Manufacturing of Superconducting Tapes for Energy Storage Applications: A Comprehensive Review

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ABSTRACT

In direct electrical energy storage systems, the technology for development of Superconducting magnetic energy storage (SMES) system has attracted the researchers due to its high power density, ultra-fast response and high efficiency in energy conversion. Hence, SMES is potentially suitable for short discharge time and high power applications. In the present chapter, a detailed description on construction and working of SMES is presented. Moreover, the superconducting wires and tapes used for the construction of superconducting magnets are described. In addition, the future application of the SMES in the electrical power grid is explained in detail.

INTRODUCTION

In present scenario, the demand for power requirements are increasing drastically. Due to electrical power losses from power generation to usage, the power requirements can't able to meet demand. During the power distribution, because of heat losses ($\dot{Q} = i^2 R$) the power losses are approximated as 40%. So, new developments in technology is needed to make power more qualitative during transmission and distribution. ***Superconductivity*** is better technology with fewer losses compared to traditional transmission and power distribution system.

Superconductivity is associated with three basic characteristic properties which are critical temperature, critical current and critical magnetic field. Critical Temperature is the temperature till the material exhibits state of superconductivity. Critical current is the maximum current carried by the material maintaining superconductivity.

Materials exhibiting superconductivity expels the magnetic lines of forces. However, when the value of magnetic field is increased beyond a certain limit, the magnetic field starts to penetrate inside the material. This phenomenon is called as pinning and the maximum value of magnetic field expelled by the superconductor is the critical magnetic field.

Superconductors possess an excellent property of handling larger transport current and hence can be useful in electrical industries as larger currents can be transferred with decrease in overall size of the conductor. Several machines have been developed on this physical phenomenon such as Superconducting Motor, Superconducting Transformer, Superconducting cables and Superconducting Magnetic Energy Storage Devices.

The Superconducting tapes are manufactured using reliable technology by compositing copper matrix and the material into a filament form for increased mechanical, electrical and thermal stability. Due to many peculiar properties, complication is involved with HTS material cuprate grain boundaries in addition with anisotropy.

By comparing different crystal structures of superconductors

a) Niobium-Tin (Nb-Sn) has a complex structure of Perovskite with A15 crystal structure which have drastic superconducting effects.
b) YBCO has a complex structure of Perovskite with orthorhombic crystal structure.
c) BSCCO has a complex structure of Perovskite with tetragonal structure of crystalline

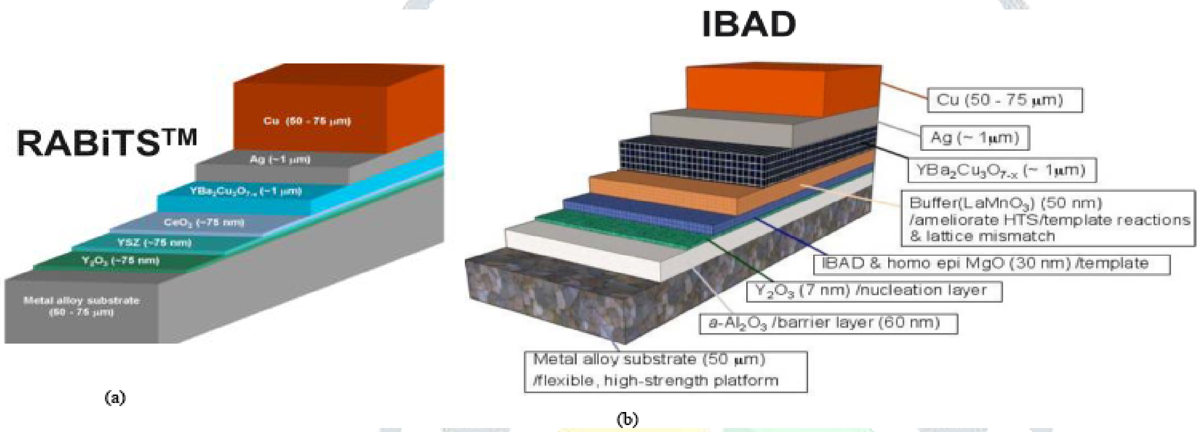
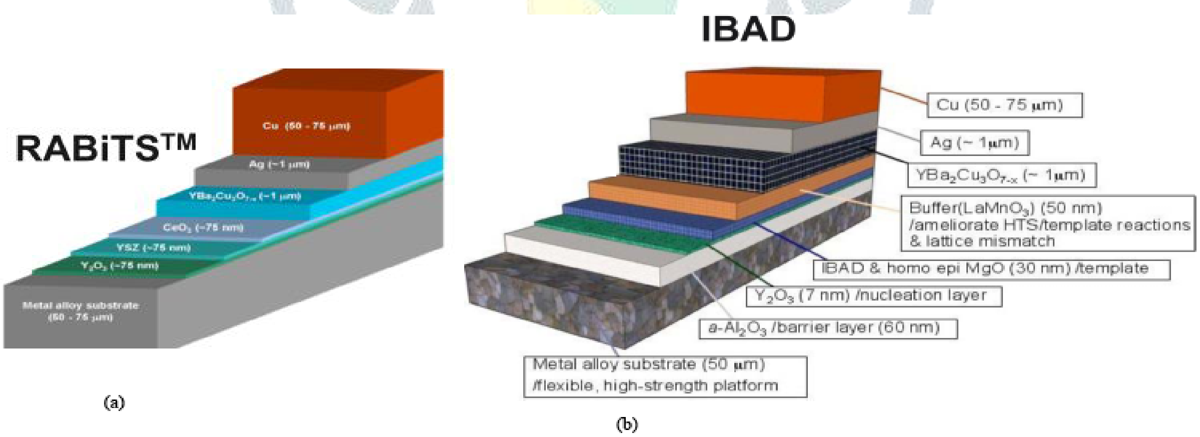


Figure 1 HTS tape manufacturing by RABiTS and IBAD techniques with different layers [1-4



The powdered tube metallurgical method is used to manufacture the filaments of BSCCO with Nb-Sn or MgB_2 composited with Silver (Ag) sheath. A film thinned method of deposition is used to manufacture 2G conductors. In CC's very cheaper Ni based coated ReBCO thin films are used instead of Silver for high costs. The thin films manufactured are formed into tape by epitaxial process. A multilayer film structures of oxide are biaxially aligned and stabilized with copper layer to get structural and chemical optimization of the CC's.

Two different approaches are used in manufacturing YBCO tapes with different crystalline structured substrate are used as buffer layer. Filaments are drawn by pouring the precursor powder in tube of Ag and these tubes are stacked and draw to tapes again. Thermal treatment and rolling are done to prepare multifilamentary tapes. Ion Beam Assisted Deposition (IBAD) process is mainly used in epitaxial growth texture of HTS tape using YSZ, MgO, Y_2O_3 and stabilized ZrO. RABiTS (Rolling Assisted Biaxially Textured Substrate) is the method used for epitaxial growth of the HTS tape by using Cu, Ni and alloys. Rolling and Annealing are used to prepare biaxial textured tape.

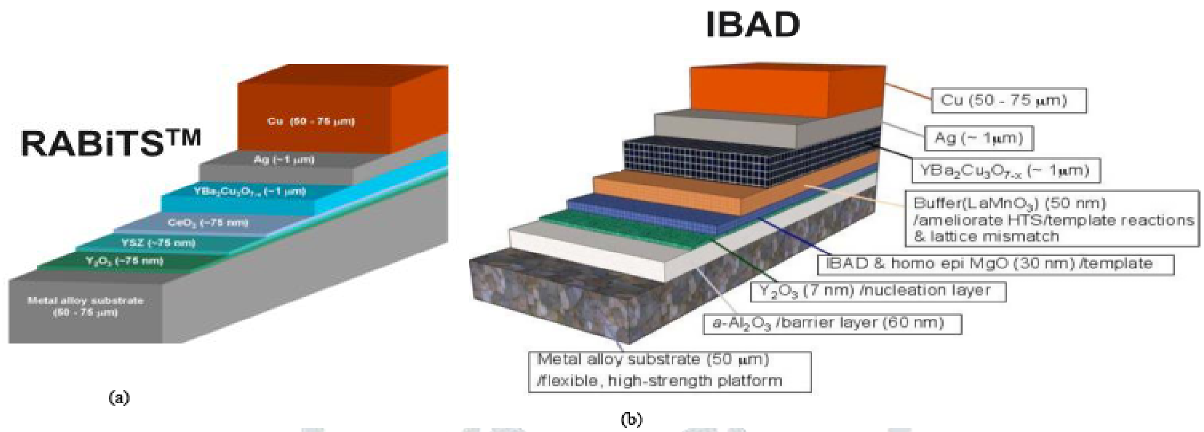


Figure 2 HTS tape manufacturing techniques RABiTS and IBAD [5]

LITERATURE REVIEW ON MANUFACTURING OF TAPES

1G and 2G tapes manufacturing processes

The bulk BSCCO powder material is liquefied and poured in Ag tube later drawn, rolled and heat treated to form 1G HTS tape. A 2G HTS tape is metallic textured substrates with multi layers having better mechanical, electrical and structural properties [6-10].

1G Tape manufacturing

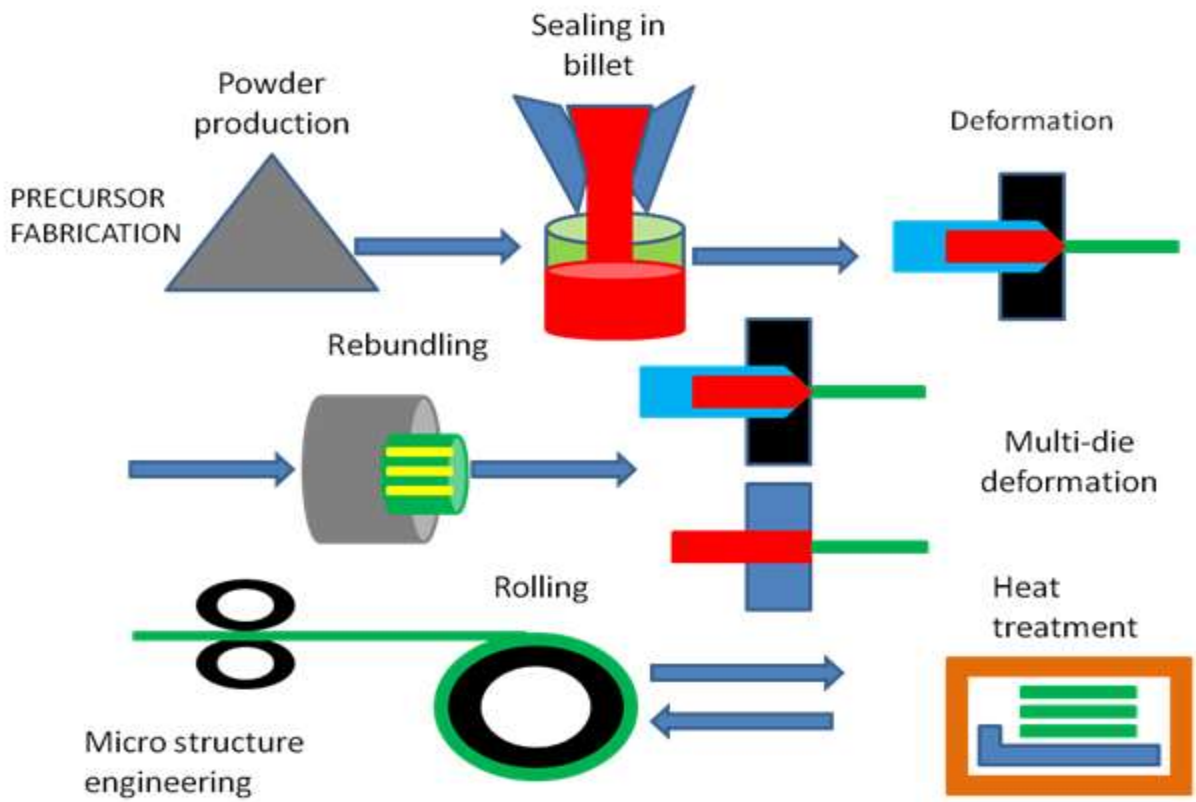


Figure 1 manufacturing of 1G tape [11-12]

1G HTS tape is manufactured by mixing the oxides of bulk BSCCO, cuprates of Earth metals, oxides of Copper to form BSCCO-2223. Dies are arranged in series to form hexagonal rod made with Silver tube packed with the mixture sealed, evacuated at high temperatures. By heat treatment many bundles of such tubes are manufactured by stretching. Multi press rolling used to deform the tapes.

2G tape manufacturing

ReBCO tapes or 2G CC's tapes uses ***Yttrium, Samarium or Gadolinium*** which are rare earth elements. The advantage with the 2G tapes are higher operating temperatures, possibility to withhold better magnetic field, cost benefits also compared to the 1G tapes.

- The extra current and heat from the surrounding are stabilized in ***Copper layer***.
- Stabilization of local heat and increased mechanical properties are done with the ***Silver Over layer***.
- Nanodots are dispersed in YBCO powder capable for carrying direct current to form ***CC layer*** which allows current to flow with zero losses.
- Yttrium oxide (Y_2O_3) is the first layer , Yttrium and Zirconium stabilized (YSZ) second layer and Ceria (CeO_2) is next consecutive layer stacked together to form ***Buffer layer***.
- The chemical and structural compatibility is provided by Ceria (CeO_2). High performance can be achieved by metal organic decomposition of precursor on Ceria.
- The atoms are precisely aligned to form crystallographic texture in Yttrium and Zirconium stabilized(YSZ) alloy substrate and the barrier for contaminating the CC's.

- Yttrium oxide (Y_2O_3) grown epitaxial over substrate to give the texture to YBCO layer after surface treatment with nanotech Sulfur.
- Deformation process of metal cannot be observed by using the ***Substrate layer*** made by Nickel-Tungsten alloy which provides high order coating.

Table 1 Thickness of different layers in HTS 2G tapes

Layers used in HTS tape	Thickness (μm)
Rare earth material	1
Copper Stabilizer	20
Silver overlayer	2
Buffer Stacks	0.2
Substrate	50

The 2G conductors are prepared in three different stages

a) Template fabrication

- Substrate preparation by texturing the metal by deformation and polishing the surface by nanotech treatment.
- Deposition of sputter or oxide buffer under vacuum or treatment in solution.

b) Superconductor Deposition

- A coating of precursor is made for deposition of Earth's Rare metal (YBCO) and the reaction between deposition of Nanodots dispersion under vacuum or treatment in solution.
- Deposition of Silver over the YBCO CC's under vacuum condition.
- Epitaxial arrangement of layers are heat treated in Oxygenated environment.

c) Assembling HTS tape

- The tapes are slitted according to their dimensions by rolling operation.
- HTS tape is electroplated or laminated by Copper for stabilization.

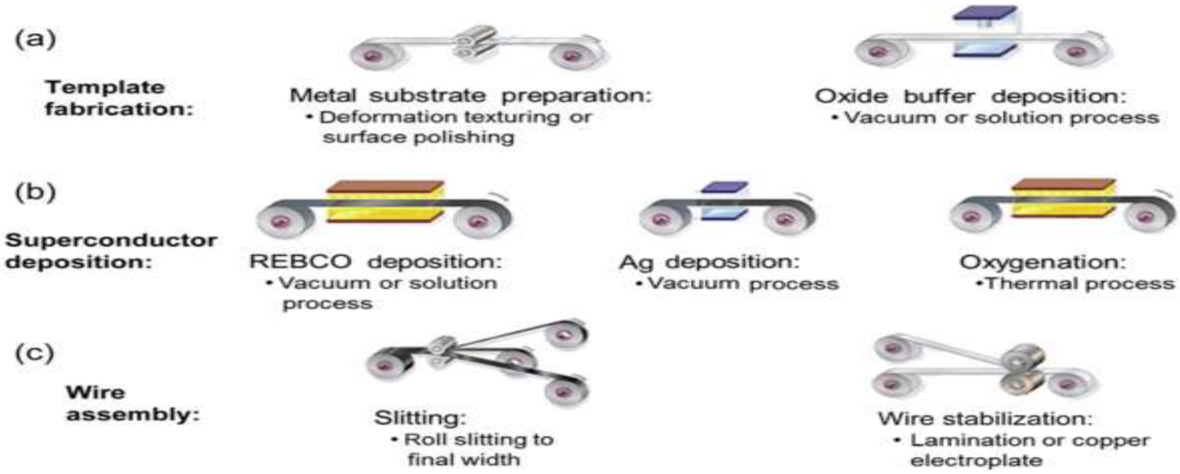


Figure 4 Second Generation HTS tape process of manufacturing [6], [7]

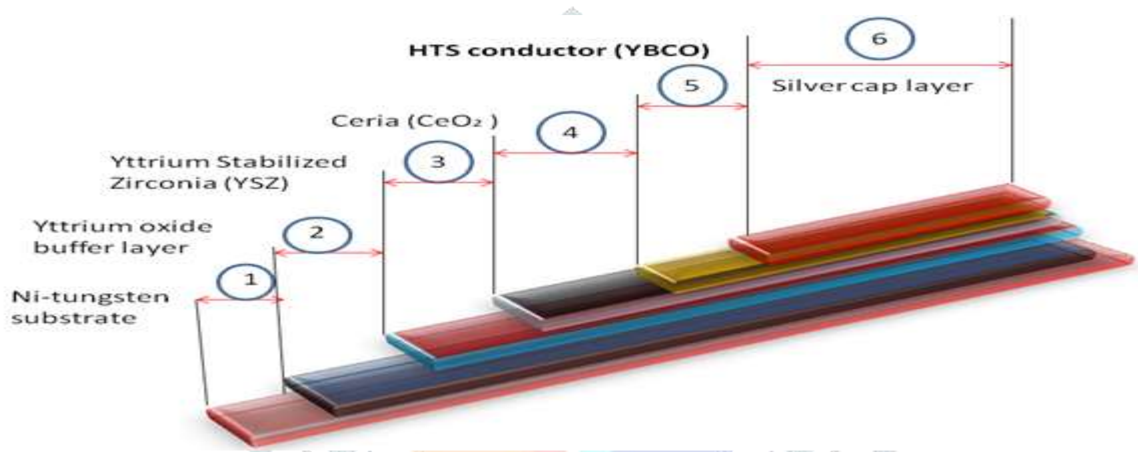


Figure 52 Manufactured HTS 2G tapes [13-14]

Table 2 Functions and Specifications of HTS 2G tape

Layer	Material used	Thickness of the layer (µm)	Method used for coating	Function
Superconductor	YBCO	1-4	PDL	Power transmission
Stabilizer	Cu	20	Electroplating	Prevent damage to SC Layer
	Ag	2-8	DC sputtering	
Intermediate layer	CeO_2	0.1	RF Sputtering	Lattice matching with SC layer
	YSZ	0.2-0.4		Dispersion prevention
	CeO_2	0.1-0.2		Seed layer
Textured metal substrate	Ni	3	Plating	Oxidation prevention
	Cu	20-50	Rolling and cladding	Textured layer
	SUS	100		Supporting base

CONCLUSIONS

There are several prominent issues associated with SMES such as design related issues of superconducting coils, cooling up components of SMES, AC losses in superconducting tapes etc. Therefore, the available literature related to Superconducting Magnetic Energy Storage Devices can be divided among those issues. In this section a typical review on the aforementioned issues is presented and efforts are made to find out a technical gap for further research.

Superconducting coil can be developed in various configurations such as Solenoid type coil, Toroidal type coil, Pancake type coil, Double pancake type coil. Sometimes the solenoid configuration is developed by keeping pancake coil one over another axially. In double pancake coil, two pancake coils are connected to each other make one unit or module. Then these units are placed either in a solenoid configuration or in toroidal configuration depending upon the requirements. Literature Review on AC losses in SMES

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