INTRODUCTION

The International Conference "S4E - Superconductivity for Energy" points at joining together researchers with high expertise and international recognition in the field of large scale applications of superconducting materials. High magnetic fields are mandatory to the exploitation of thermonuclear fusion energy production, as well as to obtain high quality particles beam in the particle colliders. These large scale applications imply the fabrication of high power cables based on superconducting technology. Although in the international market there are many companies committed to their production, there are still few centers in Europe to test them in the presence of magnetic fields. None of these can handle cables longer than few meters or large devices. In this scenario the project NAFASSY (NAtional FAcility for Superconducting SYstems) is building up a strategic facility that, once fully operative, will address the needs of the growing business based on magnet technology, especially NMR magnets, magnetic energy storage or energy production by nuclear fusion, as well as technologies based on high currents, such as fault current limiters or components for smart electrical grids. "Superconductivity for Energy" also aims to be the most important event within the high level training program called DISP (high power superconducting devices), which is being carried on within the Nafassy project, in order to transfer unique expertise and know-how to a scientific and interdisciplinary team made of physicists and engineers.

The Conference program is scheduled in oral and poster presentations, with the aim to stimulate discussions and exchange in the following thematic areas:

- High Power Applications of Superconductors: materials, cables and magnets
- Frontiers in High Field Magnet technology
- Superconductors for Energy
- Power Devices (Motors, SMES, FCL)
- High Current superconductivity
- Superconducting properties and functionalities for new applications

The Conference is promoted within the PON Project "NAFASSY" (NAtional FAcility for Superconducting SYstems) by the Physics Department of the University of Salerno in collaboration with the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), the National Research Council (CNR), and the Center for New Technologies (CRdC).
COMMITTEES

Organizers:

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Tania Santoro, CNR-IAMC
The Savoy Beach Hotel stands in a very spectacular position that overlooks the Gulf of Salerno. In fact it is positioned just between the Amalfitan and the Cilento Coast, both in the Unesco World Heritage List. The location offers a perfect mix of culture, sea and nature, being close to the ancient temples of Magna Grecia, the limpid sea reachable through a shadowy pinewood, and the National Park of Cilento, the second largest park in Italy.
### Hotel facilities

<table>
<thead>
<tr>
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<th>Time</th>
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<tbody>
<tr>
<td>American Bar (extra on payment)</td>
<td>from 11:30 to 23:00</td>
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<tr>
<td>Bar outdoor Pool (extra on payment)</td>
<td>from 11:30 to 23:00</td>
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<tr>
<td>Restaurant &quot;Tre Olivi&quot; (extra on payment)</td>
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<tr>
<td>Breakfast</td>
<td>from 7:30 to 10:00</td>
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<tr>
<td>Lunch</td>
<td>from 12:30 to 14:30</td>
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<tr>
<td>Dinner</td>
<td>from 19:30 to 22:30</td>
</tr>
<tr>
<td>Lunch Buffet</td>
<td>€.25,00 /person</td>
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<tr>
<td>Dinner Menu</td>
<td>€.30,00 /person</td>
</tr>
<tr>
<td>Room Service (€.5,00/person)</td>
<td>from 7:30 to 23:00</td>
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<tr>
<td>Outdoor Swimming pool</td>
<td>from 8:30 to 18:30</td>
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<tr>
<td>Fitness Room</td>
<td>from 8:30 to 18:30</td>
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<tr>
<td>Wi-Fi connection (Free)</td>
<td>24 h</td>
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<tr>
<td>Laundry service (extra on payment)</td>
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<tr>
<td>Shuttle Service (extra on payment on reservation)</td>
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<tr>
<td>Beach&quot;Athena&quot;(150m, Free)</td>
<td>from 8:00 to 19:00</td>
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<tr>
<td>Beach Towel</td>
<td>€.5,00 /person/day</td>
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<td>Telephone</td>
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<td>Safe</td>
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<tr>
<td>Minibar (extra on payment)</td>
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<tr>
<td>Wardrobe</td>
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<td>Wi-Fi connection (Free 24h)</td>
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### Amenities

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<tr>
<th>Service</th>
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<tbody>
<tr>
<td>Archaeological site Paestum</td>
<td>from 9:00 to 18:00</td>
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<tr>
<td>Museum of Paestum</td>
<td>from 9:00 to 18:00</td>
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<tr>
<td>Pharmacies available (Paestum, Capaccio, Agropoli)</td>
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<tr>
<td>Car rental (on reservation, various companies)</td>
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<tr>
<td>Body massage (on reservation)</td>
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<tr>
<td>Hair stylist (on reservation, in Paestum)</td>
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SOCIAL EVENTS

The Conference Organizers offer:

- Welcome drink, Thursday 15th at 18:00
- Coffee breaks
- Lunch buffets, May 16th, 17th, 18th
- Excursion trip at the archeological site with English guide
- Conference bag

Excursion will be on Saturday, 17th May (Afternoon)
Visit to the Archaeological Site and the National Museum-Guided tour

Paestum has been for a thousand years a romantic ruin in the midst of a solemn wilderness. Its Doric temples, hardly surpassed even by those of Athens in noble simplicity and good preservation, produce an incomparable effect of majesty and grandeur. The ancient site is set in a grassy field surrounded by gardens and hills. Although the site is small, it’s so charming that you may want to spend time just relaxing here, and to the exceptional museum, that holds finds excavated from the site and around, including a set of archaic period Greek metopes. Here you will find the tomb paintings, one of which, the so-called “Tomb of the Diver”, is a graceful and expressively naturalistic piece of work, the only existing example of Greek wall painting in Italy.
## Sponsor

<table>
<thead>
<tr>
<th>Savoy Beach Hotel</th>
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<th>SHI Cryogenics Group</th>
<th>SOL Group</th>
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<td>Rivoira Industrial &amp; Specialty Gases</td>
<td>SuperOx</td>
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<th>STI Superconductor Technologies Inc.</th>
<th>ICAS Italian Consortium for Applied Superconductivity</th>
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## PROGRAMME

### Thursday 15th

<table>
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<th>Time</th>
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<tr>
<td>16:00</td>
<td>Opening of Registration Desk</td>
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<tr>
<td>18:00</td>
<td>Welcome Drink</td>
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### Friday 16th

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<tr>
<td>8:20-8:30</td>
<td>Opening:</td>
</tr>
<tr>
<td></td>
<td>Filippo Giubileo and Nadia Martucciello, Organizers</td>
</tr>
<tr>
<td></td>
<td><strong>Chair: B. Holzapfel</strong></td>
</tr>
<tr>
<td>8:30-9:10</td>
<td>Hydrogen cryomagnetics: synergies between superconductivity and the hydrogen economy, B. Glowacki</td>
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<tr>
<td>9:10-9:50</td>
<td>High Temperature Superconductor Conductors for Magnets at the NHMFL, D. Larbalestier</td>
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<tr>
<td>9:50-10:15</td>
<td>R&amp;D for the next generation of superconducting devices, B. Strauss</td>
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<tr>
<td>10:15-10:40</td>
<td>Superconductivity and Fusion Energy, inseparable companions, P. Bruzzone</td>
</tr>
<tr>
<td>10:40-11:10</td>
<td>coffee break</td>
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<tr>
<td></td>
<td><strong>Chair: D. Larbalestrier</strong></td>
</tr>
<tr>
<td>11:10-11:35</td>
<td>30 tesla or bust: Development of superconductors for very high field magnets at Fermilab, L. Cooley</td>
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<tr>
<td>11:35-12:00</td>
<td>Long distance, high-current power transmission using MgB₂ and HTS cables, A. Ballarino</td>
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<td>12:00-12:25</td>
<td>A Novel Superconducting Generator Concept for a Successful Entry to the Offshore Renewable Energy Market, O. Keysan</td>
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<td>12:25-12:50</td>
<td>A Comparison of Conventional and Superconducting Machines, A. Campbell</td>
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<td>12:50-14:30</td>
<td>Lunch</td>
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<td><strong>Chair: L. Civale</strong></td>
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<tr>
<td>14:30-14:55</td>
<td>Superconducting Technologies for Large Electric Infrastructures, A. Morandi</td>
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<td>14:55-15:20</td>
<td>How to improve performance of FeSe family iron-based superconductors, Y. Takano</td>
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<tr>
<td>15:45-16:10</td>
<td>Intergrowth processing control of CSD YBCO nanocomposites for tuning vortex pinning landscape, A. Palau</td>
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<tr>
<td>16:10-16:40</td>
<td>coffee break</td>
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<td><strong>Chair: S. Pace</strong></td>
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<tr>
<td>16:40-17:00</td>
<td>Science and technology beyond the NAFASSY project, G. Grimaldi</td>
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<tr>
<td>17:00-17:20</td>
<td>Design and state of the art of the large-bore 8T superconducting magnet for the NAFASSY test facility, V. Corato</td>
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**Chair: B. Glowacki**

- **8:30-9:10** Artificial pinning in LTS by high energy irradiation and by inclusions, R. Flükiger
- **9:10-9:50** Comparative analysis of vortex pinning and dynamics in oxide, iron-based and MgB\(_2\) superconductors, L. Civale
- **9:50-10:15** Superconductors for Fusion Magnets, M. Eisterer
- **10:15-10:40** Manufacturing and properties of round cables from CC tapes, F. Gömöry
- **10:40-11:10** Coffee break

**Chair: C. Ferdeghini**

- **11:10-11:35** High current low loss AC cables from HTS coated conductors, the Roebel and Rutherford approach, W. Goldacker
- **11:35-12:00** Slotted core HTS Cable-in-Conduit conductor for high current applications, G. Celentano
- **12:00-12:25** Low Temperature High Field Continuous Measurement of YBCO Coated Conductor, J. Jaroszynski
- **12:25-12:50** Superconducting magnetic energy storage systems, W. Yuan
- **12:50-13:10** Energy transfer with hydrogen and superconductivity – the idea and review of the first experimental results, V. Vysotsky
- **13:10-15:00** Lunch

**Excursion to Archeological site and Museum**

19:00-20:00 Informal Discussion / Round Tables

**20:00** Social Dinner

### Sunday 18th

**Chair: R. Flükiger**

- **8:30-9:10** Advances in solution derived YBa\(_2\)Cu\(_3\)O\(_7\) coated conductors, X. Obradors
- **9:10-9:50** Application based aspects of Fe-pnictide superconductors, B. Holzapfel
- **9:50-10:15** Aspects on Applications in Confined Power Grids based on HTS, T. Arndt
- **10:15-10:40** Current Developments of LTS Cable-in-Conduit Conductors for the DEMO nuclear fusion power plant, L. Muzzi
- **10:40-11:10** Coffee break

**Chair: X. Obradors**

- **11:10-11:35** Properties and potential of 2G HTS tapes with ISD buffer layer, M. Bauer
- **11:35-12:00** Progress in the industrialization of MgB\(_2\) superconducting wires, G. Grasso
- **12:00-12:20** 2G HTS tapes for power applications, A. Molodyck
- **12:20-12:40** Development of Compact High Field Superconducting Magnets for Research Applications, Z. Melhem
- **12:40-13:05** An enemy of Superconductivity: the sailing-ship effect, N. De Liso
- **13:05-14:30** Lunch

**Chair: L. Cooley**

- **14:30-14:55** Can we realize strongly connected, self-organized grain-boundaries in high performance MgB\(_2\) bulks and wires?, A. Yamamoto
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<td>Groove-rolling as an alternative process to fabricate Bi-2212 wires for practical applications, A. Malagoli</td>
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<td>15:35-15:55</td>
<td>High currents MgB(_2) superconductors aimed for low external fields and mass-limited applications, P. Kovac</td>
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<td>15:55-16:15</td>
<td>Magnetic field mitigation by superconducting and hybrid shields, L. Gozzelino</td>
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<td>A simple analytical method for the calculation of the force between a magnet and a bulk superconductor, P. Bernstein</td>
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<td>Pinning mechanism in electron-doped HTS Nd(<em>{1.88})Ce(</em>{0.15})CuO(_{4+y}) thin films, A. Guarino</td>
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<td>Shear stress evaluation in the wrap insulation of a high field superconducting magnet, M. Perrella</td>
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<td>High pinning energies in the iron-based superconductors: thin films, bulks and single crystals, A. Leo</td>
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<tr>
<td>17:55-18:55</td>
<td>Informal Discussion / Round Tables</td>
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**Monday 19th**

**Chair: A. Della Corte**

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<td>Strong vortex matching effects in YBCO films with artificial defects fabricated by masked ion irradiation, W. Lang</td>
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<td>Pinning Performance of Nanostructured YBa(_2)Cu(_3)O(_x) Films Added With Artificial Pinning Centers of Different Dimensionality, P. Mele</td>
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<td>High-field transport properties of P-doped BaFe(_2)As(_2), K. Iida</td>
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<td>10:10-10:30</td>
<td>Fluctuation mechanisms induced by bicrystal grain boundaries in Co-doped BaFe(_2)As(_2) superconducting thin films, C. Barone</td>
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<td>10:30-11:00</td>
<td>coffee break</td>
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<td><strong>Chair: V. Corato</strong></td>
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<td>11:00-11:25</td>
<td>The mixed state in thin superconducting films in parallel magnetic fields, M. Kunchur</td>
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<td>Examination of the tradeoff between intrinsic and extrinsic properties in the optimization of a modern internal ( \text{tin Nb}_3\text{Sn} ) conductor, C. Tarantini</td>
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<td>Superconducting Fault Current Limiter applications: Results from the grid field testing activity and next steps, L. Martini</td>
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<td>12:15-12:35</td>
<td>Superconducting Power Complex, V. Sokolovsky</td>
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<td>12:35-13:35</td>
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ABSTRACTS
Hydrogen cryomagnetics: synergies between superconductivity and the hydrogen economy

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Currently the global production of hydrogen is mainly for industrial uses. However the production of hydrogen for alternative uses is anticipated to increase. For example compressed and liquid hydrogen can be used as both an energy storage medium and as an energy carrier. Liquid hydrogen has important additional potential as a cryogenic coolant. “Hydrogen cryomagnetics” is an enabling technology for superconductivity. In our presentation we will discuss the use of cryogenic hydrogen originated from renewable and low-CO₂ emission sources. We suggest that 20K liquid hydrogen can ultimately displace liquid helium as a coolant in a range of superconducting electromagnetic devices; such as novel engineering designs made possible through the use of medium-temperature MgB₂ superconductors.

As the world moves towards a low carbon economy the production of hydrogen from low carbon technologies will be important. Methane plasma reforming is an essentially emission-free method of hydrogen production producing both hydrogen and valuable carbon nanoforms. The hydrogen industry can grow in harmony with the carbon nanotechnology industry. The wind energy industry is seeing strong growth globally. It is another potential low carbon source of hydrogen production. An interesting hydrogen cryomagnetic application could be to use 20K hydrogen-cooled superconducting homopolar generators in combination with the advanced electrolysis of water and hydrogen liquefaction.

Our research makes use of system dynamics to model potential liquid hydrogen futures including hydrogen cryomagnetics innovations. It will help identify the stocks and flows of hydrogen (both liquid and gaseous) in a range of future scenarios including some that differ greatly from established scenarios that give emphasis to fuel cell vehicles as the dominate technology driver of a future hydrogen economy. Hydrogen’s use as a coolant, as well as an energy carrier, will spin-off new research and technological developments in superconducting materials and efficient energy use greatly increasing the scale of superconductivity applications in areas such as: MRI, SMES, Flywheel, and DC cables for datacentres.
Academy panels, COHMAG [1] (2003-2004) and most recently MagSci [2] (2012-2013), have urged development of HTS for high field superconducting magnet use, both for reasons of reducing power use and to provide lower noise continuous access for experiments that now use the 20 T all superconducting magnets at the NHMFL. To respond to this call, we have worked to apply both REBCO coated conductors and round wire Bi-2212 [3] to high field magnets. Moreover, since no superconducting magnet is ever better than the conductor from which it is made, we have worked hard on conductor development and characterization too. We have made extensive characterizations of SuperPower coated conductor in fields up to 31 T [4,5], added a capability to make continuous transport characterization with resolution of about 2 cm on 200 meter lengths of tape (in collaboration with Yates Coulter of LANL) and worked with OST and collaborators at BNL, FNAL and LBNL to make round wire Bi-2212 into a viable magnet conductor [3]. Using these conductors we have achieved world record fields of 35.4 T with REBCO and 33.8 T with Bi-2212 when small coils have been tested in the 31 T Bitter coil of the NHMFL [6,7,8]. An all superconducting magnet for NHMFL users designed to produce 32 T is under construction [9] and new overpressure furnace capabilities suitable for 2212 coils up to about 15 cm in diameter are being installed. I will summarize the goals and recent progress of the NHMFL program.

R&D for the next generation of superconducting devices

B. P. Strauss

U.S. Department of Energy

The publication of the U.S. National Academy of Sciences report entitled “High Magnetic Field Science and Its Application in the United States: Current Status and Future Directions” as well as developments in high energy physics laboratories and commercially have opened a new area of application for superconducting magnets operating well above 22 tesla and at low liquid helium temperatures. Some of the applications will also require operation in high radiation environments. These applications represent a global annual market of nearly $1 billion. A new systems approach will be required in order to define design and engineering requirements. Superconducting materials, particularly HTS, will need to meet engineering standards of length, uniformity, mechanical strength, stability and ac losses. Electrical insulation systems will need to be able to be co-processed in wind and react systems and provide mechanical and radiation resistant properties consistent with proposed applications. Revised and consistent approaches will be required for controlling the electromagnetic forces. A coordinated approach to these issues on a global basis will provide an engineering basis for the next batch of energy generation and transformation devices.

Superconductivity and Fusion Energy, inseparable companions

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Although superconductivity will never produce energy by itself, it plays an important role in energy related applications either because of the saving potential, e.g. power transmission lines and generators, or as enabling technology, e.g. for nuclear fusion energy.

The need of superconducting magnets for the plasma confinement was recognized since the early development of fusion devices. As long the R&D for plasma burning was carried out on pulsed devices, the technology of superconducting fusion magnets was aimed at demonstration of feasibility. In the last generation of plasma devices, with larger size and longer confinement time, the superconducting coils are a key, enabling technology.

The cost of the superconducting magnet system is a major fraction of the overall cost for a fusion plant and deserves high attention in the long term planning of electricity supply – only cheap superconducting magnets will help fusion to the energy market.

The requirements and design approaches for fusion magnets are critically reviewed for the past, present and future projects, starting from the early superconducting tokamaks in the seventy’s, to the running ITER and W7-X projects and the future DEMO projects. The associated cryogenic technology is reviewed: 4.2 K helium bath, superfluid bath, forced flow supercritical helium and helium free design.

The open issues and risk mitigation are discussed in terms of reliability, technology and cost.
30 tesla or bust: Development of superconductors for very high field magnets at Fermilab

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A core R&D activity under the U.S. Department of Energy Office of High-Energy Physics is the development of superconductors for frontier accelerators. The envisioned magnet technologies may include solenoids in the 30 to 50 T range, arc dipoles in the 15 to 20 T range, and special-purpose high-field magnets that must operate in extreme conditions. Nb$_3$Sn conductor technology is presently available for magnets in the 12 tesla range for LHC high-luminosity upgrades, thanks to the development of an understanding of how important properties, such as current density, dynamic stability, and degradation after cabling, can be addressed by manufacturers within a flexible parameter set that includes sub-element count, tin content, diffusion barrier thickness, and strand diameter. Pathways to evolve Nb$_3$Sn technology to accommodate 15 to 20 T magnets are few, however, and some ideas will be discussed. The fact that Nb$_3$Sn technology cannot be pushed beyond about 22 T has compelled the development of round-wire Bi-2212, which is potentially capable of supporting magnet technology beyond 50 T at 4.2 K if a conductor technology can be established. Here, tremendous progress has resulted from identifying critical current limiting mechanisms in long-length conductors including the agglomeration of porosity into gas bubbles that block current along Bi-2212 filaments and trapped and evolved gas causing long-length conductor to creep and de-densify. Strand current densities suitable for magnet technology have been demonstrated at 20 T, 4.2 K using overpressure processing (OP), and this has stimulated work to verify whether the same progress can be achieved in cables and coils. Accordingly, recent efforts have developed new OP facilities that accommodate coils and cables, and the latest activities will be described. Insulation and structural material compatible with the OP process has also received attention. Fermilab has chosen to focus on round wires to facilitate cable-wound, low-inductance magnets, which are expected to be easier to protect than magnets wound from flat conductors. Some quench studies have also begun.

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Long distance, high-current power transmission using MgB$_2$ and HTS cables

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For the feeding of the LHC magnets developed for the LHC Hi-Luminosity upgrade, high-current superconducting transfer lines operated at temperatures of about 25 K are being developed at CERN. The proposed powering layout envisages the integration in the LHC tunnel of up to 500 m long superconducting links cooled by helium gas and containing, in a compact cryogenic envelope, tens of MgB$_2$ or HTS cables rated at currents of up to 20 kA...
DC. An overview of the superconducting powering system is presented and discussed with focus on the exergetic cost of the refrigeration which is compared with that of a conventional system, together with the results of the tests performed on a recently developed 20 m long 20 kA MgB$_2$ line operated in helium gas at a temperature of 25 K. Possible application of the technology to other power transmission systems will also be discussed.

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A Novel Superconducting Generator Concept for a Successful Entry to the Offshore Renewable Energy Market

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Superconducting wind turbine generators are proposed to reduce the tower-head mass for very large (>10 MW) wind turbines. This will help to reduce the manufacturing and installation cost. Most of the proposed designs use the superconducting synchronous generator concept, which consists of a rotating superconducting field winding and copper-based armature winding. However, the authors think this topology is not designed according to the requirements of offshore conditions. Firstly, offshore wind turbine generators operate in harsh conditions and are exposed significant vibration levels in the nacelle. Secondly, maintenance of offshore wind turbines are expensive and any failures result in long down periods adding lost generation income on top of the repair cost. A superconducting wind turbine should satisfy the following requirements to compete with the existing power take-off technologies:

- High reliability (including subsystems such as the refrigeration system) to minimise operation and maintenance costs.
- Redundancy in generator systems to minimise down time.
- Modularity to enable on-site repairs without requiring large offshore cranes.
- Competitive cost compared to alternative power take-off systems such as direct-drive permanent magnet generators and geared systems.

A novel superconducting machine concept has been proposed by the authors in [1], the novelty of the design lays in having a single loop-shaped stationary superconducting field winding. This configuration eliminates the rotating transfer coupler, which is the single point of failure for most of the existing designs. Furthermore, there is no electromagnetic torque acting on the superconducting coil, which simplifies the design of the rotor structure. The rotor just consists of modular iron-cored claw poles, which can be installed or removed in situ. An improved version of the claw-pole topology will be presented in this paper, which has two independent armature windings further increasing the modularity. Furthermore, the field winding can be manufactured using three or four independent cryostats, all of which can be replaced without disassembling whole machine. The final advantage of the proposed design is the minimal use of superconducting coil, which makes the design economically competitive to conventional power take-off systems. For example, a 10 MW, 10 rpm machine is designed, the machine uses 15 km of MgB2 wire at 20 K. The outer diameter of the machine is 6.5 m and weighs 184 tonnes including the structural mass.

A Comparison of Conventional and Superconducting Machines

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Conventional machines have been developed by electrical engineers for nearly a hundred and fifty years and are full of ingenious ideas. However superconductors introduce a whole new set of parameters and there is a considerable gap between the concepts of the superconductivity community and the electrical engineering community. For example in a superconducting motor the torque is produced by pulling flux lines through the material, so that the same machine can be classified as an induction, hysteresis, or synchronous machine as it speeds up. To help bridge this gap it is useful to reduce a conventional machine to the point where simple analytical expressions can be obtained. This gives a typical power per unit volume of 25MW/m$^3$ and a ratio of loss to power equal to the ratio of the skin depth of copper to the diameter. Similar comparison for a superconducting machine gives this ratio as that of the superconductor diameter to the rotor radius. However much higher current densities in the superconductor lead to the possibility of much higher power densities, particularly if both rotor and stator can be superconducting. The use of magnetised bulks has a parallel in permanent magnet machines. However in comparison to our knowledge of permanent magnets, the behaviour of superconductors in motors where they will experience crossed fields under fault conditions, has not received enough attention. This is partly because the problem involves force free currents, but even in situations in which the Bean model should apply exactly, the experimental results show anomalies. The latest results on this will be discussed.

Superconducting Technologies for Large Electric Infrastructures

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Architecture and design methods of DC cables based on MgB$_2$ are reviewed. The electromagnetic performance of typical MgB$_2$ wires is resumed and possible layouts of the cable’s conducting core are described. Both low voltage and high voltage layouts are considered. Innovative warm dielectric cable concepts are introduced for the high voltage case. Gas helium and liquid hydrogen are considered as coolant. Total cooling losses of the cable are estimated. Possible applications of low voltage MgB$_2$ DC cables are discussed. In particular the feasibility of facility level DC power distribution at low voltage for large data centers is investigated. Breakeven length between copper and MgB$_2$ distribution is calculated and the advantages of MgB$_2$ distribution in terms of reduced losses, reduced size and weight and no voltage drop are quantitatively pointed out. Viability of bulk energy transmission by means of high voltage MgB$_2$ DC cables is also addressed with reference to cases of practical interest. Possibility to operate the system at a voltage level lower than for conventional cables is pointed out and the impact on conversion losses is evaluated. Feasibility of magnetic energy storage systems with large deliverable power for grid stabilization is finally addressed. Main parameters of the system (stored energy and power)
are derived with reference to cases of practical interest, i.e. transmission grids with a relevant amount of non-programmable (renewable) power. The concept design of a full scale facility based on MgB$_2$ with an operating field in the range 2-3 T is carried and compared with alternative solutions.

T10

How to improve performance of FeSe family iron-based superconductors

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FeSe family iron chalcogenides has the simplest crystal structure among Fe-based superconductors. However, they often show the inhomogeneous superconductivity. We think that this may due to inhomogeneity of excess iron located between superconducting layers.

We have tried several type of annealing to realize bulk superconductivity. So far, we have reported that the bulk superconductivity in the Fe-chalcogenides can be achieved by oxygen annealing, sulphur annealing and alcoholic beverages immersing [1-4]. It is proposed that excess electron given by excess Fe is compensated by intercalated oxygen. Furthermore, it is revealed that sulfure annealing or hot commercial alcoholic beverages have the ability to deintercalate the excess Fe, and hence bulk superconductivity is successfully achieved [5]. Moreover, we successfully observed the Shubnikov-de Haas (SdH) oscillations in both superconducting and non-superconducting iron chalcogenide thin crystals. This is the first report of the SdH oscillation for this compound [6]. From the analysis of SdH oscillations, we found that excess Fe changes Fermi surface nesting and then suppresses the superconductivity.

In my presentation, we will also report about Jc properties of iron chalcogenides superconductors after several type of annealing.

Iron-based Superconductors for Power Applications

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The discovery of Fe-based superconductors by the Hosono’s group has opened new chances for the investigating the mechanism of high temperature superconductivity and for understanding benefits and drawbacks of high temperature superconductors for applications.

Since the beginning it was pointed out that Fe-based superconductors share several characteristics with high temperature superconductors (HTS). In Fe-based superconductors the critical current is rather independent of the field, similarly to HTS, as a consequence of the exceptionally high upper critical field and strong pinning associated with nm-scale local modulations of the order parameter. On the other hand, they exhibit low anisotropy of the critical current with respect to the crystalline directions which allows current flow along the c-axis. Early measurements on thin films grown on bicrystals indicate that Jc exponentially decreases with the misorientation angle, with a behavior reminiscent of that already observed in HTS, thus suggesting intrinsic limitations in achieving high transport current in bulk materials.

After six years since their discovery the perspectives appear much more encouraging. In fact Fe-based superconductors have shown great flexibility to defects and/or lattice strain which affect positively the superconducting properties. Moreover, the capability of technical samples as wires and coated conductors to carry current is improving much faster than expected suggesting that grain boundaries are not a serious issue as in the case of HTS. This talk will be focused on Fe(Se,Te) compounds. This family exhibits lower Tc than other ones (optimal Tc=15 K) but huge upper critical field (above 70 T) which suggest its exploitation for high field application. Moreover it contains cheap, handy and not toxic elements which would allow the development of scale-up techniques for conductor manufacturing.

Results obtained on thin films, polycrystalline bulks and wires within will be resumed. Thin films present high critical current density values, larger than 10^6 A/cm^2 in self-field and liquid helium, together with a very weak dependence on the magnetic field and a complete isotropy. A multistep technique has been developed for polycrystalline materials which allows the flow of large inter-grain current across well interconnected grains. We studied how to adapt this promising technique for wires manufacturing.
Intergrowth processing control of CSD YBCO nanocomposites for tuning vortex pinning landscape

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Solution-derived YBCO nanocomposites have emerged as excellent low cost and scalable superconducting materials which properties can be finely tuned through processing to reach high performance long length coated conductors at high magnetic fields. We have demonstrated that the huge isotropic pinning forces obtained in the nanocomposites arise from the strains associated to a network of intergrowths (mainly Cu-O double and triple chains) emerging from the spontaneously segregated oxide nanoparticles, and a novel pinning mechanism has been proposed [1]. Moreover, natural defects of many types such us, dislocations, vacancies, low angle grain boundaries, staking faults or twin boundaries act as effective pinning centres as well.

In this contribution, we report on YBCO nanocomposites with a variety of second phase nanoparticles and off-stoichiometries where processing has enabled to control the density, length, stoichiometry and type of intergrowth. The corresponding interaction and strain has been evaluated by STEM and XRD.

The influence of the variety of intergrowths on vortex pinning has been evaluated through angular dependent transport critical current measurements. By analyzing tracks with different crystallographic orientations, over an extensive range of temperatures and fields, we have been able to determine the effect of different anisotropic pinning centers in a quantitative manner and establish their contribution in a H-T phase diagram.

We conclude that by proper tuning intergrowths characteristics, the vortex pinning landscape of CSD YBCO nanocomposites can be modified and optimized.


Science and technology beyond the NAFASSY project

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The NAFASSY (NANational FAcility for Superconducting SYstems) project is part of a broader strategy to create a center to test superconducting cables, tapes and magnets and to develop innovative superconducting materials for applications in high magnetic fields and high currents. This strategy lies within the P.O.N. program that is the national initiative for Research & Competitiveness co-funded by European structural funds 2007-2013. The joined partners are the University of Salerno, the National Institute for Nuclear Physics (I.N.F.N.), the National Agency for new technologies, energy and sustainable economic development (E.N.E.A.) and the National Research Council (C.N.R.) through the CRdC Tecnologie Scarl. The project will end in December 2014 and the facility is under construction at the University of Salerno. In addition, a high level training program called DISP (High power superconducting devices) is being carried on, within the NAFASSY project, in order to
transfer unique expertise and know-how to a scientific and interdisciplinary team made of physics, engineer and law researchers.

The quest for high power cables implies that it is necessary to test cables based on conventional low temperature superconducting materials, which are the only ones used in the large scale production, and to characterize innovative materials of potential interest for future applications. Thus, such a measurement facility with unique technological characteristics (measurements performed at high currents, variable temperatures, high magnetic fields, large scale samples) will address the need for the growing business based on magnet technology, such as NMR magnets, magnetic energy storage or energy production by nuclear fusion, as well as technologies based on high currents, such as fault current limiters or components for smart electrical grids, where the use of superconductors is the only viable solution despite the high costs. Although in the international market there are many companies engaged in the production of high power cables, there are still few centers in Europe to test them in the presence of magnetic fields. Moreover, there are also companies operating in enabling technologies (cryogenics, vacuum, high power electronics) that could possibly benefit from technology transfer.

**T14**

**Design and state of the art of the large-bore 8T superconducting magnet for the NAFASSY test facility**

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The “NAFASSY” project aims to realize a superconducting facility for testing full-size, wound conductor samples under applied magnetic field, at the University of Salerno. The Nb3Sn solenoid, having a bore of 1150 mm and a height of 1160 mm, will provide a maximum field of 8T close to the magnet inner radius. A rectangular Cable-In-Conduit conductor, designed by ENEA and manufactured by ICAS consortium, will be wound in order to obtain 10 layers and 47 turns/layer. Each pair of layers constitutes a unit length (UL) and the 5 ULs will be connected through 4 joints in shaking-hands configuration, embedded into the magnet, as patented by ENEA. The superconducting magnet will be fed by 20 kA and cooled by forced flow supercritical helium at 7bar and 4.5K. The present work focuses on the detailed design of the magnet that is currently under manufacture. In addition, the simulation of the electromagnetic, structural and thermo-hydraulic aspects, are here reported.

**T15**

**Artificial pinning in LTS by high energy irradiation and by inclusions**

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Artificial pinning can be obtained either by nanosize inclusions or by high energy irradiation. In industrial NbTi wires a strong effect on the critical current density was observed by the normal conducting α precipitations, their width being comparable to the coherence length. In industrial YBCO coated conductor tapes, BaZrO3 nanoparticles produced during the
deposition process have been found to be efficient in enhancing $J_c$ and reducing its anisotropy. Attempts to introduce artificial pinning centers in Nb$_3$Sn or MgB$_2$ by nanoinclusions showed positive effects too, but in contrast to NbTi or coated conductors, the progress was limited and has not been translated into industrial wires. The known data are analysed and discussed.

Artificial pinning centers are also created by high energy irradiation, but in contrast to nanoinclusions, their effects are combined to a decrease of the degree of atomic ordering. The question is studied in view of the Nb$_3$Sn quadrupole magnets in the LHC Upgrade accelerator at CERN, which will be exposed to several kinds of high energy irradiation sources, thus causing a strong effect on their transport properties. The effect of 65 MeV and 24 GeV protons on the critical current density of RRP and PIT Nb$_3$Sn wires is reported. The same Nb$_3$Sn wires were submitted to neutron irradiation in the frame of a collaboration with the ATi in Vienna. The values of $J_c$ were found to increase after both proton and neutron irradiation. Up to the fluence of $1 \times 10^{17}$ p/cm$^2$ reached so far, a sizeable enhancement of $J_c$ was observed, the ratio $J_c/J_{co}$ varying between 1.2 for Ta alloyed and 1.7 for Ti alloyed wires. These data are analysed using the two-component pinning force model recently introduced by T. Baumgartner et al. [1], taking into account the radiation induced nanosize defect clusters - the artificial pinning centers - as point pinning centers. It was found that at the same fluence, the radiation induced contribution to pinning for high energy protons in the above mentioned energy range is almost one order of magnitude above that one of neutrons. The effect of proton irradiation on the upper critical field $B_{c2}$ was also found to be considerably stronger than for neutron irradiation.


**Comparative analysis of vortex pinning and dynamics in oxide, iron-based and MgB$_2$ superconductors**

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Vortex physics has been a topic of interest since the discovery of the oxide high temperature superconductors (HTS). Two different driving forces are behind this interest, on one hand the fascinating new physics and on the other the pursuit of technological uses. The complex vortex phenomena in these materials arise from the strong influence of thermal fluctuations, which is a consequence of the small superconducting coherence length ($\xi$) and the large crystalline anisotropy ($\gamma$). Paradoxically these fluctuations are the main obstacle for applications; moreover the problem is general and will also occur in any new-discovered superconductor operating at high temperatures. The control of vortex matter for performance enhancement requires the design of the pinning landscape by nanoengineering of the material disorder at the scale of $\xi$, a few nm in HTS. Although the HTS vortex behavior contrasts with the simpler physics in conventional superconductors, according to the present understanding there is no sharp boundary between them. However, modern vortex matter models have been developed to describe the oxide HTS, thus it is important to test them in different systems. Our approach is to perform comparative studies on a variety of materials covering a broad spectrum of properties. The new family of iron-based superconductors provides an opportunity to “bridge the gap” and check the validity of vortex models in a new family of materials with broad ranges of $T_c$ and $\gamma$, where the small $\xi$ in some of them results in large fluctuation effects similar to those in the oxide HTS. On the other hand, the multi-band superconductivity in the Fe-based compounds
introduces a new level of complexity, requiring a re-evaluation of the concept of anisotropy in the vortex behavior. Valuable information can also be obtained from MgB$_2$, a chemically simpler two-band superconductor.

**T17**

**Superconductors for Fusion Magnets**

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Nuclear fusion based on the magnetic confinement of a hot deuterium-tritium plasma relies on the use of superconductors for gaining net energy. The magnets in the hitherto largest tokamak, ITER, which is currently built in France, will be based on Nb$_3$Sn and NbTi superconductors. In future fusion machines, however, high temperature superconductors are a promising alternative. The properties of Nb$_3$Sn and coated conductors will be compared in view of the special requirements in fusion magnets. Recent results of neutron irradiation experiments performed on these two materials will be presented.

**T18**

**Manufacturing and properties of round cables from CC tapes**

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Progress in transporting capacity of high-temperature superconductors accompanied by a reduction of cost and increase of the unit conductor length brings us closer to applications of these materials in the field of electric power. Non-existence of a current-carrying element of round shape represents significant obstacle for an easy switch from the existing metal based design and manufacturing procedures to the use of superconductors. We present our activities aimed at preparing of a round superconducting cable from coated conductor tapes. The concept is based on placing several tapes in helicoidal manner on a round former leaving the central bore free. Main advantage is the mechanical flexibility of the resulting current-carrying element of the shape resembling a round wire with diameter below 5 mm. On the other hand, the low fill factor makes it difficult to reach the engineering current density comparable with that one achievable in the Roebel cable or a stack of tapes. Our investigations, both theoretical and experimental, confirmed that the helical cabling pattern is compatible with elimination of coupling currents and losses. This makes such cable a hot candidate for the winding of coils for ramping or AC magnets. Critical review of the results achieved until now and discussion of the problems to be solved is presented.
High current low loss AC cables from HTS coated conductors, the Roebel and Rutherford approach

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Superconducting solutions are of exceptional interest for large machinery as magnets for fusion power plants, generators, motors and magnets including bus bars in the cryogenic systems of particle accelerators. The Roebel assembled coated conductors (RACC) cable design provides full transposition of the strands and is flexible with the design to achieve high current capacity. It allows to take advantage of the current anisotropy in magnetic fields in contrast to many other approaches which gives the opportunity to optimize the engineering current densities in magnet applications. We investigated the behavior of such cables in different configurations, in particular stacked in a pancake arrangement and wound in the form of a solenoid. The cable properties were modeled with a numerical approach, the accuracy with experimental data will be discussed. From the existing data base the potential of RACC cables at lowered temperatures (4-77 K) and high background fields the expected current capacity will be outlined and extrapolated. In comparison to the RACC design, a Rutherford cable structure with RACC strands is a more complicated cable design, provides the integration of a coolant channel and can reach an even larger operation current. In this case the transposition of the strands is averaging out the orientation dependence of the currents in background fields. However the cable fabrication is even more challenging due to the applied bending of the strands. We outline the general hints, present results on the first successful sample with a current of 2.5 kA at 77K and discuss the future prospects of an upgraded design. These 2 cable concepts will finally be discussed in comparison to other approaches as the CORC cable and arrangements on basis of CC stacks, discussing strong and weak properties of the different concepts.

Slotted core HTS Cable-in-Conduit conductor for high current applications

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The ENEA Superconductivity Laboratory has recently developed a full size cable-in-conduit conductor (CICC) based on High Temperature Superconducting (HTS) 2nd Generation (2G) tapes for high field magnet applications as well as for energy transmission. A manufacturing process fully compatible with existing cabling technologies has been developed together with its industrial partner TRATOS Cavi. The considered layout is based on 100 - 150 HTS tapes (depending on tape thickness), arranged as five layered structures wound on a helically slotted core with external round jacket. The cable is wrapped with stainless steel tape and compacted inside an Aluminum jacket, thus fully reproducing the structure of a typical Cable-in-Conduit Conductor (CICC) for fusion applications. As a matter of fact, the
conductor has been designed to target a transport current of 20 kA at 4.2 K and 15 T, corresponding to a $j_c$ of about 55 A/mm$^2$.

Coupled electro-mechanical and thermal behavior of the cable has been studied by developing multi-physical Finite Element COMSOL® Models. A short sub-size conductor sample has been manufactured with both fully superconducting and dummy stainless steel tape stacks. Current test has been carried out at 77 K and self-field, in order to compare the behavior of the full conductor with that of the single wires. Both the experimental and FEM results are discussed in order to emphasize the cable performances and issues to be improved in either cable layout and manufacturing process.

**T21**

**Low Temperature High Field Continuous Measurement of YBCO Coated Conductor**

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Flat, coated conductors (CC) containing a thin film of REBCO, are now commercially available in the length of hundreds of meters, but all such lengths contain a distribution of properties that must be carefully evaluated before use in a superconducting magnet. We have developed a method of continuous measurement of such tapes down to liquid helium (LHe) temperature at 4.2 K. Development of this unique quality control capability was made necessary by the MagLab’s construction of a first-of-a-kind, all-superconducting, 32 T magnet for its user program, a magnet that will increase the magnetic field available to users by superconducting magnets by more than fifty percent.

Continuous transport measurement of $I_c$ in liquid nitrogen (LN$_2$) has been developed by Coulter et al. at LANL, a 10 meter long tape usually being measured in about 6 hours. In order to improve the speed by a factor of 100, remnant field (or magnetization) measurement by a Hall sensor array has additionally been adopted as a supplement and to allow measurement at 4.2 K too where continuous transport measurements is not easily accomplished. In situ comparison of the two methods in a LN$_2$ bath indicates good agreement, given their differing resolutions of 1 mm and 20 mm for magnetization and transport. Earlier studies of ours have suggested that flux pinning above and below about 30 K are different, thus encouraging us to apply the Hall probe at LHe, not just LN$_2$. The tape moves from room temperature to a LHe cryostat, passing through a 15 T magnet and back to room temperature using one Hall sensor array to measure the remnant field profile above the magnet, while a second measures the tape magnetization in full central field. Traces of remnant field taken at 4.2 K at various magnetic fields reveal an evolution of magnetization pattern with increasing magnetic field. Strikingly, at some regions, minima observed at low fields become maxima at higher fields and vice versa. These methods make it possible to separate intrinsic properties like the vortex pinning mechanisms from defects and faults in tape manufacture. Magnetic characterization with Hall sensors is faster and has better spatial resolution but it does not measure absolute $I_c$ value as does the transport method, making both methods valuable in assessing the suitability of coated conductors for magnet construction.

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Superconducting magnetic energy storage systems

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Fast-response and long life cycle energy storage systems are a game-changing technology for integrating renewable energy into power grids in a more flexible way and reducing its cost. Due to the large variation in renewable generation, an energy storage system is required to have a large power density and respond quickly to power fluctuations on a short time scale of seconds to minutes. Additionally, an energy storage system needs to have a large energy density in order to deal with power imbalances on a longer term basis. Although the electrochemical batteries usually have large energy densities, their power density, life cycle and response speed are very limited. Therefore they cannot address the challenges of balancing frequent power fluctuations on short time scales of seconds. Even if so used, their life will be significantly reduced and hence result in significant increase of operating cost.

SMES systems have a large power density, large duty cycles and a fast response speed. Compared to flywheels and supercapacitors, SMES systems have a significantly larger power density, module power ratings. In addition, they also have advantages including a high round-trip efficiency and solid-state operation. Thus SMES systems can be used together with electrochemical batteries as a hybrid energy storage device.

In this presentation a hybrid energy storage system using Superconducting Magnetic Energy System (SMES) and Li-ion battery is proposed. The SMES is designed using Yttrium Barium Copper Oxide (YBCO) tapes which stores 60kJ electrical energy. The magnet component of the SMES is designed using global optimization algorithm. Mechanical stress, coupled with electromagnetic field, is calculated using COMSOL and Matlab. A cooling system is presented and a suitable refrigerator is chosen to maintain a cold working temperature taking into account four heat sources. Then a micro-grid system of Direct Drive Linear Wave Energy Converters (DDLWECs) is designed. The interface circuit connecting the generator and storage system is given. The result reveals that the fluctuated power from DDLWECs is balanced by the hybrid energy storage system. The maximum power of wave energy converter is 10 kW.

Energy transfer with hydrogen and superconductivity – the idea and review of the first experimental results

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The transfer of massive amounts of both electrical and chemical power over long distances will present a major challenge for the global energy enterprise in future. Attraction of hydrogen is apparent as a chemical energy agent, possessing among the highest energy density content of various common fuels, whose combustive “waste” is simply water. The usage of “gratis” cold to cool a superconducting cable made of proper superconductor
permits to deliver extra electrical power with the same line. This, rather old theoretical idea recently found its experimental realization. The team of Russian institutes and organizations with using Italian-produced MgB$_2$ wire has made and successfully tested two hybrid energy transfer lines with liquid hydrogen as a chemical source of power and superconducting cable as a source of electricity.

The first line has been tested in 2011. It has length $\sim$10 m, maximum hydrogen power flow $\sim$31 MW and maximum current of MgB$_2$ superconducting cable 2600 A @ 20K. This test was the first experimental proof of conception of the hybrid energy transfer line [1].

The second line has been tested in October 2013. It has length $\sim$30 m. The new MgB$_2$ cable has critical current @ 21 K $\sim$3500 A and successfully passed high voltage DC test of 50 kV. New hydrogen cryostat has three sections with different types of thermal insulation in each section: simple vacuum superinsulation, vacuum superinsulation with liquid nitrogen precooling and active evaporating cryostatting system. In the later section the heat transfer from room temperature to the main hydrogen flow has been practically eliminated.

The idea of hybrid energy transfer is discussed and details of first experiments are reviewed.


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**Advances in solution derived YBa$_2$Cu$_3$O$_7$ coated conductors**

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Achieving high current superconducting wires for large scale applications has been one of the most challenging objectives during all the HTS era. Extraordinary new ideas and materials developments have been demonstrated and second generation YBa$_2$Cu$_3$O$_7$ conductors (coated conductors, CCs) have emerged as the most attractive opportunity to reduce the cost/performance ratio down to the levels required for energy applications. Chemical solution deposition (CSD) has become a very competitive cost-effective technique to obtain nanostructured films and CCs. The development of high performance superconductors and high production throughputs requires, however, a full understanding of the different steps included in the Trifluoroacetate (TFA) or F-free (FF) processes, particularly the crystalline transformation to the superconducting phase and the oxygenation process. On the other hand, vortex pinning landscape engineering is foreseen as the route to high performance YBCO CCs at high fields. In solution-derived nanocomposites this is achieved generating randomly oriented second phase nanoparticles which induce huge isotropic pinning forces.

In this presentation I will report on our recent advances concerning the analysis of advanced CSD processing methodologies of YBCO films grown on different sorts of cap layers based on YSZ-ABAD metallic substrates. We have particularly used Ink Jet Printing as a practical approach for continuous reel-to-reel solution deposition and in-situ resistance measurements to investigate the influence of several processing parameters on nucleation.
growth and oxygenation of YBCO thin films and CCs. Highly textured YBCO films have been obtained on Ce$_{0.9}$Zr$_{0.1}$O$_2$ (CZO) buffered ABADYSZ/SS substrates. Finally, we will report as well on different YBCO nanocomposite processing approaches including BaZrO$_3$, Y$_2$O$_3$, BaCeO$_3$ or Ba$_2$(Ta,Y)$_2$O$_6$ as second phase nanoparticles. A highly effective novel pinning mechanism, coupling superconducting pairing to lattice strain is proposed. The nanoscale strain is evaluated from X-ray diffraction line broadening while HRTEM and STEM investigation evidences a ramified shape of inhomogeneously distributed nanostrained regions.

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**Application based aspects of Fe-pnictide superconductors**

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After several years of intense research of the Fe-based superconductor family, especially with regard to basic properties, several lessons can be learned to estimate their potential towards power, magnet or electronic applications. In this talk I will discuss these issues based on experiments using epitaxially grown thin films and heterostructures of the various families of Fe-based superconductors, as well as based on the actual status of Fe-based superconducting wire synthesis. This will include a short overview of the current status of thin film and wire synthesis of Fe-based superconductors, key experiments for evaluation of their basic physical properties, realized conductor architectures and potential applications. Critical aspects towards the realization of Fe-based superconductor applications include not only the critical current density, anisotropy, pinning and in-field properties of the different Fe-based superconductors, but also their grain boundary properties, available conductor and film synthesis technologies and their upscaling potential and specific conductor aspects like mechanical properties. I will discuss these aspects for the different Fe-based superconductors and try to draw a rough picture for the coming path towards potential applications of Fe-based superconductors.

**Aspects on Applications in Confined Power Grids based on HTS**

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Following the discovery of HTS materials, Scientists and Researchers developed “powder-in-tube” processes to produce industrial lengths of HTS wires of the so-called “1st generation type” HTS – or in short the 1G-HTS based on a BiSrCaCuO-compound. The first demonstrators of HTS in Power Technology were built in the late 90’s of the last century using 1G-HTS: power transmission lines, transformers, fault current limiters, motors/ generators, SMES and current leads. From the beginning of the new millennium on, researchers succeeded in preparing the so-called “2nd generation type” HTS – or in short the 2G-HTS based on a REBaCuO-
compound by layer deposition processes quite similar to the processes used in the semiconductor industries. This was a landmark as from that point on there was a clear improvement in performance/price ratio of the material.

From the viewpoint of a scientist in physics, HTS is an amazing material: the long length wires are a macroscopic proof of a nanoscale quantum phenomenon. For the eyes of an engineer in Power Technology, the HTS offer three appealing main benefits:

- HTS are able to carry extremely high currents in tiny cross sections
- HTS will not produce ohmic losses/heat
- HTS exhibit these outstanding properties even at high magnetic fields and “elevated” temperatures (“low” temperatures like liquid air, but “high” temperatures in terms of cryogenics and physics – easy to achieve with small technical effort)

These properties are enablers not only to build extremely compact power equipment. In addition cooling efforts and technology hurdles are reduced (consider that the biggest part of IP in power technology is related to get rid of the ohmic heat of the equipment). The third benefit mentioned above is perhaps not so evident, but due to the high magnetic field tolerance of the HTS (much higher than e.g. saturated iron) the design of compact, lightweight and efficient power equipment with improved dynamic behavior is possible.

In densely populated areas and Megacities the supply of heat, cold and electricity is frequently managed by district centers of high power density. When co-generation is considered and the equipment is to be included into a building rather than into a dedicated large area power plant site size and weight of the components come into play – in addition to the efficiency requirements. In this situation the use of HTS technology might be of considerable benefit as actually it is attractive for machines and devices in the power rating range of about 1...1000 MVA (or MW).

In this contribution we pick some applications along the flow of energy and perform a deep dive to elaborate on the specific benefits.

We comment on the implications of using 1G or 2G HTS.

Finally, we will outline the requirements to have HTS technology becoming a successful element of the product portfolio in power technology.

Current Developments of LTS Cable-in-Conduit Conductors for the DEMO nuclear fusion power plant

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The efforts for the development of nuclear fusion as a valuable energy source are mainly concentrated worldwide on the ITER project, currently in construction phase in France. The superconducting magnets, that represent a key-technology in the ITER tokamak, are wound by low temperature superconductor (LTS) Cable-in-Conduit conductors (CICC). The construction of ITER will represent the fundamental milestone for nuclear fusion development, but the availability of a commercial power plant will require further technology advancements, to be implemented in a Demonstration Power Plant, DEMO. Whereas ITER is a common project, different DEMO design choices are being pursued for example within Europe, Japan, or Korea. Depending on the chosen reference electromagnetic scenario and machine geometrical characteristics, different operating conditions at the level of the superconductor are foreseen. However, in most cases the required performances exceed those of ITER, thus requiring challenging technological developments for coils and conductors. As far as the European DEMO is concerned, the presently developed conceptual design of the Toroidal Field (TF) coil requires conductors...
operating at currents as high as 82.4 kA, in peak magnetic field larger than 13 T. A layered magnet structure is being considered, with a graded and hybrid structure: 6 Double Layers (DLs) being constituted by Nb$_3$Sn CICCs, 3 DLs being constituted by NbTi ones. In fact, in spite of the fact that design solutions based on High Temperature Superconductors are being developed, the magnets of DEMO will most probably rely on LTS materials. Two different conductor design concepts are being proposed and evaluated for the DEMO TF conductor, either based on a React & Wind flat cable, or on a Wind & React rectangular conductor. In the present paper, the layout of the conductors is illustrated in detail, and the main results of the supporting electromagnetic, thermo-hydraulic and mechanical analyses are reported. At present, the manufacture of prototype samples is foreseen, to be tested in the course of 2015, with the aim of demonstrating the proposed technological approach for the design and manufacture of superconducting CICCs.

**Properties and potential of 2G HTS tapes with ISD buffer layer**

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Several different approaches for the fabrication of coated conductors were developed during the last years. One route to produce second generation coated conductors is by using inclined substrate deposition (ISD) and reactive evaporation of the superconductor. Based on this technology, we developed an all-PVE approach for buffer layers, HTS, and silver coating.

We report on recent progress towards high current carrying capacity using this technique. Optimized ISD buffer layers were used to prepare highly textured DyBaCuO thin films with in plane orientation of 5°- 6° FWHM. Even the thick films showed a homogeneous density of precipitates over the whole thickness and no accumulation of defects. An explanation for this unique feature of superconductor films on ISD buffer layers is given. Due to the homogeneity the $j_c$ is not depending on the thickness and high $j_c$ of 2 MA/cm$^2$ could be obtained in thick films. Critical currents exceed 1000 A/cm$^2$-with in the thick films. To improve the magnetic field performance the influence of doping by Zr was analyzed. TEM revealed BaZrO$_3$ nanoparticles but no nanorods in our HTS films. A decrease of the $j_c$-anisotropy was measured.

**Progress in the industrialization of MgB$_2$ superconducting wires**


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The manufacturing of MgB$_2$ superconducting wires through the ex-situ process has been implemented in a new production line with very high throughput for an HTS material. The ex-situ route, although more complex and delicate than the in-situ one, has been selected for the scaling-up to large manufacturing volumes because of the higher homogeneity of the wire performance along its length, as well as the higher n-value and better mechanical properties. The MgB$_2$ filament density larger than 80% guarantees a more uniform current flow than with the in-situ, in which the filament mass density is typically below 50%. A significant effort has been devoted in strongly reducing microstructural defects and
inhomogeneities that may cause local fluctuations of the critical current over very long lengths. New in-line technologies for MgB\textsubscript{2} wires have been implemented in order to increase the reliability of long length conductors, as eddy currents defect inspection. The good chemical and mechanical compatibility of MgB\textsubscript{2} with a number of pure elements and alloys has allowed us to develop and produce multi-Km long wires with various filament architectures, matching the requirements of very different applications, as MRI magnets, rotating machines, induction heaters, fault current limiters and cables.

\textit{T30}

\textbf{2G HTS tapes for power applications}

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The SuperOx group of companies manufactures and markets 2G HTS tapes for various power applications. SuperOx (Moscow, Russia) and SuperOx-Japan LLC (Tokyo) combine a unique portfolio of expertise in chemical and physical deposition techniques and work together to deliver 2G tapes based on the IBAD-MgO/PLD-GdBCO core technologies and strong, nonmagnetic Hastelloy substrate.

At present, standard tapes delivered to customers have single piece length of 100 m and critical current at 77 K, self-field exceeding 300 A/12 mm-width and 100 A/4 mm-width. Longer lengths and higher currents are also available, concurrent with the continuous and rapid improvement in all manufacturing processes.

Along with the world competitive quality, SuperOx’s differentiating point is the deep customisation of 2G HTS tape, in order to meet the specific needs of various HTS device applications. In particular, customisation options include on-demand thickness of silver and copper coatings, surround polyimide insulation as an alternative to Kapton wrapping, low resistance soldered joints, and solder plating of continuous lengths of tape.

SuperOx has been supplying tapes to a number of projects, both in Russia and worldwide, aimed at making various HTS devices for power applications including HTS cables of various designs, FCL, SMES, motors, maglev systems, current leads, and magnets.

We will present characterisation results of SuperOx 2G HTS tapes measured by independent laboratories, as well as by SuperOx.
Development of Compact High Field Superconducting Magnets for Research Applications

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Recent advances in superconducting and cryogenic technology combined with increased demand for superconducting magnets for research applications at high field (HF) are enabling the development of new generation of compact HF magnets. Compact HF magnets will require enhanced performance of low temperature superconductors (LTS) materials and innovative coil structure solutions and effective magnet quench management. This paper presents an update on the development of a new generation of HF magnets including wide bore ones for research and industry. In particular the emphasis is on coil technology and the dependence of coils on the performance of superconducting materials at high field. Recent advances in internal Sn superconductors have opened up a new era in superconducting magnet technology. New LTS outsert magnets are undergoing development enabling high field magnets greater than 22T using high temperature superconductors (HTS). The new magnets are compact in size with enhanced access bore.

An enemy of Superconductivity: the sailing-ship effect

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Since superconductivity was discovered, a bit more than a hundred years ago, many expectations on its use have emerged. The technology has experienced many improvements in terms of the quality and quantity of materials and compounds which can be superconductors, as well as in terms of higher temperatures which allow superconductivity to occur. Many applications have been attempted, from magnetic levitation trains to cryogenic cables. Many revolutions have been announced, one being, for instance, “superconducting lines for the transmission of large amounts of electrical power over great distances” (which is the title of a famous paper published in 1967 by Garwin and Matisoo) with an efficiency close to 100%. The superconducting electrical power line with low Tc superconductors was a technological possibility that did not attract much funding in order to put it into practice. Instead, a revolution which got very close to become a reality was that of superconducting computers. IBM spent huge human and financial resources between 1965 and 1983 trying to build a “Josephson computer”. The coming revolution was announced in 1980 with two different publications, one for the experts (a special issue of the IBM journal of research and development), and one for the wider public (in Scientific American). However, despite significant progress, the project was dropped; the incumbent semiconductor technology, despite being inferior from the point of view of performance, was being incessantly developed, thus partly displacing the new technology. The response of an old technology to a new one is a phenomenon which has been observed in quite a few cases, and is referred to as the “sailing-ship effect” – named after
the battle between the old canvas and the new steam-engines to provide propulsion for ships. Such an effect describes the dynamic interactions between different technologies, and is thus a further (and not-so-often considered) mechanism that prevents technological superiority from implying economic viability in the short term.

In this paper we present the idea of the sailing-ship effect in mathematical form (De Liso and Filatrella 2008, 2009, 2011) and provide a simplified version of the model, linking the model to the actual case of superconducting technology. The mathematical formulation of the model contains both technical characteristics (e.g., the maximum performances compatible with the physics law) and economic factors (e.g., interest rates). The analysis of the model suggests that a sailing-ship effect has displaced the superconducting technology in the case of computers and, possibly, in large power applications, while it confirms that superconductivity is well placed to play a key role in the high magnetic field market. We finally discuss some technical factors that should be considered to foresee the success of applications.


T33

Can we realize strongly connected, self-organized grain-boundaries in high performance MgB$_2$ bulks and wires?

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Metallic HTS MgB$_2$ is one of the most promising superconductors for power and magnet applications. Unlike other HTS, polycrystalline MgB$_2$ does not exhibit intrinsic weak-link behavior at grain-boundaries [1], however it is widely known that effective cross-sectional area for transport current (connectivity) is suppressed to ~10% by extrinsic structural defects. Early studies have shown that packing factor and microscopic intergranular coupling are the key factors to improve connectivity and $J_c$ [2]. An ex-situ method which uses prereacted MgB$_2$ powder is favorable in terms of principally high packing factor >70% compared to other methods. However the weak intergranular coupling has been the issue for the ex-situ method presumably because compacted polycrystalline MgB$_2$ is hard to sinter at typical heat-treatment temperatures 600-900°C. If strongly connected and densely packed grain-boundaries can be realized in a way similar to self-assembling during heat-treatment, $J_c$ can be largely enhanced owing to high connectivity and dense flux pinning centers. In the present study, artificial promotion of self-sintering was studied to clarify the factors associated with higher intergranular connectivity in ex-situ MgB$_2$ bulks and wires. Starting MgB$_2$ powders with different magnesium precursor powder size and carbon additive in the form of B$_4$C powder were prepared and used to synthesize sintered MgB$_2$ samples to investigate the influences of interface impurities and intragrain lattice defects on self-sintering of MgB$_2$. Laboratory-made high purity MgB$_2$ powder with less oxidized surface and carbon-substituted MgB$_2$ powder were effective to stimulate self-sintering at 900°C by
increasing the specific surface area and enhancing the driving force of mass transfer. Microstructural analyses showed that ex-situ MgB$_2$ samples synthesized from such pretreated powders demonstrated increased sintered grain boundary area with the evolution of intergrain necks. Record high connectivity over 35%, which is among the highest in pressureless MgB$_2$ samples, was achieved by a sintering period of 24 h [3], which is one-fourth of our conventional sintering time [4,5]. On the other hand, MgB$_2$ grains rather maintained their small initial grain size during the high-temperature processing. As a consequent, high engineering $J_c$ exceeding 10 kA/cm$^2$ at 20 K under 3 T was obtained for wires owing to the self-organized strong inter-grain coupling and small grain size, i.e. dense and coherent grain boundaries. Our results show that self-sintering is a simple but strongly effective way to extract the superior current carrying potential of high bulk density ex-situ MgB$_2$ bulks and wires.


Towards the applications of high stresses and pressure to high $J_c$ in wires, tapes and thin layers superconductors technology in practice

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The application of high stress in ceramic superconducting materials is one of the most explored methods for the densifications. The high pressures are not only used in densifications but also to some technological processes of formation of the special shapes and instant densification e.g. extrusion processes- especially in primary geometrical formations. The cold pressing (CP) or cold isostatic pressing (CIP) is mostly used for high inter grains densification. For commercial HyperTech Inc. wires buy use of high pressure of 1.0 GPa gas HIP process, the highest $J_c$ in pure and SiC doped MgB$_2$ wires were found. Higher $J_c$ in BISCO and NbTi wires was found as well. The presented HIP process densifies the superconducting core, improves grain connectivity and provides positive modification of reaction dynamics due to an increase of magnesium melt temperature. It was also shown; that HIP can be applied to coils of small diameter, as low as 12 mm, with only small decreases in $J_c$. The HIP processes for large production scale is presented.

Pressure is also used to change the phase equilibrium, melting temperatures, assurance of the neutral atmosphere, equilibration of the vapor pressure level, changing the kinetic of the phase formations. For cleaning and milling processes of materials, the liquid phase epitaxy or just simply the high gas vapor condensation and growth of the layers on the specific substrates. For the growth processes the high purity neutral gas/medium pressure
uses is essential. This growth processes benefit additionally in some kind of new method of isolating of the high purity volume system, which in consequences give the possibility in growth of pure crystals of e.g. Hg and Tl family of the superconductor as well as new FeSe or FeSeTe or even FeAs family superconducting materials. The High Gas Pressure Trap System (HGPTS) was used for crystal growth with or without the additional flux. The thin films have been obtained by the epitaxial process performed on LaAlO$_3$, SrTiO$_3$ or Al$_2$O$_3$. Thin layers have been manufactured by the mixed procedures with use of DC sputtering on the substrate from the in situ and ex situ targets. After obtaining thin layers on LaAlO$_3$ substrates were annealed under equilibrium Se vapors pressures obtained by use of HGPTS. The similar system was earlier used by us for the Hg and Tl family of superconductors. The FeSe$_{0.88}$ bulk material has $T_c$ from 8 to 12 K, some especially quenched layers had $T_c$ over 80 K with indication of the higher possible $T_c$ around 100 K. All samples were synthesized at high Se vapor pressure at equilibrium pressure and temperature conditions.

The uses of HGPTS assure full separation of the active volume for synthesis or crystal growth of material and the inert gas medium. The material has been investigated by SEM, EDX, XRD, magnetic susceptibility measurements and resistivity by four points method.

**T35**

**Groove-rolling as an alternative process to fabricate Bi-2212 wires for practical applications**

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In large scale applications of superconductivity, research and technology development are strongly focused on material optimizations on conductor forms which can satisfy high magnetic field applications, which are widespread in physics, chemistry and biology research, for example accelerator dipoles and NMR magnets. In this scenario round wires made of multifilamentary Bi$_2$Sr$_2$CaCu$_2$O$_x$ (Bi-2212) could make a good alternative conductor for high field magnet applications. However Bi$_2$Sr$_2$CaCu$_2$O$_{8+x}$ (Bi-2212) superconducting long-length wires are mainly limited in obtaining high critical currents densities ($J_c$) by the internal gas pressure generated during the heat treatment, which expands the wire diameter and dedensifies the superconducting filaments. Different routes have been proposed to increase the density of the Bi-2212 filaments and therefore diminish the bubble density and / or size and as a consequence increase the critical current along the conductor. All of them act on the final as-drawn wire: $J_c$ was doubled through the use of a 2 GPa cold isostatic pressure (CIPping) and through swaging after drawing, while very high (up to 100 bar) over pressure (OP) applied during heat treatment was able to generate an eight-fold increase in the engineering critical current density $J_E$ in wires with densities higher than 95%. All the described approaches, though reaching extremely appealing $J_c$ values, might not be as simple and straightforward over long lengths and coils. We here try to pursue the same goal of having a denser wire by acting on the deformation technique, through a partial use of the groove-rolling at different working stages. Such technique has a larger powders compaction power, is straightforwardly adaptable to long length samples, and allows the fabrication of samples with round, square or rectangular shape depending on the application requirements. Here, through a comparison between the critical current densities measured in open- and closed-ends samples, we demonstrate the capability of this alternative deformation process of increasing the density in Bi-2212 wires. This leads to a three-fold increase in $J_c$ with respect to drawn wires, making this approach very promising.
for fabricating Bi-2212 wires for high magnetic field magnets, i.e. above 25 T. The electromechanical characterization of a new rectangular wire, even at temperature around 10K (achievable by commercial cryocooler and thus even more appealing for industrial applications) is shown as well.

**T36**

**High currents MgB\textsubscript{2} superconductors aimed for low external fields and mass-limited applications**

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MgB\textsubscript{2} superconducting compound is a light and cheap material promising for application in superconducting cables and windings. Applicable MgB\textsubscript{2} wires are made in the form of filamentary composite structures containing superconducting filaments surrounded by metallic barriers protecting the MgB\textsubscript{2} from well conductive metallic stabilization. Recently, MgB\textsubscript{2} superconducting wires and cables were made by using of Mg, Ti and Al components, which offer light and high current density conductors. Low temperature measurements have shown that high critical current densities can be obtained if Al-stabilization is protected against the interdiffusion with Ti. Bending stress applied to Rutherford MgB\textsubscript{2} cable has shown the critical current degradation below 35 mm, what suggests using it for small-scale windings and applications where low bending diameters are required (e.g. multi-pole generators). These MgB\textsubscript{2} conductors can be attractive also for the applications, where the total mass should be limited as much as possible (e.g. offshore wind turbines).

**T37**

**Magnetic field mitigation by superconducting and hybrid shields**

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The answer to the always increasing problems of electromagnetic compatibility makes necessary the development of more and more efficient magnetic shielding solutions. This includes both the mitigation of the magnetic field produced by high-field devices and the protection of sensitive detectors as well as the reduction of possible health hazards. At this respect, the use of superconducting (SC) and ferromagnetic (FM) materials both separately and in hybrid configurations have brought significant results with respect to the shielding of quasi-static magnetic fields [1-5].

In this framework we investigated both experimentally and numerically the efficiency of superconducting (MgB\textsubscript{2}) and hybrid (MgB\textsubscript{2}/Fe) systems for magnetic field mitigation. We considered two geometries: disks and cups, both subjected to a uniform external magnetic field parallel to its axis. Shielding capability was measured as a function of temperature, external magnetic field, position and time by means of cryogenic Hall probes mounted on a custom-designed stage, moveable along the sample axis with micrometric resolution.
Hybrid systems result the most efficient solutions at higher magnetic field, where the SC/FM coaxial cups allow obtaining a shielding efficiency 3-4 times higher than that measured with a single superconducting cup [5], coupled with a reduction of the flux creep phenomena [6]. On the contrary, at low field, the superconducting solution is the most efficient [5]. Starting from these experimental results numerical simulations were performed using a finite element software on these disk/cup systems in order to further improve their shielding efficiency. In particular, a simple approach based on the London equations was developed [7], which results exploitable to optimize the shape of the superconducting shield also above the lower critical field, provided that the penetration of the flux lines inside the sample contributes weakly to the field values outside the superconductor itself.


T38

A simple analytical method for the calculation of the force between a magnet and a bulk superconductor

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In the design of magnetic bearings including high T\(_c\) superconductors, as well as in MagLev systems [1], the objective is to increase the force acting between magnets and superconductors. A possibility is to drop the use of liquid nitrogen at 77K and to cool down the superconductors at a lower temperature. Since the superconducting critical current density increases strongly as the temperature decreases, an improvement of the interacting force is expected. It is however essential to determine what gain in force can be expected in order to make the balance between this gain and the additional cooling costs. As a general rule, the calculation of the levitation force is done using numerical techniques [2,3]. The great advantage of these techniques is that they permit one to determine the force acting on the superconductors, if the distribution in space of the field generated by the magnets is known. Their disadvantage is that their implementation can be hard work.

What we intend to show in this contribution is that we can obtain a good insight of the behavior of the levitation force as a function of the critical current density using an analytical expression proposed by E.H.Brandt [4] for the magnetic moment generated in a superconducting disk by a perpendicular field. We show firstly that it is possible to reproduce force measurements carried out on various YBCO samples at 77K in the vicinity of a magnet after field cooling, both when the magnet-superconductor separation is decreased and when it is subsequently increased. Then, we calculate the force that can be expected by the modulation of the critical current density of these samples. As predicted by Sanchez [5], the force tends towards a maximum value. For YBCO samples, the calculated maxima are less than twice the force measured at 77K and show a very good agreement with the results of measurements carried out at low temperature in a cryo-cooler. As a conclusion, we show the results of measurements and calculations carried out when the magnet is replaced by a section of a MagLev magnetic guideway.

Pinning mechanism in electron-doped HTS \( \text{Nd}_{1.85}\text{Ce}_{0.15}\text{CuO}_4\) thin films

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The electrical transport properties of c-axis oriented superconducting \( \text{Nd}_{1.85}\text{Ce}_{0.15}\text{CuO}_4\) films have been investigated in order to analyse the pinning mechanism in this material. The samples were grown on \( \text{SrTiO}_3\) substrates by dc sputtering high pressure technique, whereas a detailed analysis of the structure and local composition of the films has been achieved by high-resolution electron microscopy and X-ray microanalysis. Magneto-resistance and current-voltage measurements, in the temperature range from 1.6 K to 300 K and in magnetic field up to 9T, have been reported. In particular the anisotropic coefficient \( \gamma \) defined as the ratio between the parallel upper critical field \( H_{c2||} \) and the perpendicular one \( H_{c2\perp} \) has been evaluated, pointing out the high anisotropy feature of this compound. Critical current density and depairing current have also measured giving a ratio \( J_d/J_c \) around 15, comparable with other high temperature superconducting materials. Finally, the vortex activation energy as a function of the applied magnetic field, parallel and perpendicular to the \( \text{CuO}_2 \) planes, has been derived and compared with the flux-pinning forces in order to enlighten the peculiar nature of pinning centres in this material.

Shear stress evaluation in the wrap insulation of a high field superconducting magnet

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High-field superconducting solenoids are widely used in scientific research in a large number of fields, such as physics, medicine, biology and chemistry. Magnet systems are the last effective technology for magnetic confinement fusion devices, with the possibility to realize high magnetic fields. Almost all design concepts for power producing commercial fusion reactors rely on superconducting magnets for efficient and reliable production of these magnetic fields. Future superconducting magnets for these applications require improvements in components, materials and configurations to significantly develop the possibility and practicality of fusion reactors as an energy source. The structural integrity of the superconducting cable insulation is one of the major task to improve in the design of high-field superconducting magnets protection systems. The correct evaluation of the local stress field of the insulator material is of particular importance mainly when the geometrical magnet’s configuration is complex, according to the
technological manufacturing process. Moreover, the insulation integrity under high mechanical stress is essential for high field magnets with high Lorentz forces at cryogenic temperatures.

In this paper the operating behaviour of a wrapped cable insulator is investigated. In particular, the field of the shear stresses on the adhesive interface of adjacent turns is calculated in order to design the type and the location of a proper external structural constraint. Numerical coupled field simulations are performed using the Finite Method Element (FEM) code ANSYS.

In particular, the results of coupled magnetic-structural analyses on a superconducting magnet with 10 layers and 47 coils, supplied with an operating current of 20 kA are reported. The Nb3Sn superconducting cable is inserted inside a steel (AISI 316 LN) jacket with a thickness of 2.1 mm and is wrapped with a G10 insulator cable. The research leading to these results has received funding from the Italian Research Program “PON Ricerca e Competitività 2007-2013” under grant agreement PON NAFASSY, PONA3_00007.


T41

High pinning energies in the iron-based superconductors: thin films, bulks and single crystals

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We study the pinning properties in iron-based superconducting samples realized in the forms of thin films, bulks and single crystals in order to obtain information useful to the optimization of the fabrication processes, which is the first step for producing tapes and cables for practical high power conductors. By current-voltage characterizations and magneto-resistance measurements, we investigate flux pinning mechanisms in epitaxial thin films grown on different substrates. In particular, from the Arrhenius plots in the magnetic fields up to 9 T, the activation energy is derived as a function of magnetic field and current density, $U(H, J)$. A comparative analysis has been carried out on iron-based bulk samples and single crystals, thus enlightening that the high pinning energies and the low magnetic field anisotropies can allow iron-based materials to be competitors of actual superconductors in high current superconducting applications.
Superconducting Electronics: Solving Energy Problem in High-End Computing

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The explosive growth of the Internet transformed data centers into large industrial scale computer facilities with extraordinarily high energy demands. From Google and Facebook to banking, cloud computing and supercomputing, an average data center already use as much electricity as a medium-size town. Energy considerations are forcing construction of new data centers in areas where climate helps cooling and electricity is cheaper. Besides just high energy costs, there is a compelling technical reason to improve energy efficiency of computing technologies. The development of the next generations of high-end computers will not be possible unless a significant improvement in energy efficiency is achieved over the technology available today. The heart of the problem is in a relatively low energy-efficiency of current computer circuit technologies consuming too much energy for computing, storing and moving data between processors and memories. This is the reason that energy efficiency rather than switching speed or circuit area has now become the dominant metric dictating the course of the future technology development. Superconducting single flux quantum circuits by virtue of their inherent low power dissipation, high speed, lossless interconnect present an excellent opportunity to dramatically increase energy efficiency of high-end computing applications impacting energy-efficiency of data centers and enabling new generations of supercomputers. I will review several key innovations happened just within last few years which dramatically increased a potential of superconductivity addressing known critical problems which prevented the use of superconductivity in high-end computing in the past.

Strong vortex matching effects in YBCO films with artificial defects fabricated by masked ion irradiation

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We investigate a convenient route to periodically modulate the superconducting order parameter in order to enable enhanced vortex pinning. He+ ion irradiation is directed towards the surface of a thin YBCO film on MgO substrate and a particular pattern created by shadow projection through a Si stencil mask. In the application discussed here, a square array of nonsuperconducting cylinders (antidots) was created within the YBCO film. Distinct peaks of the critical current can be observed when the density of magnetic flux quanta matches the antidot density or multiples thereof. It will be shown that the high density of intrinsic pinning defects in typical YBCO films require artificial defect lattices with a spacing well below 1 µm to achieve a pronounced vortex matching signature.
Pinning Performance of Nanostructured YBa$_2$Cu$_3$O$_x$ Films Added With Artificial Pinning Centers of Different Dimensionality

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In order to be disclosed to the practical applications (lossless current transportation, winding of magnets and so on), superconducting materials should possess not only $T_c$, but also $J_c$ (critical current density) and pinning force ($F_p$) as large as possible to have a wide application range. Introduction of nanosized Artificial Pinning Centers (APCs) was widely used to strongly enhance $J_c$ and $F_p$ of High Temperature Superconductors (HTSC) like YBa$_2$Cu$_3$O$_x$ (YBCO, $T_c$ = 92 K) in magnetic field.

At first, we considered addition of BaSnO$_3$ (BSO) to YBCO films grown on SrTiO$_3$ substrates by Pulsed Laser Deposition (PLD). By ablation of mixed BSO-YBCO targets with increasing BSO content (2–9 wt%), we obtained high quality YBCO thin films incorporating BSO in form of nanorods, which are classified as one-dimensional APCs (1D-APCs). YBCO films added with 4 wt% BSO have $J_c$ = 0.3 MA/cm$^2$ and $F_{p,\text{MAX}}$ = 28.3 GN/m$^3$ (77K, 3T, B//c). However, $J_c$ is intrinsically anisotropic with the direction of applied magnetic field (with a maximum for B//c axis) and this is a critical issue for practical applications, since the value of $J_c$ might be constant in all directions of applied magnetic field.

To solve this issue, we tried the incorporation of Y$_2$O$_3$ nanoparticles (three-dimensional APCs, 3D-APCs) inside the YBCO film, using surface-modified YBCO targets. Areas of Y$_2$O$_3$ sectors on YBCO target were increased (2.51%, 5.44% and 9.22% of the YBCO pellet area). Randomly distributed Y$_2$O$_3$ particles, which density was proportional to the area of sector, were incorporated in YBCO films. Consistently with the microstructure, $J_c$ was isotropic. The 5.44 A% Y$_2$O$_3$ added sample presented $F_{p,\text{MAX}}$ = 14.3 GN/m$^3$ (77K, 3T, B//c)) which is significantly large, tough inferior to the value reported in YBCO-BSO films in same conditions.

Ultimate approach we tried was combination of advantages of 1D- and 3D-APCs pinning, incorporating BSO nanorods and Y$_2$O$_3$ nanoparticles at the same time. Multilayered films, alternating YBCO+Y$_2$O$_3$ and YBCO+BSO layers were prepared in PLD chamber by switching surface-modified YBCO+ ~2A% Y$_2$O$_3$ target and mixed YBCO+ 4wt% BSO target. Different combinations, varying the thickness of layers, were tried. Best result was obtained with the combination [(90 nm YBCO+BSO)/(30 nm YBCO+Y$_2$O$_3$)] × 3 presenting $F_{p,\text{MAX}}$ = 17.6 GN/m$^3$ (77K, 2.2T, B//c). Significantly, the pinning performance of 1D+3D-APCs multilayer lies between 1D-APCs and 3D-APCs YBCO films.
High-field transport properties of P-doped BaFe$_2$As$_2$

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Electron or hole doped BaFe$_2$As$_2$ (Ba-122) is one of the promising candidates for pnictide coated conductor applications thanks to high upper critical field with its low anisotropy at low temperatures$^1$ and robust critical current density ($J_c$) across grain boundaries (GBs)$^2$. Additionally, Ba-122 system showed less deteriorating transition temperature ($T_c$) even with a high density of secondary phases$^3$$^4$, which leads to achieving desired $J_c$ for applications (i.e., isotropic $J_c$ against fields and their orientation). Among the Ba-122 families, isovalently P-doped Ba-122 is the second highest $T_c$, and readily fabricated by both pulsed laser deposition (PLD)$^5$ and molecular beam epitaxy (MBE)$^6$. Furthermore a high $J_c$ of around 1 MA/cm$^2$ even at a large GB angle of 24° and 4 K$^6$. However, in-field transport properties of P-doped Ba-122 especially in high fields have not been reported. Here we report on in-field transport properties up to dc 35 T of P-doped Ba-122 epitaxial thin film by MBE. The single crystalline film with $T_c$ of 30 K showed a high $J_c$ over 10$^4$ A/cm$^2$ even for $H \parallel c$ at 35 T and 4.2 K. We will also report on structural and transport properties of P-doped Ba-122 on ion beam assisted deposition (IBAD) MgO coated conductor templates.

The research leading to these results has received funding from European Union’s Seventh Framework Programme (FP7/2007-2013) under grant agreement number 283141 (IRON-SEA). A portion of this work was performed at the National High Magnetic Field Laboratory, which is supported by National Science Foundation Cooperative Agreement No. DMR-1157490, the State of Florida, and the U.S. Department of Energy. This research has also been supported by Strategic International Collaborative Research Program (SICORP), Japan Science and Technology Agency.

Fluctuation mechanisms induced by bicrystal grain boundaries in Co-doped BaFe$_2$As$_2$ superconducting thin films

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The use of iron pnictide superconductors for electric power lines could bring advantages over other high critical temperature superconductors. The principal obstacle in fabricating high quality superconducting wires and tapes is given by grain boundaries (GBs). In order to study the effect due to the presence of GBs, a detailed characterization of the dc electrical transport and voltage-noise properties has been performed in Co-doped Ba-122 superconducting films with controlled grain boundary structures, induced with a bicrystalline substrate. The samples, deposited by pulsed laser deposition, have been subsequently patterned by ion beam etching to form several measurement configurations and geometries. The rather standard $1/f$ noise, observed in the case of the homogeneous films, has been compared with the unusual behavior of the voltage-spectral density found for the GB junctions. In particular, the grain boundary seems to induce a strongly temperature-dependent multi-Lorentzian noise spectrum.

Near the superconducting critical temperature, the type of fluctuation mechanisms in the film are similar to other high-$T_c$ materials. Alternatively, an anomalous transition from a 3D to a 2D percolating network is observed in presence of GB. The correlation between transport and noise measurements can help building a better understanding of the current transport in this class of materials, and to improve their performances.

The mixed state in thin superconducting films in parallel magnetic fields

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We have observed a transition in the mixed-state transport response of superconducting films in parallel magnetic fields, which seems to correspond to the Likharev vortex core explosion that occurs above the temperatures at which the film thickness becomes smaller than 4.4 times the coherence length. Above the transition temperature the parallel magnetic field can no longer source vortices but influences the resistive state through its pair breaking action in reducing the superfluid density.
**Examination of the tradeoff between intrinsic and extrinsic properties in the optimization of a modern internal tin Nb$_3$Sn conductor**

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In modern Nb$_3$Sn wires there is a fundamental compromise to be made between optimizing the intrinsic properties associated with the superfluid density in the A15 phase (e.g. $T_c$, $H_c$, $H_{c2}$, all of which are composition dependent), maximizing the quantity of A15 that can be formed from a given mixture of Nb, Sn and Cu, minimizing the A15 composition gradients within each sub-element, while at the same time generating a high vortex pinning critical current density, $J_c$, by maximizing the grain boundary density with the additional constraint of maintaining the RRR of the Cu stabilizer above 100. Here we study these factors in a Ta-alloyed Restacked-Rod-Process (RRP®) wire with ~70 µm diameter sub-elements. Consistent with many earlier studies, maximum non-Cu $J_c$ (12 T, 4.2 K) requires preventing A15 grain growth, rather than by optimizing the superfluid density. In wires optimized for 12 T, 4.2 K performance, about 60% of the non-Cu cross-section is A15, 35% residual Cu and Sn core, and only 5% a residual Nb-7.5wt.%Ta diffusion barrier. The specific heat and chemical analyses show that in this 60% A15 fraction there is a wide range of $T_c$ and chemical composition that does diminish for higher heat treatment temperatures, which, however, are impractical because of the strong RRR degradation that occurs when only about 2% of the A15 reaction front breaches the diffusion barrier. As this kind of Nb$_3$Sn conductor design is being developed for sub-elements about half the present size, it is clear that better barriers are essential to allowing higher temperature reactions with better intrinsic A15 properties. We present here multiple and detailed intrinsic and extrinsic evaluations because we believe that only such broad and quantitative descriptions are capable of accurately tracking the limitations of individual conductor designs where optimization will always be a compromise between inherently conflicting goals.

**Superconducting Fault Current Limiter applications: Results from the grid field testing activity and next steps**

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Ricerca sul Sistema Energetico S.p.A. (RSE) has been gaining a relevant experience in the simulation, design and installation of resistive-type Superconducting Fault Current Limiter (SFCL) devices in the framework of a more than five years program supported by the R&D national project funded by the Ricerca di Sistema (RdS). The final result of this research activity is the finalization of the first Italian Superconductive Fault Current Limiter (SFCL) (12 kV/4.6 MVA), that was developed and lab tested by RSE and then installed in the Milan 9 kV distribution grid at S. Dionigi substation belonging to A2A Reti Elettriche S.p.A. (A2A). This SFCL prototype has been coping with the real grid conditions (9 kV/3.4 MVA) for more than two years since March 2012, providing a large amount of experimental data and a significant
experience in the management of superconductive devices. An important event was organized in April 2014 at the A2A premises to celebrate the two-years long operating life of the SFCL and to officially present the first SFCL device successfully installed in Italy to industries, universities and Italian press. Some preliminary results were already presented, however this paper is focused on the main outcomes at the end of this first field-testing activity of the SFCL device, including performance and behavior of its refrigeration system. Further to this first successful installation, the hosting utility A2A agreed to install in the same substation a new SFCL prototype protecting four feeders, therefore implying a SFCL device upgrading up to 15.6 MVA. The new SFCL device is very challenging and the design has already been initiated. After having reported on the results of the first experimental activity, this paper deals with the first steps towards the development of the upgraded SFCL prototype. The last section is dedicated to the determination of the most suitable winding architecture, including the results coming from the laboratory tests performed on single-phase BSCCO and YBCO prototypes aimed at checking their behavior during short-circuit tests. Some details about the project schedule towards the new SFCL device real installation in the Milan distribution grid (foreseen in early 2015) are also anticipated.

**T50**

**Superconducting Power Complex**

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We consider an energy complex unifying renewable energy power stations, hydro-plant and superconducting devices: generators, transformers, cables, energy storage systems, and fault current limiters. Complex approach to building the effective energy system can be based on the recently approved project of the Red Sea - Dead Sea Canal linking the Red Sea to the rapidly shrinking Dead Sea and on the 500 MW solar stations currently developed in Israel. The main attention is given to investigation of joint operation of the superconducting devices in the complex. It is shown that joint application of different types of ecologically friendly energy sources and energy storage systems allows one to compensate disadvantages of the renewable energy sources, to reduce fault currents, and to increase the stability of the power system. Application of superconducting (SC) power devices decreases heat emission, footsteps of the power devices and their weight. The application of unified cryogenic system increases competitive capacity of SC devices.
POSTER SESSION

(Friday 16th)
Study of properties of YBa$_2$Cu$_3$O$_{7-\delta}$ films grown by pulsed laser deposition on CeO$_2$-buffered sapphire

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YBa$_2$Cu$_3$O$_{7-\delta}$ (YBCO) superconducting films, deposited on the sapphire substrates, have been suggested as materials suitable for the design of resistive fault current limiters [1]. In the present work we study the growth by pulsed laser deposition of YBCO films on the R-cut sapphire substrates. To improve the matching of the lattice parameters between the substrate and the film we use CeO$_2$ buffer layer, recrystallized prior to the deposition of YBCO. The optimal thickness and temperature of recrystallization of the buffer layer is first determined using atomic force microscopy (AFM) and X-ray diffraction. Next, we use the AFM to examine the dependence of YBCO film roughness on the film thickness, and we study the homogeneity of magnetic flux penetration into the films by magneto-optical imaging. We find that the superconducting critical temperature and the critical current density of these films are very close to similar parameters for the YBCO films grown on lattice-matched single crystalline substrates. It appears that the structural defects in the buffer layer affect the microstructure of YBCO films, resulting in high values of the critical current density, suitable for applications.

This work was supported by the European Union within the European Regional Development Fund, through the Innovative Economy grant POIG.01.01.02-010/09.

Interplay of Superconductivity and Magnetism in Fe Pnictides

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The interaction of superconductivity and magnetism is studied in 122-family of iron based superconductor using the Hamiltonian which includes the itinerant electrons, localized electrons moment, and s-f interaction. Using Greens function superconducting order parameter $\Delta$ and magnetic order parameter $\langle S^z \rangle$ is calculated. We found an expression for $\Delta(T)$, $\Delta(0)$, $\langle S^z \rangle$, and $T_c$ which reduce to BCS result in the absence of magnetic interactions. Preliminary analysis of the result shows that the findings are in broad agreement with the experimental observations.
Preparation of Fe-Se-Te Superconductors by Liquid Metal Infiltration

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The iron-containing intermetallic compounds such as FeSe with PbO-type layered structure have attracted much attention due to several interesting reasons. FeSe has a simple crystal structure and compositional tolerance without toxic element unlike other iron-based superconductors. Furthermore, the synthesis and handling are relatively easy, compared to other oxypnictides. The application of an external pressure or doping with a third element such as Te result in the increase of critical temperature ($T_c$). However, the critical current density ($J_c$) of FeSe-based compound has been insufficient to be applicable for practical uses. It is considered that low sintered density is one of causes to limit high $J_c$. To overcome this problem and to obtain near full-density, we employed liquid metal infiltration technique to Fe-Se-Te superconductors. Porous skeletons of Fe were infiltrated by molten Se-Te alloy. We have examined various processing parameters such as infiltration temperature, atmosphere, duration, infiltrant compositions and post-annealing. The wettability of liquid Se-Te with solid Fe and annealing were crucial for full densification of the materials. Highly dense Fe-Se-Te could be obtained by a proper control of infiltration parameters, and the resulting materials exhibited improved superconducting properties.

The advantages of a transduce flux high temperature superconducting generator design

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Geared generator systems suffer from continuous efficiency and maintenance issues which have plagued the technology for decades. The gears and bearing failures lead to high costs and downtime periods. Direct drive (DD) systems offer higher reliability and efficiency but require large diameters for high output generators; magnet costs, mass and installation time are substantially higher thus leading to an unwillingness to replace tried and tested geared systems.

Superconducting (SC) machines offer various benefits for machine design, especially for DD systems. High flux densities and air cored machine designs can lead to mass savings of up to two thirds, however SC tape or wire costs can make the technology very costly. Additionally issues arising from electrical losses, rotating SC cores and cryogenic systems drastically reduce reliability and create problems for mechanical machine design. For large output generators (>5MW) the mechanical structure becomes the main challenge, optimising the structurally sound design while maintaining low mass and a simple design.

The proposed paper will describe the design of a transduce flux high temperature superconducting machine (HTS) with the aim of highlighting the electrical design and the major mechanical benefits. The proposed design utilises rotating claw pole elements to transfer flux from a stationary superconducting field core around the armature windings. This method effectively separates the cryogenic system from the electrical and mechanical elements, producing a high output machine that is structurally simpler, with low SC tape or wire costs and reasonable mass savings.
The paper will highlight specific beneficial features such as:

- Modular SC and electrical design
- SC coil design which requires less wire/tape
- Fewer end losses and a reduction of the mechanical gap
- Separation of hot and cold elements

The paper will also discuss the benefits of this design for using in industries such as offshore wind and ship propulsion. The final aim of this paper is to highlight SC technology as a versatile technology which offers major benefits for DD systems enabling industry to replace problematic geared systems which continue to evade reliability improvement.

**Mechanical characterization of welded joints for superconductivity applications**

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The jacketing of cables is necessary for the construction of superconducting magnets; this jacket, in general, consists of stainless steel and is made from the junction of tubes which are welded together. The presence of the jacket allows to realize the coils of the magnet. The technique, which is usually used to produce these joints, is gas tungsten arc welding (GTAW). This technology is also suitable for the creation of beads on thicknesses of considerable size by adopting filler material.

In the industrial field for innovative applications, as in the aeronautical sector, laser beam welding is preferred to GTAW, as it has advantages from morphological point of view of the bead (with reduced widths, greater depth of penetration, and limited extent of the heat affected zones (HAZ)) and higher productivity, being more easily automated even for complex geometries. The drawback with respect to GTAW is connected with weldable thickness, which is lower in laser welding without filler material.

The extent of HAZ may be an output of considerable interest for the jacketing of superconducting cables, especially when an annealing treatment for the coils is not taken into account. The annealing makes uniform the material and, therefore, mitigates the differences in microstructure between the bead and the base material. Such heterogeneity without a heat treatment could favour the starting of fractures because of a localized stress concentration.

This issue suggests the use of laser welding for cable-in-conduit conductors (CICC), which do not require a subsequent heat treatment after the production of the coils, because the reduced HAZ entails a better performance. The aim of this paper is the preliminary study of disc laser welding on 316 stainless steel. In particular, the input parameters, which guarantee a full penetration on thickness comparable to that of the jacket adopted for the toroidal coils of Nafassy CICC, are determined. Butt welds are carried out and joints are analyzed from the microstructural point of view to verify the presence of defects (cuts, cracks, porosity, ...) and through mechanical characterization tests to obtain indications about the strength of the different parts of the bead.
First approach to large scale Hot Isostatic Pressing (HIP) of MgB$_2$ wires in a toroidal chamber

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The superconducting wires of MgB$_2$ are currently on an edge of wide application. Rising price of helium lead to a significant improvement of the market for helium-free cooled superconductors. Among them, magnesium diboride is the one closest to a large scale production that is economically justified. However, it is still important to improve performance of MgB$_2$ wires, especially for medium to high field application.

An already proven method of improving critical current $j_c$ is to heat treat the wire under high isostatic pressure. Such HIP process densifies the superconducting core, improves grain connectivity and provides beneficial modification of reaction dynamics due to an increase of magnesium melt temperature. It was also shown, that HIP can be applied to coils of small diameter (12 mm) with similar benefits.

Unfortunately, high pressure gas chamber is limited to small volumes and therefore usable mainly for scientific research. To apply HIP on a large scale a demo toroidal chamber was built, that can produce a semi-isostatic conditions with a low viscosity, non-gas medium. Hypertech multifilamentary MgB$_2$ wires were HIPed in such a chamber in the shape of coils with 120 mm diameter. Pressures up to 200 MPa were applied during heat treatment. Such samples are compared with wires after argon HIP and atmospheric pressure heat treatment. This includes direct current measurements for critical current density $j_c$ and pinning force density $F_p$, calculation in 4.2 K and 20 K as well as SEM analysis.

Enhancement of Normal Zone Propagations Velocity of Coated Conductors and Design of Resistive Fault Current Limiters

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The REBaCuO-based high temperature superconducting coated conductors (HTS-CCs), currently available on the market, have a non-uniform critical current (Ic) along their length, low thermal diffusivity and consequently a low normal zone propagation velocity (NZPV). These two factors are particularly dangerous when HTS-CCs are used for Resistive Fault Current Limiter (RFCL) purposes. The inhomogeneity of Ic is responsible of localized quenches that, as a consequence of the low NZPV, cannot rapidly propagates along the
length of the coated conductors. The HTS-CCs are then exposed to high risk of local thermal runaway. The enhancement of the NZPV is a powerful approach which could lead both to local thermal stability of the superconducting tapes and to a consistent reduction of the cost of the design of RFCLs. We tuned our numerical models with promising experimental data, taken from recent scientific literature, and we analyze the effect of the enhancement of the NZPV on the design of RSFCLs. The preliminary results of our simulations confirm that the NZPV enhancement can significantly limit the amount of HTS-CCs needed for the design of medium voltage (MV) grid RSFCLs with evident economic benefits.

Relation “microstructure - critical current density” of NbTi superconductor subjected to the plastic deformation with pulse current

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Current trend in materials science, undoubtedly, is unique possibilities realization of increasing a complex of various materials properties due to nanostructure creation in them. One of the well-known examples of nanostructure materials is the superconductor based on NbTi alloy. A combination the properties such as high critical current density, strength and deformability allows niobium - titanium superconductors to be widely used for production of current-carrying elements of magnetic systems for scientific and industrial applications ranging from medical diagnostic MR-scanners to a thermonuclear reactor such as the International Thermonuclear Experimental Reactor.

For ensuring the listed properties in the superconductor, the nanostructure with uniform distribution of high dispersed α-Ti precipitations in a high conductivity matrix has to be created. Therefore one of the main materials science problems in studying of superconductors based on NbTi alloys is optimization of the deformation and heat treatment parameters, allowing to achieve the required microstructure and critical properties.

At present a perspective deformation method of structure refinement is severe plastic deformation by rolling (SPDR) with pulse current. This approach increases deformability, strength and, at the same time, ductility, viscosity, wear resistance.

The aim of this study is to investigate relation between microstructure and critical current density in superconductive NbTi wire.

The influence of SPDR and pulse current combined effect on composite, which includes electrical and thermal Cu-stabilizer, Nb-diffusion barrier and Nb-47wt.%Ti core, has been investigated. Specimens were rods by size of $\varnothing \times 120$ mm. SPDR with pulse current was carried out using a setup that included a rolling mill with 1 to 7 mm rolls, a pulse current generator, and an oscillograph. The rolling was performed at room temperature without heating. The current density was $j = 100 \, \text{A/mm}^2$.

It was shown that pulse current allows to obtain a nanostructure in the samples during the rolling. It was found that SPDR with pulse current retains the superconductivity effect. The opportunity of critical current density enhancement by formation of nanosize α-Ti as well as matrix grains is discussed.

The reported study was supported by RFBR, research project No. 14-08-31390 mol_a and No. 13-08-12222 ofi_m.
The influence of Hot Isostatic Pressure (HIP) on $J_{c}$, $B_{irr}$, $B_{c2}$, $T_{c}$ and $F_{p}$ in undoped MgB$_2$ wires

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The critical current density ($J_{c}$), pinning force density ($F_{p}$) measurements and analysis of pinning force density scaling, critical temperature ($T_{c}$), irreversible magnetic field ($B_{irr}$) and upper magnetic field ($B_{c2}$) have been made for multicore monel-sheathed type MgB$_2$ wires. The wires were manufactured by Hyper Tech Research Inc., with their standard technology of Cu-based monocore wire with the precursor Mg+B powder. The in-situ method with Nb barrier was used. The Hot Isostatic Pressing (HIP) process has been performed at IHPP PAS Unipress with high Ar gas pressure for short wire samples of about 130 mm length. The 0.1 MPa to 1 GPa argon gas pressure was used in the HIP annealing, and temperature from 680 °C to 725 °C have been applied typically in 15 min. dwell temperature. The critical current was measured at 4.2 K in ILHMFLT PAS and at 10K, 20 K and 25 K in Institute for Solid State and Materials Research, Dresden. The perpendicular field configuration to the 25 mm length of the samples have been used. Method of transport were made measurements of critical temperature and critical magnetic fields. The microstructure investigations were performed with SEM and EDX methods.

Critical current property of coated conductor under cyclic tensile stress and bending strain


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Long high-temperature superconducting coated conductors (HTS CCs) have been developed by using various processes such as PLD (pulsed laser deposition), MOCVD (metal organic chemical vapor deposition), MOD (metal organic deposition) and reactive co-evaporation. Usually, metal tapes are used as a flexible substrate to improve the mechanical property of HTS CCs. It is inevitable that bending strain and tensile stress applied simultaneously to the HTS CCs when we make a coil and cable for electric application using HTS CCs. In order to examine the critical current property of HTS CCs by bending strain and tensile stress, we invented a new device that can apply the cyclic tensile stress and bending strain simultaneously to HTS CCs. It is possible to evaluate mechanical properties of HTS CCs at the conditions of the bending diameter (30~200mm) and tensile stress (1~15kgf). In this paper, we have evaluated the critical current property of three kinds of HTS CCs under cyclic tensile stress and bending strain by using new device. Stainless steel substrate HTS CC shows superior mechanical properties at tensile (5kgf~15kgf) and bending (30mm~ 40mm)
conditions. But, critical current of textured Ni alloy substrate HTS CC are drastically decreased by repetition of tensile and bending.

**P11**

3D Modeling of Trapped Field in One Rotor Pole by Application of Various External Magnetic Fields

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Starting from the previous experimental results, the decay of the trapped magnetic flux densities on the surface of the YBCO bulk array was realised. This severely affect the performance of the fully high temperature superconducting motor built in our laboratory recently. This paper used a three-dimensional (3D) numerical model to model the one pole of the YBCO bulk array which is on the surface of the rotor. The model is characterised by the E-J power law and H-formulation, and is successfully implemented using finite element software - Comsol 4.4. Numerical simulation of pulsed field magnetization (PFM), decay of trapped magnetic field in one pole caused by various DC background fields and/or higher harmonic AC fields produced by the three phase stator windings were simulated. The results of the simulation reproduced the experimental ones qualitatively. In this study, the main reasons of field decay were evaluated and the methods of how to alleviate the decay were proposed as well.

**P12**

Scanning SQUID microscopy of local superconductivity in inhomogeneous combinatorial ceramics

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Although combinatorial solid state chemistry promises to be an efficient way to search for new superconducting compounds, the problem of determining which compositions are diamagnetic within a mixed phase sample is challenging. We have produced samples by reaction within a system of randomly mixed starting components (Ca, Sr, Ba, La, Y, Pb, Bi, Ti and Cu oxides) that showed an onset of diamagnetic response above 115 K in bulk measurements. Imaging of this diamagnetic response within ceramic samples using scanning SQUID microscopy (SSM) revealed local superconducting areas, with areas down to as small as our spatial resolution of a few microns. In addition, locally formed superconducting matter was extracted from mixed phase samples by magnetic separation. The analysis of single grains (d < 80 µm) performed by X-ray diffraction, elemental analysis and bulk SQUID measurements allowed us to identify Tl₂Ca₂Ba₂Cu₄O₁₂, TlCaBaSrCu₂O₇−δ, BaPb₀.₅Bi₀.₂₅Tl₀.₃₅O₃₆, TlCaBaSrCu₂O₇−δ and Ba₂YCu₃O₇ phases. SSM, in combination with other diagnostic techniques, is therefore shown to be a useful instrument to analyze inhomogeneous reaction products in the solid state chemistry of materials showing magnetic properties.
**P13**

**Absence of Reconfiguration in the Antidot Lattice**

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We have studied the magneto-resistance oscillations of varying period of two consecutive antidots in a rectangular array of antidots on superconducting Nb film by transport measurement. We have investigated the four different samples of rectangular array of antidots with different period. We found the interesting magneto-resistance oscillations of these four samples with different period of antidots. The reference sample with rectangular array of antidots showed the magneto-resistance oscillations reveals the existence of of two types matching effect with different constant magnetic field intervals. As the period of the antidots of rectangular array becoming very large than we found the one or two magneto-resistance oscillations but there is no reconfiguration. Also when the period of the antidots of rectangular array becoming very small i-e approaches to zero, there are sharp and narrow magneto-resistance oscillations, no reconfiguration.

**P14**

**Effects of sintering temperature on superconducting properties of Mg$_2$Si doped MgB$_2$ wires**

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The effects of sintering temperature on the superconducting properties of Ti-sheathed, SiC or Mg$_2$Si doped MgB$_2$ wires have been studied. The wires were fabricated by in situ powder-in-tube (PIT) method and characterized by x-ray diffraction, magnetization and transport measurements. Samples were sintered for 30 minutes at the following temperatures: 650 °C, 750 °C, 800 °C, 850°C, and 950°C. It is found that except for the sample sintered at 950°C, the cores of these wires are almost in pure MgB$_2$ phase, indicating that the Ti-sheath does not react with Mg or B. The critical current density $J_c$ peaks up for samples sintered at around 750 °C. The correlations between the $J_c$, $T_c$, and sintering temperature will be discussed in detail for these Mg$_2$Si doped MgB$_2$ wires.

This work is supported by the National Science Foundation under Grants No. CHE-0718482, an award from Research Corporation for Science Advancement, and an FRG grant of Sam Houston State University.
A novel Rotary Permanent Magnet Magnetic Refrigerator

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In this paper a novel Rotary Permanent Magnet Magnetic Refrigerator (RPMMR) is described. The principle of operation of the presented magnetic refrigerator is based on the AMR thermodynamic cycle. Gadolinium is selected as magnetic refrigerant and demineralized water is employed as regenerating fluid. The total mass of gadolinium (1.20 kg), shaped as packed bed spheres, is housed in 8 regenerators. A magnetic system, based on a double U configuration of permanent magnets, provides a magnetic flux density of 1.25 T with an air gap of 43 mm, while a rotary vane pump forces the regenerating fluid through the regenerators. The operational principle of the magnetic refrigerator concerned, the description of the development process and initial experimental results for certain key elements are shown.

Superconductivity limits in current-carrying YBCO-based films and wires: a unified approach based on their thermal instability

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Superconductivity of current-carrying superconductors in the dissipative regime, i.e., above the critical current J\textsubscript{c} is broken down abruptly at the so-called supercritical or quenching current J\textsuperscript{*} switching then to the normal state. Supercritical currents are of interest not least because most of the times the quench is a much deleterious process due to the high power dissipated from the jumping to the normal state. In other cases the jump to the normal state is integrated into high-energy devices behavior as with current limiters. An analytical model based on thermal instability ideas for the supercritical current has been recently put forward and confronted with experimental data of YBCO-based films \cite{1} and commercial wires \cite{2}. The extrinsic thermal nature, as opposed to the intrinsic electrodynamical nature, of the quench provides scope for at least partial tailoring of the process. In this work we will make a side by side comparison of the film and the wire superconductors behaviors under high currents. The focus will be on two quantities of interest, the supercritical current J\textsuperscript{*} and the supercritical power P\textsuperscript{*} (the electrical power just before the jump to the normal states). The role of the size, structure and substrate nature will be discussed, highlighting the most influential parameters on J\textsuperscript{*}.

P17

‘Convergence’ across European regions through R&I: the NAFASSY project as a case study

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The ‘convergence’ objective, intended as the structural adjustment of economic and social imbalances across a territory, is a key priority for the European Union. Since economic theory provides evidence that Research and Innovation (R & I) is a necessary lever for development, the European policy has long promoted R & I as a fundamental tool for achieving regional convergence. In particular, research and innovation actors working in regions whose development is lagging behind can benefit from a well financed fund (€ 201 bn, almost 20 % of the entire EU budget for 2014-2020), called ERDF (European Regional Development Fund), to invest in promising activities.

This has been the case with NAFASSY – National Facility for Superconduction SYstems –, a project at the forefront of scientific research led by a EU convergence region University together with other Italian top research centers. This poster aims at presenting the project in the broader context of the EU regional policy, and in so doing it shows how a complex, though well-established supranational policy can create effective cooperation with national-level policies, actors and far-reaching objectives.

P18

Densification of MgB$_2$ processed by Spark Plasma Sintering

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Spark Plasma Sintering (SPS) is a promising rapid consolidation technique that results in a better understanding and manipulating of sintering kinetics than other techniques. It therefore makes it possible to obtain MgB$_2$-based ceramics with tailored microstructures. Commercial MgB$_2$ powders were spark plasma sintered with an applied mechanical pressure. The obtained MgB$_2$ discs or rings (figure 1) show 98% relative density and a sharp superconducting transition with an onset $T_c$ equal to 38 K. Otherwise, the critical current density at 20 K under 1 T was measured and found equal to $J_c \approx 10^5$ A/ cm$^2$. The trapped field was also investigated on a 5 mm thick pellet with a 20 mm diameter, prepared at the optimized processing temperature. At 15 K the trapped field was equal to 1.2 T. Levitation force measurements were carried out as a function of the temperature and have shown that it takes the same value from 17 to 32 K for the disc and the ring samples. These measurements have also given a 38K critical temperature, in good agreement with the results of other techniques. The results suggest that, bulk MgB$_2$ superconductors could be a viable variant for magnetic levitation applications. In addition, the similarity of the results obtained with discs and rings support the calculations made by E.H. Brandt [1] that show that the screening current in thin disks flow at first along the outside edge of the samples.
The NAFASSY (NAtional Facility for Superconducting SYstems) project pursues two main objectives: 1) the implementation of a new Research Infrastructure, 2) reinforcing actual research activities. The former task is being performed starting from the realization of a new building with high power wiring and cooling facility, by using a proper design for the fabrication of the high current superconducting cable in conduit conductor needed to the final construction of a unique large warm bore magnet, then available in the facility for coiled shape samples to be tested. The second issue is being addressed by upgrading preexisting equipments as well as by installing new instruments for the mechanical and electrical characterization of innovative materials under high magnetic fields and very low temperatures. Within the NAFASSY project there is also a financed training program called DISP (superconducting power devices) with a high level scientific and interdisciplinary program devoted to physicists, engineers and law researchers. The facility is under construction at the University of Salerno and the project will end in December 2014.
Experimental and simulation study of HTS coils

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High Temperature Superconducting (HTS) coils of different shapes (typically circular or trapezoidal) wound on iron or ironless core, are fundamental components of many superconducting electrical power devices like Superconducting Magnet Energy Storage (SMES) and other electrical machines. The knowledge of components behavior, both electrical and magnetic, is important for the preliminary design of these devices. To this aim, different circular coils in double pancake configuration have been designed and realized at Superconductivity Laboratory of ENEA in Frascati. In particular, we have realized HTS coils with different turns and insulation, to investigate the effect of the respective techniques.

In this work, we have simulated and measured both the critical current, \( I_c \), and the transport current loss of HTS coils made of commercial grade ReBa₂Cu₃O₇₋ₓ (Re = Y or rare earths, ReBCO) tapes. From DC measurements, the coil critical current, \( I_c \), and the magnetic field distributions measured by Hall sensors are derived. The transport current losses of these coils have been measured at liquid nitrogen temperature using a compensated electrical method.

A 2D finite element method (FEM) model for the cross section of such coils, based on the H-formulation, has been implemented in the FEM software package COMSOL Multiphysics. The implemented equations have been derived from Maxwell’s equations, Faraday’s and Ampere’s law. Additionally, the E-J power law has been used to describe the macroscopic behavior of the HTS. Our main aim is to calculate, by using a magnetic field dependent critical current density, the transport current losses of the coils due to the variation, in magnitude and frequency, of the transport current in the superconductor tape. The FEM model has been validated by comparing the simulation results with the experimental data.

This work was supported by funding from the Italian Research Program “PON Ricerca e Competitività 2007-2013” under grant agreement PON NAFASSY, PONa3_00007.

Synthesis of Massive MgB₂ Superconductors by Using Hot Pressing Method

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For some applications, such as superconducting radio-frequency films in cavities, YBCO films have a too short mean free path. Alternative films are being explored, such as MgB₂. The Mg-B system has its own challenges due to the very different properties of magnesium (metal) and boron (semiconductor). Actual sized (diameter 50.8 mm, and 6.25 mm thickness) profiled products of MgB₂ has been fabricated and optimal technologic scheme for fabricating them has been development using a fast sintering method. Technological regimes of nontraditional fast consolidation methods has been developed. The maxima temperature for synthesis MgB₂ targets were 1050°C, and time of loading ~ 10 min, maximum pressure ~ 300kg/cm².

Magnetic measurements reveals that the targets of MgB₂ has critical transition temperature 39K. Investigation of X-ray structure of samples show that the samples has impurities of MgO.
and MgB$_4$ phases. Physic-mechanical properties of the obtained samples have been already studied.
The future superconducting accelerator could be based on this technology, potentially leading to large cost savings compared to conventional superconducting technology.

**P22**

**Pinning-improved thick YBa$_2$Cu$_3$O$_{7-\delta}$ films on highly alloyed textured Ni-W tapes**

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High-temperature superconductors grown on metallic tapes (coated conductors) might be applied in a wide range of applications such as electric cables, MRI devices or fusion magnets. To achieve higher transport currents ($I_c$) the film thickness needs to be increased. A high growth rate is essential for large-scale fabrication processes, however, mostly detrimental to the film’s crystalline quality, which leads to lower values for $I_c$. To raise the current transport capability in magnetic fields, flux lines have to be immobilized by introducing nanoscaled pinning centres into the superconducting matrices.

We have prepared YBa$_2$Cu$_3$O$_{7-\delta}$ (YBCO) thick films (~1 µm) by pulsed laser deposition (PLD) on both single-crystalline SrTiO$_3$ (001) substrates and on biaxially textured metallic Ni-9 at.% W tapes$^{[1]}$, where a standard Y$_2$O$_3$/YSZ/CeO$_2$ buffer layer system was applied$^{[2]}$. To evaluate the effect of different doping materials on the structural and superconducting properties of YBCO coated conductors, we introduced secondary phases, i.e. BaZrO$_3$, Ba$_2$YTaO$_6$, Ba$_2$YNbO$_6$$^{[3]}$ and BaHfO$_3$, by using mixed PLD targets. In order to perform transport critical current density ($J_c$) measurements, the samples were patterned afterwards by laser cutting.

X-ray diffraction showed an undisturbed epitaxial growth on single crystals and a good texture transfer from the nickel alloy tape via the buffer system to the superconducting layer. The nanoscaled pinning centres are incorporated biaxially textured in the YBCO matrix in all cases. In general, a superconducting transition temperature $T_c$ of above 88 K with a small transition width was observed. The application of artificial pinning centres led to improved in-field $J_c$ and to an increase of the irreversibility field $H_{irr}$. The influence of the preparation conditions, the pinning materials and the doping content on the angular dependence of $J_c$ will be discussed in detail.

The authors acknowledge financial support from EUROTAPES, a collaborative project funded by the European Community’s Seven Framework Programme (FP7 / 2007 - 2013) under Grant Agreement n.280432.

**P23**

**Fault Current Test of High Temperature Superconducting Cable with Hollow Former**

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The former (stabilizer) of high temperature superconducting (HTS) cable plays the role of bypassing fault current and consequently limit the temperature rise during the fault state. Its cross sectional is defined by considering operational requirements of HTS cable such as the evaporating temperature of pressurized liquid nitrogen and the amount of fault current given by the utility company based on the specification of the power grid where the HTS cable is installed.

The hollow former can be applied to the superconducting cables with thicker insulation layers with the purpose of improving the heat transfer capacity by the flow of cryogen through the hollow.

The test on the temperature rise of superconducting cable simulating the fault state should be done in order to verify the design results not in its development process but also as a part of the type test.

The design of former and the fault current test on HTS cable is implemented with the assumption that the heat transfer from former to cryogen is negligible because the fault duration is very short and the thermal conductivity of insulation layer is very low.

However, the assumption may not be valid for the test of HTS cable with hollow former due to the convective heat transfer by the boiling of liquid nitrogen in the hollow - which cannot be occurred at the real operation of HTS cable. The boiled nitrogen is rapidly discharged through the hollow and the heat on the former will be directly transferred to the cryogen. As a result, the temperature of HTS cable will not increase to the expected values.

This kind of difficulties in fault current test can be solved by using a pressurized liquid nitrogen chamber but it is not easy to be realized at laboratories.

We suggested an alternative test measure to provide accurate temperature data related to the temperature rise of HTS cable during fault current state. In this paper, the test method and the results of fault current test will be introduced.

**P24**

**Cable architecture in high current power transmission applications**

Thomas Taylor

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For some applications it is necessary to transmit large currents via superconducting cables in close proximity within in a single cryogenic envelope. The path taken by this power transmission system may be tortuous and the environment hostile. These factors can have a strong impact on the layout of the cables which in some cases calls for their division into sub-cables. It is also important to ensure long term reliability at reasonable cost. The paper addresses the optimization of such systems.
Superconducting transmission lines have much lower total electrical losses, a tremendous size advantage for high-capacity transmission and a number of technological advantages compared to solutions based on standard conductors. That makes them very attractive for transmission system operators (TSO) in order to reduce losses, especially for long-distance applications, and to potentially reduce the approval time due to higher public acceptance.

At IASS the possibility of replacing standard HVDC (High Voltage Direct Current) lines with DC superconducting cables is investigated. Superconducting transmission lines can also be operated in AC mode but will then have electric losses depending on the design of the conductor and cable. IASS is especially investigating the possibility of using the superconductor magnesium diboride (MgB$_2$) for high-capacity long-distance electric energy transport. The cost per kA and meter are much cheaper for MgB$_2$ than for high-temperature superconductors (HTS) and also significantly cheaper than for copper. IASS works in cooperation with several international partners from industry and research as well as with TSOs to show the technical feasibility and reliability of MgB$_2$-based high-capacity transmission lines. In a collaboration with CERN, a high-current test facility was built and a multi-kA rated MgB$_2$ DC cable was developed and will be tested. The current status of superconducting projects at IASS will be shown and the socio-economic aspects of various transmission line options (costs, public acceptance) will be discussed, by comparing superconducting transmission lines based on MgB$_2$ and HTS with state-of-the-art HVDC overhead lines and underground cables based on standard (resistive) conductors. The economic competitiveness with standard solutions will be shown.

Quantum phase slips in superconducting Nb nanowire networks deposited on self-assembled Si templates

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The formation of interconnected networks consisting of superconducting Nb nanowires was recently achieved depositing Nb ultrathin films on porous silicon (PS) substrates. Due to the extremely reduced Nb thickness, $d_{\text{Nb}} \sim 10$ nm, the deposited material tends to occupy only the substrate pitch. As a consequence, the sputtered films, at a later stage patterned into micro-bridges (length $L_b = 100$ $\mu$m $\times$ width $W_b = 10$ - $20$ $\mu$m) by standard optical lithography and lift-off procedure, resulted in a network of 250-500 interconnected nanowires, whose average diameter was comparable to the superconducting coherence length, so that each individual nanowire behaved as a 1D object. The samples exhibited nonzero resistance over a broad temperature range below $T_c$ and the data were explained...
considering the occurrence of thermal activated phase slips (TAPS) and quantum phase slips (QPS) processes. However, no signatures of the presence of QPS phenomena were detected measuring the current-voltage characteristics, $V(I)$, of the samples. Later, by using Electron Beam Lithography (EBL), we have fabricated microbridges whose in-plane area was 50 times smaller than the previous samples. In particular, the samples were patterned in a four-terminal geometry consisting of a pair of current-carrying Nb electrodes which contact the ($L_b = 30 \, \mu m \times width \, W_b = 1.67 \, \mu m$) nanoporous Nb film and a pair of voltage pads 10 \, \mu m apart. As a consequence, the resulting network had a drastically lower number of interconnected nanowires ($N \sim 30$) and quantum fluctuations of the superconducting order parameter were consistently revealed both in the resistive transitions and $V(I)$ measurements.


Low-Cost 2G HTS Coated Conductors Scale-Up at STI

Jeong Huh, Jian Cao, Xiaofeng Qiu, Joseph Chase, Steve Roberts, Ken Pfeiffer

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2G HTS coated conductors using reactive co-evaporation with cyclic deposition and reaction (RCE-CDR) of HTS films onto simplified templates have been fabricated at Superconductor Technologies Inc.. RCE-CDR is a low-cost, high-yield, scalable process for deposition of HTS films. Our simplified template structure consists first of a multi-layer metal oxide film deposited by solution deposition planarization (SDP) process onto Hastelloy substrates. Subsequently MgO is deposited via ion beam assisted deposition (IBAD). Multiple SDP chemistries have been screened and Design of Experiment (DOE) has been performed on IBAD process to optimize simplified template performance. Also silver and copper encapsulation on end-product has made progress. Through these improvements, hundreds of meters of templates are being fabricated. The 100m RCE-CDR is producing tens of meters of Conductus coated conductors carrying over 400A/cm of critical current. At the moment, RCE-CDR equipment scale-up is in progress to produce 1000m length HTS coated conductors. Along with the deposition chamber that will produce 1000m length, process control software is under development and this will incorporate real time process monitoring that enables fast adjustment to the process parameters during film growth for optimum HTS performance. Detailed data of Conductus wire will be presented at the conference.
On the plateau-like behavior of the thermal conductivity of solid parahydrogen with heavy atomic impurities of extremely low concentrations

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The possibilities of plateau-like behavior of the thermal conductivity of solid p-H\(_2\) doped with Ne and Ar extremely low concentrations were investigated. The usefulness of heavy impurity Hg for the further verification of segregation hypothesis in solid p-H\(_2\) impurity subsystem in chains along the dislocation cores was shown. It is noted that this solid p-H\(_2\) with Hg could have electric conductivity or even superconductivity, because the Cooper electron pairs correlation size is on three orders of magnitude higher than the average distance between the impurities in the chain. We discuss the conditions of the relevant experiments for this heavy impurities in solid p-H\(_2\).


The MgB\(_2\) composites milled in various kind of high energy ball mills and in various medium for practical applications as ex-situ barrier for high current low cost wires.

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The new low costs, proper and not reacted with Mg core material and Cu sheathes barrier with good thermal and electric transport properties is highly needed for Cu sheathed superconducting wires. The MgB\(_2\) with nano SiC and nano carbon additions have been milled in high energy ball mill by using the tungsten carbide balls and vials and iron one as well. The appropriate amount of the nano plastifer and a locker of the easy diffusion voids for high densifications process of the milled ex situ MgB\(_2\) material was used and proposed. The medium for the milling process was chosen. The pure 5N argon and the hexane liquid medium have been compared. The 24 hours high energetically milling process were made.
in two different ball mill machines. The obtained well milled MgB₂ material was used in the same, for all samples, HP (hot pressing) sintering process at 800 °C and 0.2 GPa for 30 minutes in Cu and Fe container. Such conditions simulate the conditions of the Cu or Fe sheathed wires pressed isostatically in toroid kind chamber used for manufacturing of long superconducting wires.

The SEM, EDX and susceptibility investigations made for pinning force (Fp) calculations, critical current density (Jc) and critical temperature (Tc), have been made and presented. The best homo barrier solution is presented as well.
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