PDHonline Course E168 (1 PDH)

Introduction to High Temperature Superconductors

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2020

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Introduction to High Temperature Superconductors

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Course Content

Introduction

High temperature superconductors (HTS) and their characteristics are fascinating topics. I hope that students that take this course will be inspired to experiment with superconductors. Perhaps the student may be the one that develops a *room* temperature superconductor and changes the world!

In this course, the student will be introduced to the fundamental properties of superconductors, the basics of high temperature superconductors, the Meissner effect, the zero resistance effect, practical experimentation kits, how to make a superconductor from scratch, applications for superconductors, and superconductor patent information.

Superconductors in General

A superconductor is a material that has zero resistance to electrical current when it is cooled to a certain temperature. What's the big deal? Electrical resistance causes things to be heavier and less efficient. In other words, it costs money. So, if you get rid of electrical resistance, you save lots of money. Using superconductors can also result in a smaller size for equivalent power in equipment. For example, using superconductor windings in electromagnets can increase the Tesla rating for a given physical size.

Superconductors also exhibit strange properties such as excluding all magnetic fields from their interiors. This is called the Meissner effect. It results in magnets *levitating* above a piece of superconductor material! This is truly a strange effect. It is magical except there is no trickery. It is very real.

You get conductors to become *super*conductors by cooling them. Any conductor will superconduct if cooled enough. Unfortunately, the required temperature is often very close to absolute zero (-273 C) or 0 degrees Kelvin

(K) which is the lowest temperature that is theoretically possible. For example, around 100 years ago it was discovered that liquid Helium could make superconductors out of materials such as Mercury. Liquid Helium has a temperature of 4.2K or only 4.2 degrees above the coldest temperature possible in the universe. Liquid Helium is not very practical or cheap. Higher temperature superconductors were needed.

High Temperature Superconductors (HTS)

High Temperature superconductors (HTS), which were discovered in the 1980s, will exhibit superconductor properties at much higher temperatures than that of liquid Helium. In fact, relatively cheap and easily obtainable liquid Nitrogen (LN2) will sufficiently cool a HTS. LN2 has a boiling point of –196 C. This is still very cold but much easier to accomplish than –273 C! Really, they should be called *relatively* high temperature superconductors since the temperatures involved are not high by any means.

One of the most popular HTSs is Yttrium-Barium-Copper-Oxide (YBCO). It is a ceramic material that is an insulator at room temperature. You read that correctly. It is an electrical *insulator* at room temperature but when you cool it with LN2 it becomes a perfect *conductor* of electricity. Strange stuff!

One drawback to current HTS material is that it is brittle. It is difficult to make a flexible wire out of the current HTS materials. The brittleness is a very big hindrance to practical usage. This manufacturing difficulty (increased labor and wasted material) can make equipment that uses HTS material more expensive than ordinary versions of the equipment. HTS wire can be ordered from companies such as American Superconductor, http://www.amsuper.com/products/htsWire/index.cfm

Vendors such as FutureScience, Inc. (http://www.futurescience.com) will sell you fairly cheap kits that contain a small disk of YBCO, rare earth magnet, tweezers, Styrofoam cups to hold LN2, etc. LN2 is not included with the kits but you can get it from your local industrial/medical gas supplier (see Figure 1). LN2 usually costs about $2/gallon in small quantities. LN2 can be safely handled if proper procedures are followed. However, if you get careless with LN2, it can hurt you.

With these superconductor kits, you can check the conductance of the YBCO disk with a common continuity meter at room temperature to verify that it is, in fact, an insulator. Once cooled with LN2, you can check the continuity of the YBCO disk again to verify that it has now turned into a conductor. You can also experiment with the unusual characteristics of superconductors such as the Meissner effect and the zero resistance effect.

Figure 1. A 10 liter LN2 container from Airgas (931-645-8276) in Clarksville, TN. As the LN2 warms, it changes back into the gas state. The loose fitting top prevents explosion. The LN2 lasts a surprisingly long time (several days) in this type/size container.

Meissner Effect

A substance that exhibits diamagnetism opposes a magnet similarly to the way two magnets faces of the same polarity oppose each other. A superconductor exhibits perfect diamagnetism since they exclude magnetic fields from their interiors. When a superconductor repels a magnet that is placed on it prior to cooling, it is called the Meissner effect. The effect is named for one of its discoverers, W. Meissner. This effect results in a magnet being levitated above a superconductor (or vice versa depending on which one is fixed). When the superconductor disk is cooled with LN2, the magnet actually rises (levitates) to a position above the disk from a resting position on top of the superconductor disk.

Zero Resistance

If a magnet is placed on the superconductor disk *after* the disk is cooled, the zero resistance effect is demonstrated as opposed to the Meissner effect. This will result in the magnet floating above the superconductor disk. The physical height at which a magnet floats above the superconductor disk due to zero resistance is higher than the levitation height that is achieved with the Meissner Effect. Figure 2 and Figure 3 show the zero resistance effect in action floating a neodymium-iron-boron magnet above a disk of YBCO superconducting material.

Figure 2. Neodymium-iron-boron magnet floating about .25” above a LN2 cooled yttrium-barium-copper-oxide superconductor. When I poured about a quarter of a cup of LN2 into the Styrofoam cup, the levitation effect lasted, amazingly, for almost 15 minutes before it needed a boost from another shot of LN2.

Figure 3. Another view of a Neodymium-iron-boron magnet floating about .25” above a LN2 cooled yttrium-barium-copper-oxide superconductor.

Making Superconductors From Scratch

Oak Ridge National Laboratory (ORNL) has a nice Web site, http://www.ornl.gov/reports/m/ornlm3063r1/contents.html, which gives the background of superconductors as well as experiments, and demonstrations. The ORNL Web site also covers the safe handling procedures for LN2. This Web site even tells you how to make your own YBCO pellet from scratch.

To make a YBCO pellet from scratch, you basically combine the yttrium oxide/copper oxide/barium carbonate, heat the mixture, cool the mixture, grind the mixture, heat the mixture, cool the mixture, press the mixture into a pellet, and heat the mixture. Of course, it is really more complicated than this but well within the capability of an individual with basic chemistry knowledge and equipment. The details of the procedure can be seen at http://www.ornl.gov/reports/m/ornlm3063r1/pt7.html.

Applications for Superconductors

There are numerous applications for superconductors such as levitating trains, smaller cheaper medical imaging equipment, power line conductors, super fast computers, floating cars, electromagnetic spacecraft launching devices, high Tesla electromagnets, magician's equipment, floating furniture, non-contact bearings, etc. But the really exciting thing is that the best applications have not even been thought of yet. When transistors were invented, did the pioneers imagine that they would eventually be shrunk down to microscopic size and used in cell phones, GPS receivers, video games, PDAs, satellites, etc? I doubt it!

Goldmine?

Why anyone would want to learn about superconductors, play around with the materials, or develop practical applications? It is fun, interesting, and relatively inexpensive to do for one thing. Another reason is that a gold mine is awaiting superconductor application pioneers the same way the transistor was a gold mine back in its early days. It will probably be some hobbyist in their garage that makes a big breakthrough in new superconducting materials or applications for existing materials. The government even encourages superconductor research by expediting patents associated with the subject.

Patent Information

When you submit a patent application, you can request, via a petition, that the application be "made special" such that the patent prosecution is accelerated. This is called a Petition to Make Special (PTMS). As slow as the United States Patent and Trademark Office (USPTO) processes are, this is a good thing.

Certain things such as advanced age of the applicant, environmental applications, energy applications, illness of the applicant, and superconductivity result in a free PTMS. A PTMS usually requires payment of a fee. Therefore, the free PTMS for superconductivity illustrates the importance of this subject matter to the U.S. government. The following is an excerpt from the USPTO Manual of Patent Examining Procedures (MPEP) chapter 700 regarding superconductivity:

"In accordance with the President's mandate directing the U.S. Patent and Trademark Office to accelerate the processing of patent applications and adjudication of disputes involving superconductivity technologies when requested by the applicant to do so, the U.S. Patent and Trademark Office will, on request, accord "special" status to all patent applications for inventions involving superconductivity materials. Examples of such inventions would include those directed to superconductive materials themselves as well as to their manufacture and application. In order that the U.S. Patent and Trademark Office may implement this procedure, we invite all applicants desiring to participate in this program to request that their applications be accorded "special" status. Such requests should be accompanied by a statement under 37 CFR 1.102 that the invention involves superconductive materials. No fee is required."

A search for "superconductor" on the USPTO Web site, www.uspto.gov, issued patent database in the "title" field, on 7-09-05, resulted in 886 hits as shown in Figure 4. The search results are issued patents from 1976 to the present.

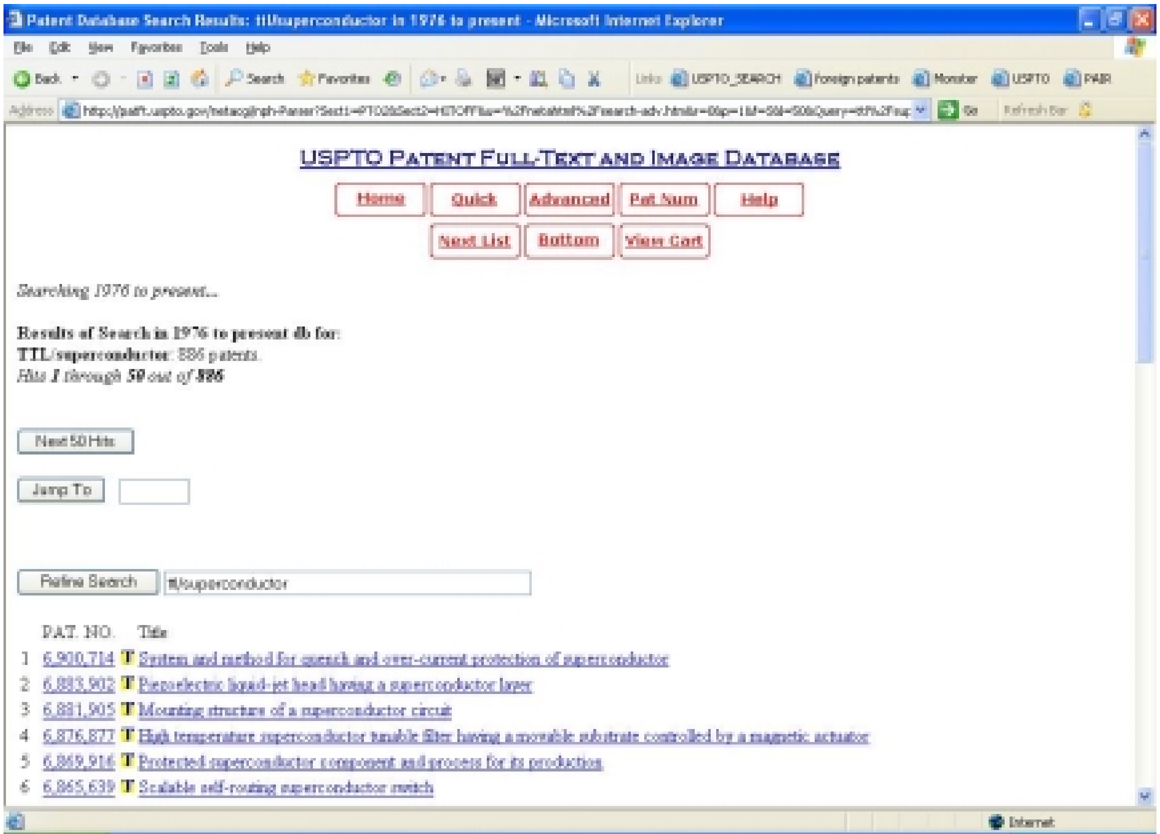

Figure 4. Results of a search for an issued patent with "superconductor" in the title on the USPTO patent database.

Summary

Room temperature superconductors (or even materials that will superconduct via Freon cooling) are one of the next great technological leaps awaiting mankind. Even LN2 cooled superconductors that can easily be formed into flexible wires would be a great leap. If higher temperature superconductors can be developed, it has the potential to change the world into the science fiction representation we often see in the movies (floating cars, trains, furniture, etc). It will open new doors for inventors the way microelectronics did in its early days.

I hope that this course inspires some of you to start playing around with superconductors and come up with a major breakthrough in the basic technology or at least start generating ideas for applications. Also, current

HTS materials can be utilized in various pieces of equipment, such as large electromagnets, to save weight and increase output.

More information on superconductors can be found on the Web by searching for “superconductors”, “high temperature superconductors”, “superconductor magnet”, HTS, or YBCO. The references listed with this course are also excellent sources for more information.

Related Links and References

1. Oak Ridge National Laboratory, “A Teacher's Guide to Superconductivity for High School Students”, http://www.ornl.gov/info/reports/m/ornlm3063r1/contents.html, 04/01/1996
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3. Future Science, Inc., http://www.futurescience.com
4. Superconductivity – Magnetic Levitation demonstration Kit Model 150, Future Science, Inc., 1994
5. American Superconductor, HTS Wire, http://www.amsuper.com/products/htsWire/index.cfm