Superconducting materials

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LECTURES TITLES & SCHEDULE

- Historical highlights	March 10,2023
- Superconducting principles	“
- Superconducting properties	“
- LTS Superconducting materials	March 17,2023
- HTS Superconducting materials	“
- MgB2 (I part)	“
- MgB2 (II part)	March 24, 2023
- MgB2 (III part)	“
- Commercial superconducting applications	“
- Electromechanical superconducting future applications	March 31, 2023
- Electronic superconducting future applications	“
- Cryogenics for new superconducting materials	“

REFERENCE TEXTBOOK

M.Wilson «Superconducting Magnets» (Oxford Science Publications, 1983)
M. Tinkham «Introduction to Superconductivity» (II ed. Mc Graw-Hill,1996)
C. Krabbes et al. « High Temperature Superconductor Bulk Materials» (Wiley-VCH,2006)
Y. Iwasa «Case Studies in Superconducting Magnets» (II ed. Springer Science , 2009)
R. Flukiger «MgB2 superconducting wires: Basics and Applications» (World Scientific, 2016)

INTRODUCTION TO THE LECTURES

by Giovanni Giunchi

The importance of the materials development to apply the superconductivity

The superconductivity started at 1911, in Leiden University (Nederland), by professor Kamerlingh Onnes, after his successful liquefaction of the He gas at the cryogenic temperature of 4.2K (R.T. = 296 K). After the first experiments on the disappearance of the resistivity for some metals at the He liquefaction temperature, he soon discovered that this behavior was limited to low current densities and at low magnetic fields.
The application of the superconductivity started more than 50 years later by the search on materials having superconducting characteristics at high magnetic fields. The first material used for the construction of the first high field magnet (about 2.5 Tesla) was a Nb alloy (Nb_3Sn), having a Critical Temperature, Tc=18 K. After this result, other metal alloys were tested, and the preferred choice was NbTi (Tc=9K), that overpasses the brittleness of Nb_3Sn, even if it had low Tc and lower characteristics in high magnetic fields.
NbTi and Nb_3Sn are, also today, the main materials for the superconducting applications. Their cables are used to build magnets for physics experiments (LHC accelerator), for medical analysis (Magnetic Resonance Imaging) and in chemical laboratories, for the Nuclear Magnetic Resonance analysis.
All the attempted electrotechnical applications, with these alloys, (superconducting train levitation, cables for high current transmission, superconducting motors, fault current limiters, transformers, etc.) were technically and practically prohibited, due to the need of cooling with the liquid He.
Starting from 1986 new superconducting materials were discovered (Copper oxides based: cuprates) having Critical Temperatures around 100 K, and from 2001 many other materials showed intermediate Critical Temperatures (MgB_2 with Tc=39K, iron-based materials (Tc=20K ÷ 58K) and organic materials (Tc < 33K). All these materials have created the hope to avoid the cryogenics with the liquid Helium, particularly the cuprates, with their Tc above the N_2 liquefaction point (77K). These new classes of superconductors are mainly ceramics and require advanced preparative techniques, as for example the multilayer thin film depositions, to obtain useful and not brittle manufacts and sometime require thermal treatments in controlled atmosphere, for several days. During my Lectures I will describe the main chemical-physical characteristics of these materials and I will present the today main drawbacks in their applications. Then, I will present the ongoing research lines that can overcome the hurdles.
The theoretical comprehension of the superconductivity of metals will be briefly summarized, starting from a semiclassical description, to a full a quanto-mechanical one.

My preferred materials choice: Magnesium diboride

Magnesium diboride is, today, the potentially less expensive and environmentally friend superconducting material, among the High and Intermediate Temperature Superconductors (Tc ≈ 39 K). The synthesis and densification of this material can benefit of a new and easy preparation technique, discovered in Edison Italy labs early 2001, based on the Reactive Liquid Infiltration (RLI) of Magnesium in a boron powder preform. With this technique it is possible to obtain very dense ceramic-like manufacts of optimal superconducting and mechanical characteristics. In my lectures

I will present the peculiar aspects of the Infiltration technology and some typical manufacts as bulk tubes and plates and special hollow wires. Many of these manufacts, as for example the large bulk materials, are unique in the materials scenario of the High temperature superconductors.
The hollow wires and related cables resulting from the infiltration process are today under intense research activity to reduce the filaments thickness under 10 μm diameter, to allow their winding in the already reacted-superconducting state.
All these research activities will open the way to the large-scale worldwide superconducting applications.

Description of the Present & Potential future applications of the superconductivity

List of the today commercial superconducting materials which enter in the low temperature applications.

Present commercial main applications

- **Long magnets for physics** (Large Hadron Collider), working @ 1.8K and 8 Tesla , using NbTi cables
- **High bore magnets for human body MRI** (Magnetic Resonant Imaging), working @4.2K and 3T-5 T , using NbTi cables
- **High field magnets for NMR chemical analysis** , working @4.2 K and 8T-11T, using Nb_3Sn cables
- **Radiofrequency Cavities for accelerating charged particles**, working @ 1.8K- 4.2K , using Nb bottle-like thick systems
- **Magnetic sensors** (SQUID=Superconducting Quantum Interference Device), working @ 4.2K, by using Nb or other LTS thin film

Here, there is a list of future applications, opened by the research activity on High Tc materials

The electromechanical future applications

- Superconducting motors/generators
- Levitating transportation
- Fault Current Limiters
- Mechanical and Electrical Energy Storage
- High bore magnets for Intermediate field (< 5 Tesla)
- High Direct Current transportation
- Low frequency Magnetic field shielding

The Cryogenic issues for the applications at intermediate temperatures

The most efficient way to maintain cold a body is to insert it in a cooling bath. But in the range of intermediate-high temperatures of the today superconductors, there is a limited numbers of cryogenic liquids (H_2 at T≈18K, Ne ≈27K, N_2≈77K) and, in many cases, they have economic and safety issues. Therefore, the most practical cryogenics for the new superconductors is based on thermo-mechanical systems, the cryocoolers, which act not by immersion in a cooling bath, but via conduction cooling through a cold head attached to the superconductors. Even if many cryocoolers have been developed and are fully commercial, their cooling power is limited to small cooling volumes. Furthermore, during the cooling of the superconductors it must be guaranteed that a good contact between cryocooler head and the material is realized, to avoid thermal instabilities. Also, the vibrations of the cryocooler may be dangerous in some applications.

An overview of the most recent developments and cryogenic equipment, useful for the superconducting applications, will be presented.

Como, October 19th, 2022