WHAT'S HOT IN... PHYSICS , May/Jun 2009

The Good Samarium Hots Up Superconductivity

by Simon Mitton

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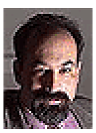
More than 20 years have passed since physicists discovered copper oxides with a high critical temperature (T_c) for the onset of superconductivity. The highest-performance ceramic superconductors have T_c > 77 K, the temperature of liquid



nitrogen, which is a cheap and ubiquitous coolant in physics labs. The underlying physical mechanism is still under debate, because standard BCS theory (named for Nobel Laureates John Bardeen, Leon Cooper, and John Robert Schrieffer) cannot explain the microscopic phenomenon in terms of electron pairs. Consequently interest in the cuprates has declined. They are brittle materials; making superconducting devices from them is hard because the material cannot be fabricated into wires by any mass-production process.

The Physics Hot Papers in this period show that superconductivity research is now hotting up, thanks to the unexpected discovery of a new class of iron-based superconductors. Papers #2, #3, #7 and #9 capture the tremendous interest stimulated by the recent discovery of superconductivity at T_c = 26 K in the iron-

based oxypnictide $La(O_{1-x}F_x)$ FeAs (Y. Kamihari, *et al.*, *J. Am. Chem. Soc.*, 130 [11]: 3296-7, 2008; currently #1 in the Chemistry Top Ten). That research, by Hideo Hosono and colleagues of the Tokyo Institute of Technology, put high-temperature superconductivity back on the agenda with a bang.

Physics Top Ten Papers

Rank	Papers	Cites This Period Nov-Dec 08	Rank Last Period Sep-Oct 08
1	D.N. Spergel, *et al.*, "Three-year *Wilkinson Microwave Anisotropy Probe* (*WMAP*) observations: Implications for cosmology," *Astrophys. J. Suppl. Ser.*, 170(2): 377-408, June 2007. [13 U.S. and Canadian institutions] *178TD. [see also]	138	1
2	X.H. Chen, *et al.*, "Superconductivity at 43K in $SmFeAs O_{1-x}F_x$," *Nature*, 453 (7196): 761-2, 5 June 2008. [U. Sci. & Tech., Hefei, China] *308UK	55	2
3	Z.A. Ren, *et al.*, "Superconductivity at 55 K in iron-based F-doped layered quaternary compound $Sm[O_{1-x}F_x]FeAs$," *Chinese Phys. Lett.*, 25 (6): 2215-6, June 2008. [Chinese Acad. Sci, Beijing] *306MN	45	5
4	J.Y. Kim, *et al.*, "Efficient tandem polymer solar cells fabricated by all-solution processing," *Science*, 317 (5835): 222-5, 13 July 2007. [U. Calif., Santa Barbara; Gwangju Inst. Sci. Tech., Korea] *189DC	41	7

5	J.K. Adelman-McCarthy, *et al.*, "The Sixth Data Release of the Sloan Digital Sky Survey," *Astrophys. J. Suppl. Ser.*, 175 (2): 297-313, April 2008. [84 institutions worldwide] *327WN	35	†
6	J. Bagger, N. Lambert, "Gauge symmetry and supersymmetry of multiple M2-branes," *Phys. Rev. D*, 77(6): no. 065008, 15 March 2008. [Johns Hopkins U., Baltimore, MD; King's Coll. London, U.K.] *282CF	32	4
7	Z.A. Ren, *et al.*, "Superconductivity and phase diagram in iron-based arsenic-oxides $ReFeAsO_{1-d}$ (Re = rare-earth metal) without fluorine doping," *EPL- Europhys. Lett.*, 83(1): no 17002, July 2008. [Natl. Lab. Superconduct., Chinese Acad. Sci., Beijing] *345TQ	30	†
8	M.Y Han, *et al.*, "Energy band-gap engineering of graphene nanoribbons," *Phys. Rev. Lett.*, 98(20): no. 206805, 18 May 2007. [Columbia U., New York, NY] *169WY	28	†
9	J. Dong, *et al.* "Competing orders and spin-density-wave instability in $La(O_{1-x}F_x)FeAs$," *EPL-Europhys. Lett.*, 83(2): no. 27006, July 2008. [Beijing Natl. Lab. Condensed Matter Phys., Chinese Acad. Sci.] *345TZ	28	†
10	A.G. Riess, *et al.*, "New *Hubble Space Telescope* discoveries of type Ia supernovae at z = 1: Narrowing constraints on the early behavior of dark energy," *Astrophys. J.*, 659(1): 98-121, 10 April 2007. [10 U.S. institutions] *158EF	27	3

SOURCE: Thomson Reuters Hot Papers Database. Read the Legend.

Paper #2 describes an experiment designed by Xian Hui Chen, and conducted together with colleagues at the University of Science and Technology, Hefei, China. They followed up on the Japanese discovery paper by looking at superconductivity in a related compound, $SmFeAsO_{1-x}F_x$, in which samarium is substituted for lanthanum. They aimed to see how high they could push T_c in a

layered rare-earth superconductor. In doing so they broke the record for a non-copper-oxide superconductor, by reaching T_c = 43 K, comfortably above the previous record of 39 K for magnesium diboride.

The Sm-doped material is intriguing: according to Chen, it has T_c above that suggested by standard BCS theory, which argues for the oxypnictides being unconventional superconductors. Furthermore, the jump in T_c from 26 K to 43 K just by substituting Sm for La immediately suggested that further research would produce higher T_c in layered oxypnictides doped with F.

That's where #3 takes us: in it Zhi-An Ren and colleagues from Beijing, China, report T_c = 55 K in the same F-doped compound. In fact, related experiments by this group, in which they also substituted Ce, Pr, and Nd, have shown that FeAs superconductors constitute a new family with T_c > 50 K. The high-citation rate of #3 is partly driven by the comprehensive information it gives on fabrication. The materials are grown using a high-pressure technique similar to that used for turning graphite to diamond.

Zhi-An Ren's collaboration is also responsible for #7, in which they point out that the compounds have a simple structure of alternating FeAs and ReO layers (where Re is a rare earth). Instead of doping with F to achieve superconductivity, they created vacancies of oxygen atoms in the lattice. That move creates more electron carriers, which should be a more efficient approach to the realization of superconductivity. And indeed, tuning the O content leads to the occurrence of superconductivity in a way that resembles the situation in cuprates. That's encouraging because the parallels between the two compounds suggest that the arsenides with O vacancies rather than F doping could be the more competitive choice for higher T_c.

Newcomer #9 is a paper that neatly illustrates how research on F-doped arsenides may contribute to fundamental physics. The experiments described in this paper show how F doping suppresses spin-density-wave (SDW) instabilities and leads to superconductivity. SDW is a low-energy ordered state that occurs at low temperatures. SDW inhibits the onset of superconductivity.

Superconductivity is one of the most dramatic phenomena in condensed matter physics. Part of the motivation for the groups in China and Japan is the ultimate goal: the realization of the phenomenon at room temperature. There are plenty of physicists who will state informally that room temperature operation is about as likely as cold fusion, or hot fusion. But fast progress has energized research. In 2008 there were at least seven international symposia devoted to Fe-based superconductors, and those events have no doubt propelled the citation rates. For researchers it's a matter of striking while the iron is hot!

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