AUTHOR COMMENTARIES - From Special Topics

High-Temperature Superconductors - February 2009
Revised: April 2009*
Interview Date: May 2009

PDF

Amit Goyal

From the Special Topic of High-Temperature Superconductors

In our analysis of High-Temperature Superconductor research published over the past decade, the work of Dr. Amit Goyal ranks at #1 by total citations and at #4 by number of papers, based on 138 papers cited a total of 1,738 times. The majority of his work can be found in the field of Materials Science in Essential Science IndicatorsSM *from Thomson Reuters.*

Our analysis reflects only a small portion of Dr. Goyal's work in this field. The Web of Science® *reports that he has 191 papers cited close to 4,600 times from 1991 to April of this year. He also holds more than 50 patents.*

Dr. Goyal is a UT-Battelle/ORNL Corporate Fellow and a Battelle Distinguished Inventor at Oak Ridge National Laboratories in Tennessee. He is also a Fellow of AAAS, APS, ASM, ACERS, WIF, and IOP. He presently serves on the editorial board of the Journal of Materials Research, Journal of the American Ceramic Society, *and the advisory boards of NASA's* NanoTech Briefs, *the* Journal of the Korean Institute of Applied Superconductivity, *and the journal* Recent Patents on Materials Science.

Below, ScienceWatch.com *talks with Dr. Goyal about his highly cited research.*

SW: Would you tell us a bit about your educational background and research experiences?

I received a Ph.D. in Materials Science & Engineering from the University of Rochester, NY, in 1991, a MS in Mechanical & Aerospace Engineering from the University of Rochester in 1988, and a Bachelor of Technology in Metallurgical Engineering from the Indian Institute of Technology, Kharagpur, India, in 1986.

I am presently a UT-Battelle/ORNL CORPORATE FELLOW and a Battelle Distinguished Inventor1 at Oak Ridge National Laboratory. I have worked at the Oak Ridge National Laboratory since 1991. My broad research contributions have been in the area of large-area, low-cost, high-performance "flexible electronic" devices, including superconducting devices, photovoltaics, etc., as well as in 3D self-assembly of nanodots of complex materials within another complex material for device applications.

SW: What influenced your focus on superconductors?

High-temperature superconductors were discovered in 1986 by two IBM scientists, Bednorz and Müller. They received a Nobel Prize for their discovery in 1987. Typically, Nobel prizes are given for discoveries many years after the discovery occurs (10, 20 years later). In this case, the two IBM scientists received the Nobel Prize just one year after the discovery because of the immense potential applications of high-temperature superconductors (the theory or mechanism of high-temperature superconductors is still unknown). Every newspaper and magazine carried articles of how these novel materials would change the world we live in!

In 1987, I was completing my master's at Rochester (I received the degree formally in a graduation ceremony in 1988) and was actually all set to go to business school as I had always had a business mindset. However, after the awarding of the Nobel Prize and after reading many articles in newspapers and magazines back in 1987 which speculated on how the world we live in would change due to these materials, I found myself at a unique place or stage in the development of the HTS field. It could be compared to the stage when transistors were discovered in 1947, in the developmental timeline of the field of microelectronics. Of course, we all know that within a few decades, the world was completely transformed by microelectronics. So, I decided that I could always get to business school later and decided to focus my background in Materials Science & Engineering to enable the development of "practical or useful" high-temperature superconductors. Ever since then, this has been the primary focus of my research work!

Figure 1: +details

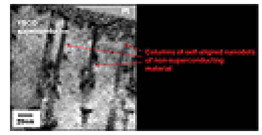
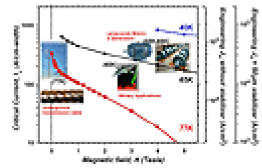


Figure 2:



SW: In the list of the top 20 authors worldwide with the highest number of papers during this period, you have the highest number of papers of anyone in the US or outside of Japan. Only three other people from the US figure in this list and two of them are from your institution. Can you comment?

There are many co-authored papers between myself and the other two people from my institution in your list of top 20 authors worldwide with the highest number of papers. This might explain why three out of the four people from the US in this list are from the same institution.

SW: One of your most-cited papers in our analysis is the 2005 *Supercond. Sci. Tech*. paper, "Irradiation-free, columnar defects comprised of self-assembled nanodots and nanorods resulting in strongly enhanced flux-pinning in $YBa_2Cu_3O_{7-d}$ films." Would you walk our readers through this paper and its significance to the field?

Based on prior experiments done by others in the early nineties, it was common knowledge in the HTS field that columnar defects comprised of amorphous damage tracks are generated by irradiating high-temperature superconducting single crystals with heavy ions. It was also shown that the critical current density is dramatically enhanced when the applied magnetic field is aligned parallel to columnar damage tracks. Hence, for over a decade, scientists worldwide have sought the means to produce such columnar defects in HTS materials without the expense and complexity of ionizing radiation.

In this paper, we demonstrated that long, parallel, columnar defects similar to those mentioned above can be obtained using a simple process without using ionizing radiation.

We demonstrated that nearly continuous columnar defects or vortex pins along the c-axis in $YBa_2Cu_3O_{7-\delta}$ (YBCO), in the form of self-assembled stacks of $BaZrO_3$ (BZO) nanodots and nanorods can be formed (See Fig. 1). When the applied magnetic field was aligned parallel to these defects, a massive improvement in critical current density of the superconductor was obtained. The work reported in this paper was first presented publically at the US-DOE Annual Peer Review in July, 2004 in Washington, DC in a talk titled "RABiTS Based Strategic Research" (view). This was the first report of the formation of columnar defects in coated conductors without the use of ionizing radiation.

Shortly thereafter we reported very high critical currents in 3 µm thick films in a paper published in *Science* in 2006 (See Fig. 2; Kang S, *et al*., "High-performance high-T-c superconducting wires," 311 [5769]: 1911-14, 31 March 2006). This work has now been extended to more scalable deposition processes such as MOCVD as presented for the first time at the ORNL-SuperPower CRADA presentation in the US-DOE Annual Peer Review in July, 2008 in Washington, DC, in a talk titled "ORNL/SuperPower CRADA: Development of MOCVD-based, IBAD-2G wire" (refer to).

Researchers worldwide are now finding a range of materials that can be incorporated in a similar manner into REBCO-type coated conductors to form such nanoscale columnar defects to obtain massive improvements in the superconducting properties, especially in high applied magnetic fields. HTS wires with such defects may eventually enable applications by meeting the price/performance requirements for large-scale applications of HTS.

SW: Another paper garnering citation attention is the 2000 *Applied Physics Letters (APL)* article, "Low angle grain boundary transport in Yba2Cu3O7-delta films." Would you tell us about this paper, its goals and findings?

"I expect to see materials engineering increase the performance of HTS wires significantly, while at the same time I expect the costs for fabricating the wires to reduce substantially due to process optimization and economies of scale."

Let me discuss this paper together with two additional papers – (1) "The RABiTS approach: Using rolling-assisted biaxially textured substrates for high-performance YBCO superconductors" (Goyal A, *et al*., *MRS Bulletin* 29[8]: 552-61, August 2004) and (2) "Texture formation and grain boundary networks in rolling assisted biaxially textured substrates and in epitaxial YBCO films on such substrates" (Goyal A, *et al.,* Micron 30[5]: 463-78, October 1999).

These three papers discuss the effect of grain boundaries and texture on superconducting properties of HTS wires. The *MRS Bulletin* paper provides a summary of the RABiTS process for making single-crystal-like HTS wires, which are being scaled-up in manufacturing by companies such as American Superconductor Corporation and Sumitomo Electric Corporation. The *Micron* paper discusses the grain boundary networks present in RABiTS-based conductors, characterized using the technique of Electron Backscatter Kikuchi Diffraction. The *APL* paper discusses the effect of grain boundary angle and grain boundary networks in RABiTS as well as the IBAD-type, polycrystalline, biaxially textured HTS wires on the superconducting performance. This paper pointed out an exponential decrease of the critical current density occurs when grain boundaries greater than 4 are present.

The area continues to be of great research interest, and significant advances have recently been made in this area. New results indicate that different grain boundary types have a different effect on the superconducting properties. Results in this general area will continue to guide research towards the development of HTS wires with better performance.

SW: What sorts of applications are possible for superconductors—are there any in common use now (or close to it)?

Many applications are possible for HTS materials. In just the area of electrical power there are several large-scale application areas such as underground transmission cables, transformers, generators, and fault-current limiters. Motors and magnets are some other big application areas.

SW: In what directions do you see this field going in the next decade?

I expect to see materials engineering increase the performance of HTS wires significantly, while at the same time I expect the costs for fabricating the wires to reduce substantially due to process optimization and economies of scale. This should eventually enable massive, large-scale applications of these materials, thereby finally fulfilling the prophecies of the late 1990's when the fever of HTS materials took the world by storm!

SW: What would you like the "take-away lesson" about your research to be?

For a given material with certain "intrinsic" physical properties, there is generally a lot of room for improvement in the materials performance via optimization of the "extrinsic" properties. Understanding the reasons why a certain material does perform to a certain level, or understanding what are the extrinsic factors that limit the performance of a material, is very important. Once an understanding is obtained, materials engineering can be effectively used to result in massive improvements in the performance!

Dr. Amit Goyal
UT-Battelle/ORNL Corporate Fellow
Battelle Distinguished Inventor & ORNL Distinguished Fellow
Fellow AAAS, APS, ASM, ACERS, WIF, IOP
Oak Ridge National Laboratory
Oak Ridge; TN, USA

1 Corporate Fellow is the highest recognition and designation for scientists at DOE's national laboratories. Corporate fellowships characterize innovation, dedication, and significance of extraordinary contributions to research and development. These contributions have been

acknowledged throughout the United States as well as other nations. ^

Amit Goyal's current most-cited paper in *Essential Science Indicators*, with 65 cites:

Goyal A, *et al.*, "Irradiation-free, columnar defects comprised of self-assembled nanodots and nanorods resulting in strongly enhanced flux-pinning in YBa2Cu3O7-delta films," *Superconduct. Sci. Technol.* 18(11): 1533-8, November 2005. Source: *Essential Science Indicators* from Thomson Reuters.

KEYWORDS: HIGH-TEMPERATURE SUPERCONDUCTORS, COLUMNAR DEFECTS, IONIZING RADIATION, NANODOTS, NANORODS, YBA2CU3O7-DELTA, YBCO, BZO, RABITS, SUPERCONDUCTING WIRES, GRAIN BOUNDARY NETWORKS.

PDF

back to top

Special Topics : High-Temperature Superconductors : Amit Goyal Interview - High-Temperature Superconductors