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Superconductivity Applications and Challenges

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Abstract

Nowadays, superconductivity has found many attractive applications in medicine, science, power systems, engineering, transport and electronics. There is no doubt, that the most Prominent applications of superconductivity are superconducting magnets. Most of the magnet applications like e.g. MRI magnets, NMR magnets, Accelerator magnets and magnets for Fusion still use low temperature superconductors. Since the discovery of high temperature superconductivity (HTS) in 1986 there has been a tremendous progress in R&D of HTS material, wires and applications. Especially for power system applications HTS offers considerable economic benefits. This paper gives an overview about the different LTS &HTS applications with the main focus on present and future applications.

I. INTRODUCTION

The phenomenon of superconductivity is one of the most interesting and sophisticated in condensed matter physics in which the electrical resistance of certain materials completely vanishes at low temperatures. It was first discovered by the Dutch physicist Heike Kamerlingh Onnes. In 1911 Kamerlingh Onnes and his assistants discovered the phenomenon ofsuperconductivity while studying the resistance of metals at low temperatures.

II. PROPERTIES OF SUPERCONDUCTING MATERIALS

- Zero resistance to direct current
- Extremely high current carrying density
- Extremely low resistance at high frequencies
- Extremely low signal dispersion
- High sensitivity to magnetic field
- Exclusion of externally applied magnetic field
- Rapid single flux quantum transfer
- Close to speed of light signal transmission

Zero resistance and high current density have a major impact on electric power transmission and also enable much smaller or more powerful magnets for motors, generators, energy storage, medical equipment and industrial separations. Low resistance at high frequencies and extremely low signal dispersion are key aspects in microwave components, communications technology and several military applications. Low resistance at higher frequencies also reduces substantially the challenges inherent to miniaturization brought about by resistive, or heating.

The high sensitivity of superconductors tomagnetic field provides a unique sensing capability, in many cases 1000x superior to today's best conventional measurement technology. Magnetic field exclusion is important in multi-layer electronic component miniaturization, provides a mechanism for magnetic levitation and enables magnetic field containment of charged particles. The final two properties form the basis for digital electronics and high speed computing well beyond the theoretical limits projected for semiconductors. All of these materials properties have been extensively demonstrated throughout the world.

III.TYPES OF SUPERCONDUCTOR MATERIALS

In 1911, H. K. Onnes, a Dutch physicist, discovered superconductivity by cooling mercury metal to extremely low temperature and observing that the metal exhibited zero resistance to electric current. Many other metals and metal alloys were found to be superconductors at temperatures below 23.2K. These became known as Low Temperature Superconductor (LTS) materials.

A superconducting material with a critical temperature above 23.2K is known as a High Temperature Superconductor (HTS)

IV. PRESENTLY USED COMMERCIAL APPLICATIONS

- Magnetic Resonance Imaging (MRI)
- Nuclear Magnetic Resonance (NMR)
- High-energy physics accelerators
- Plasma fusion reactors
- Industrial magnetic separation of kaolin clay

The major commercial applications of superconductivity in the medical diagnostic, science and industrial processing fields listed above all involve LTS materials and relatively high field magnets. Several smaller applications utilizing LTS materials have also been commercialized, e.g. research magnets and MagnetoEncephalograhy (MEG).

The only substantive commercial products incorporating HTS materials are electronic filters used in wireless base stations. About 10,000 units have been installed in wireless networks worldwide.

V. EMERGING APPLICATIONS

Superconductor-based products are extremely environmentally friendly compared to their conventional counterparts. They generate no greenhouse gases and are cooled by non-flammable liquid nitrogen (nitrogen comprises 80% of our atmosphere) as opposed to conventional oil coolants that are both flammable and toxic. They are also typically at least 50% smaller and lighter than equivalent conventional units which translate into economic incentives. These benefits have given rise to the ongoing development of many new applications in the following sectors:

VI. ELECTRIC POWER

Superconductors enable a variety of applications to aid our aging and heavily burdened electric power infrastructure - for example, in generators, transformers, underground cables, synchronous condensers and fault current limiters. The high power density and electrical efficiency of superconductor wire results in highly compact, powerful devices and systems that are more reliable, efficient, and environmentally benign.

VII. TRANSPORTATION

The rapid and efficient movement of people and goods, by land and by sea, poses important logistical, environmental, land use and other challenges. Superconductors are enabling a new generation of transport technologies including ship propulsion systems, magnetically levitated trains, and railway traction transformers.

VIII. MEDICINE

Advances in HTS promise more compact and less costly Magnetic Resonance Imaging (MRI) systems with superior imaging capabilities. In addition, Magneto-Encephalography (MEG), Magnetic Source Imaging (MSI) and Magneto Cardiology (MCG) enable non-invasive diagnosis of brain and heart functionality.

IX. INDUSTRY

Large motors rated at 1000 HP and above consume 25% of all electricity generated in the United States. They offer a prime target for the use of HTS in substantially reducing electrical losses. Powerful magnets for water remediation, materials purification, and industrial processing are also in the demonstration stages.

X. COMMUNICATIONS

Over the past decade, HTS filters have come into widespread use in cellular communications systems. They enhance signal-to-noise ratios, enabling reliable service with fewer, more widely-spaced cell towers. As the world moves from analog to all digital communications, LTS chips offer dramatic performance improvements in many commercial and military applications.

XII. SCIENTIFIC RESEARCH

Using superconducting materials, today's leading-edge scientific research facilities are pushing the frontiers of human knowledge - and pursuing breakthroughs that could lead to new techniques ranging from the clean, abundant energy from nuclear fusion to computing at speeds much faster than the theoretical limit of silicon technology.

XIII. CHALLENGES

- Cost
- Refrigeration
- Reliability
- Acceptance

Many years of development and commercialization of applications involving LTS materials have demonstrated that a superconductor approach works best when it represents a unique solution to the need. Alternatively, as the cost of the superconductor will always be substantially higher than that of a conventional conductor, it must bring overwhelming cost effectiveness to the system. The advantage of HTS has changed the dynamic of refrigeration by permitting smaller and more efficient system cooling for some applications. Design, integration of superconducting and cryogenic technologies, demonstration of systems cost benefits and long term reliability must be met before superconductivity delivers on its current promise of major societal benefits and makes substantial commercial inroads into new applications.

XIV. CONCLUSION

Superconductivity is widely regarded as one of the great scientific discoveries of the 20th Century. This miraculous property causes certain materials to lose all resistance at low temperatures to the flow of electricity. This state of “losslessness” enables a range of innovative technology applications. At the dawn of the 21st century, superconductivity forms the basis for new commercial products that are transforming our economy and daily life.

Recent progress in superconductivity follows a pattern that marked previous developments in new materials - for example, in transistors, semiconductors and optical fibers. Materials-based technology development entails high risk and uncertainty compared to more incremental innovations. It typically takes 20 years to move new materials from the laboratory to the commercial arena. Yet products using new materials often yield the most dramatic benefits for society in the long run.

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