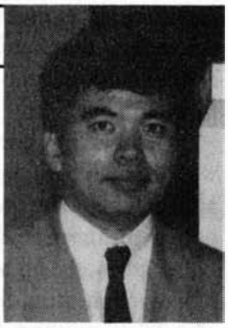
Interview: Dr. Masato Murakami

Turning HTSCs into magnets



Superconductivity holds a great deal of promise for a wide variety of applications, one of which is the development of superconducting electric motors. A simple idea of the implications of the use of zero-resistance superconducting materials to improve the efficiency of electric motors can be gained from considering that electric motors consume half of the electricity used in the United States. With the advent of new high-temperature superconductors (HTSCs), efforts are moving ahead to use these materials for electric motor applications.

There are two basic approaches: One is to use HTSCs to form wires which are wound into coils. These coils then are used to produce the magnetic field to run the motor. American Superconductor Corp. and Reliance Electric Co. have had success with this approach. Their most recent effort has been a 5-horsepower motor using a bismuth-based HTSC for the coils. The other approach is to turn some high-temperature superconducting material directly into a magnet, which is done by using the material's ability to trap magnetic fields. The magnetic field is then used in motors or other applications. This is the approach being used by Roy Weinstein at the Institute for Beam Particle Dynamics, University of Houston and Emerson Electric, where they recently tested a motor/generator which produced an output of 100 watts. The magnets they use are made of an yttrium-barium-copper-oxide (YBCO) compound. The material is also referred to as Y-123.

Researchers use the interplay between the magnetic field and electrical currents in the high-temperature superconducting material: If a superconductor is placed in a magnetic field and cooled, then, when the field is removed, a current is induced in the superconductor which generates its own magnetic field. In a superconductor, this field would quickly dissipate. Therefore, researchers try to produce an imperfect superconductor in which the magnetic flux is pinned into place at faults and discontinuities in the crystal structure. Thus the field is trapped in the material, and, because it is a superconductor, the induced current will persist as long as it is kept cool.

In related work, Weinstein has set records for the highest trapped fields using Y-123. He has trapped 7 tesla at 55 K and 2.25 T at 77 K (1 T = 10,000 gauss; the Earth's magnetic field is only 0.5 G). The magnetic fields used in the motor research are only a small fraction of this strength, on the order of 1,500 G.

Recently in Japan, Masato Murakami, at the Superconductivity Research Laboratory in Tokyo, has developed rare earth (RE) superconductors based on neodymium and samarium—Nd-123 and Sm-123—which are similar in structure to Y-123. These materials have shown high critical current densities in a high magnetic field; 15,000 $\mathrm{A/cm^2}$ at 77 K in a 3 T field. The magnetic field is applied parallel to the c-axis or vertical direction of the crystal structure.

Murakami finds that these RE-123 compounds have higher pinning forces than Y-123, which means they should trap larger fields. He believes this is due to regions which have an excess of rare earth compared to barium, these regions are finely dispersed in a good RE-123 superconducting matrix. Although Murakami has yet to trap large fields, he is confident he will be able to trap over 3 T.

Dr. Masato Murakami, Director of Division VII, Superconductivity Research Laboratory of International Superconductivity Technology Center (ISTEC) in Tokyo, was interviewed by Mark Wilsey on April 5, 1994.

EIR: The laboratory press release reports high critical currents at high magnetic fields. Are your results close to record levels?

Murakami: This is a kind of record. Of course, field direction is important. In our achievement, the field was parallel to the c-axis—this is very important.

EIR: What role does this play in the current flow?

Murakami: The current is perpendicular to this direction. In order to increase the trapped field, critical current in this field direction is very important. Everybody in the world has been trying to increase critical current density in this direction.

EIR: How do your results apply to research into transmitting

higher currents and trapping larger fields?
Murakami: Our achievement will benefit both the transmission and trapped field.

EIR: Are these rare earth compounds, Nd-123 and Sm-123, new materials?
Murakami: Although they are of the family of yttrium, Y-123, we believe these are new. The crystal structure is very similar to that of Y-123. In normal material, there is a subsitution between the rare earth and barium. Usually the rare earth goes to a barium site; this is bad, because critical temperature is lowered by this substitution. The new discovery, we believe, is this: By processing in the reduced oxygen atmosphere, barium goes to the rare earth site, which is good because critical temperature is increased.

We solidify crystals in a reduced oxygen atmosphere, called oxygen-controlled melt growth process, or OCMG. It is a very simple process. The oxygen partial pressure was 0.001 atmosphere. Now, zero resistivity has reached 96 K, this is the highest critical temperature in a 123 system.

EIR: You have ascribed the flux pinning in these materials to the fine dispersion of the substituted phases in the superconducting matrix. Could you elaborate further?
Murakami: In a neodymium or samarium system, there is a region where solid solution takes place, and those regions are not good superconductors. When we apply an external field, those regions will become normal conductors and act as very effective pinning centers. That's the idea.

EIR: These are the finely dispersed regions of what could be described as rare-earth-rich phases within the superconductive matrix?
Murakami: Yes, that's right.

EIR: Do you understand how the two phases are dispersed?
Murakami: No, not yet. We have done a lot of observations using different equipment, including electron microscopy. But right now it is very difficult to detect those, as you have mentioned, rare-earth-rich regions. We are planning to use finer techniques like scanning tunnelling microscopy, or other techniques to detect those fine regions, but we have succeeded in detecting them. However, X-ray photoelectron spectroscopy showed that there should be some substitution, but that's all.

EIR: What are the main questions regarding the RE-123 compound that you are trying to address?
Murakami: This new compound exhibits very good pinning behavior at 77 K.

Actually, it's too good, right now. We disclosed several findings to the public. Right now, we have better results, but it's too good to report. We are checking it very carefully. I don't understand why this material shows such good pinning properties.

EIR: What is the highest trapped field that you have achieved with these materials?
Murakami: In the yttrium system we could trap 1.5 T at 77 K, but we would need to produce a larger sample of our material to trap such a high field. So far, we have not yet produced a large sample in these neodymium and samarium systems. The size is now only 2 centimeters. Therefore, the trapped field is less than 1 T. But, according to our calculation of critical current versus magnetic field properties, we believe we can trap at least 3 T.

EIR: Do you do any treatments to the materials, such as neutron or ion bombardment?
Murakami: No, we don't. It is a good technique, but I don't think it is a practical way to increase critical current.

EIR: What are the possible applications for trapped fields?
Murakami: As far as applications are concerned, one big project is a linear motor car. We started a collaboration with Japan Railways Technical Research Institute and several heavy industries to levitate a train using this new compound. We are trying to use the idea of a very high trapped field to levitate a train.

EIR: What materials would you used for the field trapping?
Murakami: For the first prototype we would probably use Y-123, because right now we can generate 1.5 T, and some think this field is high enough to levitate a heavy object. Probably we will first try to construct the first prototype using Y-123. We are now trying to make bigger neodymium- and samarium-123 systems, and if we can generate 3 T then we will replace Y-123 with new Nd-123 and Sm-123 superconductors. That's our plan.

EIR: What sort of timescale are you looking at for prototype development?
Murakami: Our plan is that in the first three years, which starts this year, we will focus on optimization of processing of the new compounds, Nd-123 and Sm-123. We will provide Y-123 to heavy industry companies, and they will check the electromagnetic properties of the Y-123 and design the prototype. It will not be a big train, but a small "train," probably 500 kg, or something like that. We will be trying to understand if the trapped field can really work as a substitute to conventional low critical temperature magnets. This will take three years. The next three years we will probably replace Y-123 with new compounds and design a bigger levitated train. Then we would begin to design a practical kind of levitated train. So, it is a nine-year project right now.