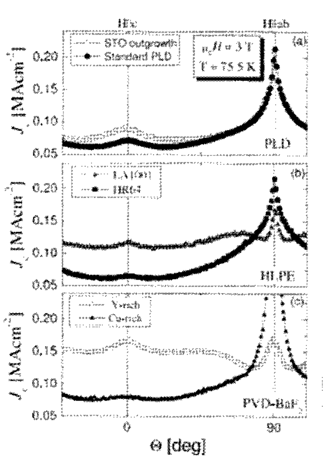

Fig. 7. Jc(Θ) measured at $\mu_0 H$ = 3T for (a) 4.8μm thick PLD films, YBCO grown on buffer with extra STO outgrowths (b)LA1001, HR64 - 2.9μm thick HLPE films(different growth rate) (c)1 mm thick YBCO Y-rich and Cu-rich films grown by $PVD-BaF_2$ on RABiTS substrates.

Hybrid liquid phase epitaxy(HLPE) is a new technique with characteristics both vapor and liquid-assisted growth method. In B.Maiorove et al. article[4], they obtained very strong pinning in about 3mm thick films which are fabricated by HLPE, yielding critical currents over 300 A cm^{-1}width at self-field,and35Acm^{-1}widthatm$_0$H=3Tat T = 75.5K, compared to films which are fabricated by PLD and PVD. In fig. 7, we can see pinning improvement according to growth methods. Especially in case of LA1001, in Fig. 7(b), there is an overall increase in Jc and the lack of improvement for Jc(H//ab) is related to a decrease in Jc(Q) when H is rotated closer to the ab planes.

The films which are fabricated by HLPE at high temperature experience the reduced strain associated with particles. And also, as the thicknesses of films are different, their characteristics are similar to either those of PLD or those of BaF_2 conversion process. As a result, the method of HLPE is expected to engineer the vortex pinning landscape.

4) Neutron irradiation of CC

Besides methods for enforcing pinning force referred above, neutron irradiation of CC creates randomly distributed defects, which increase the intragrain currents at high fields but decrease intergrain currents at low fields.

3. CC characterization

1) Jc Homogeneity of (long) CC tapes ; Magnetoscanning

To investigate local inhomogeneities of long coated conductors for a nondestructive way, the magnetoscan technique has been widely used. As for magnetoscan, schematic sketch is shown in Fig. 8. The principle of this equipment is inducing supercurrents by the permanent magnet in the conductor and simultaneously recording the z component of the field of these currents (Bz) by the Hall probe. From field map measured by magnetoscan, current distribution over the cross section is observed and scan over a long coated conductor rapidly and directly [5].

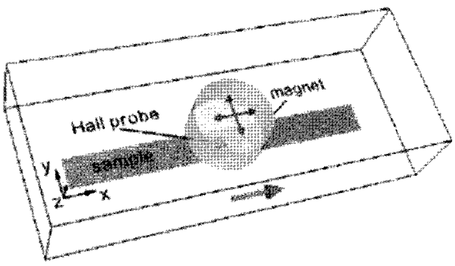

Fig. 8. Experimental setup.

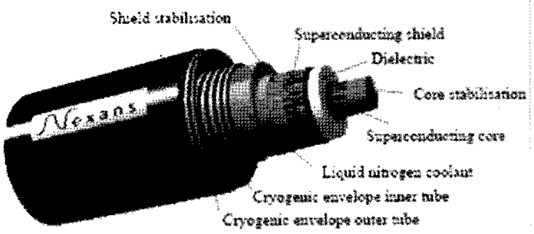

Fig 9. Super coated conductor cable by NSC.

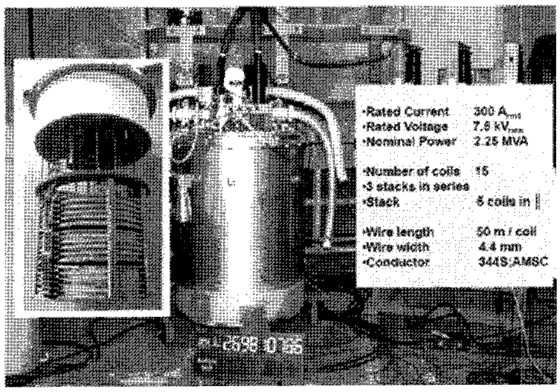

Fig. 10. Superconducting Fault current limiter (SFCL) by SIEMENS.

2) Electromechanical properties

Critical axial stress of the CC with Au and Ag plating is determined by IBAD/YBCO films on stainless steel substrate that are fabricated by EHTS and ZFW. From measurements,

III. CC applications in Europe

1. Power Cables

Super coated conductor cables are supplied by Super3C and coordinator, NSC(Fig. 9). The cable consists of core part (14 YBCO EHTS tapes, 4mm, ~75A) and shield part (16r ReBCO Nexans tapes, 10mm, ~35A). The capacity of cable of 30m in length was designed to be 1kA and 10kV.

2. Superconducting Fault current limiter(SFCL)

Superconducting fault current limiter is designed so that under the normal operating condition. In case of an overcurrent, FCL automatically switches to a high Ohmic resistivity state, so FCL reduces damage to electrical systems and components due to systems faults/overcurrents and operating costs of utilities. Fig. 10 shows that Superconducting Fault current limiter (SFCL) by SIEMENS and its characteristics.

IV. Conclusion

The long term goals in Europe for development of the next generation coated conductors is realization of 1/2~1km long length tapes, 250~300A/cm-w at 77K, self-field and 35~75m/hr(w=4mm). Challenges and prospects in Europe are reliable and robust processing of CC with specifications. required for high performance and low cost CC. By controlling of microstructure such as pinning and current limiting effects, or fabrication of twisting or transposition, AC losses can be reduced. As are sult, power applications of superconductors will be available in the near future.

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