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Iron-based superconductors: Current status of materials and pairing mechanism

Hideo Hosono [a,*], Kazuhiko Kuroki [b]

[a] Materials and Structures Laboratory & Materials Research Center for Element Strategy, Tokyo Institute of Technology, 4259 Nagatsuta, Midori-ku, Yokohama 226-8503, Japan
[b] Department of Physics, Graduate School of Science, Osaka University, Toyonaka, Osaka 560-0043, Japan

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ABSTRACT

Since the discovery of high T_c iron-based superconductors in early 2008, more than 15,000 papers have been published as a result of intensive research. This paper describes the current status of iron-based superconductors (IBSC) covering most up-to-date research progress along with the some background research, focusing on materials (bulk and thin film) and pairing mechanism.

Contents

* Corresponding author. Tel.: +81 45 924 5009; fax: +81 45 924 5196.
E-mail address: hosono@msl.titech.ac.jp (H. Hosono).

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1. Introduction

The dynamic formation of electron pair is prerequisite for emergence of superconductivity, while (anti)ferromagnetism emerges by long range static spin ordering. This is the reason why it is widely believed both compete with each other. Iron is a typical magnetic element with a large magnetic spin moment, and had been believed to the most harmful for emergence of superconductivity. However, the situation was totally changed since the discovery of an iron oxypnictide superconductors $LaFeAsO_{1-x}F_x$ with T_c = 26 K [1] in early 2008. This discovery sparked intense research activity on superconductivity in this system. As a consequence, more than 15,000 papers have been published to date along with several comprehensive review articles [2] and monographs [3].

What is the impact of iron-based superconductors? There will be two answers, i.e., the first is the breaking of a widely accepted belief that "iron is antagonistic against superconductivity", which led to the opening of a versatile frontier in superconducting materials. It has become clear through intense research in the last 7.5 years that iron can be a good friend for high T_c-superconductors under certain conditions. The second is a rich variety in candidate materials and in pairing interaction. It has turned out that there are many material varieties in iron-based superconductors such as 10 parent materials, 1111, 122, 111, 112, 245, 11, thick-blocking layer bearing materials, and so on (where the number denotes the atomic ratio in constituting the compound, see Fig. 2 for crystal structure of each compound). Each type has rather different electrical and magnetic properties including anti-ferromagnetic semimetal, Pauli para metal and antiferromagnetic Mott insulator.

Iron-based superconductors (IBSCs) have several unique properties such as robustness to impurity, high upper critical field and excellent grain boundary nature. These properties are advantageous for wire application. Recent progress in the performance of superconducting wires of IBSC is wide eyed, i.e., the maximal critical current has reached the level of commercial metal-based superconducting wires and exceeded under high magnetic field.

In this article we review the current status of IBSC focusing on materials and pairing mechanism along with a brief research background in order to give a comprehensive view of this rapidly growing superconductor to relevant researchers.

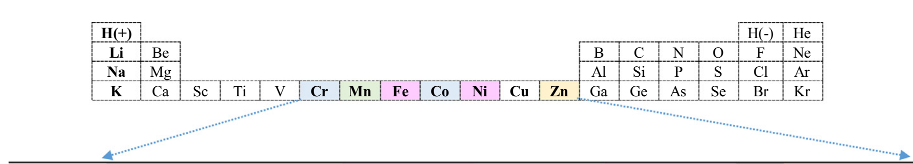
2. Materials: bulk

2.1. 3d transition metal oxypnictides

IBSC was first discovered in LaFePO [4] with T_c = ~4 K in 2006. Subsequently superconductivity was found in LaNiAsO [5] with T_c = 2.4 K in 2007 and then T_c jumped to 26 K in early 2008 for $LaFeAsO_{1-x}F_x$ [1]. The electromagnetic properties of 3d transition metal (TM) oxypnictides vary drastically with TM [6]. Fig. 1 summarizes the properties of LaTMPnO, where TM = 3d transition metal, Pn = P or As. One may see that electric and magnetic properties of layered TM oxynictides strongly depend on TM. The synthesis of early TMs and Cu oxypnictides was tried but unsuccessful even using high pressure up to ~9 GPa and no distinct correlation was found between the stability of the 1111-type compound and the kind of TM. Bulk superconductivity appears in TM = Fe^{2+} and Ni^{2+}, both of which have even number of 3d electrons but no superconductivity has found in TM = Cr^{2+} [7] with $3d^4$ electronic configuration. Undoped LaFeAsO is an antiferromagnetic metal but does not exhibit superconductivity. For TM = Mn, an exceptionally high electron doping is possible by applying H^- [8] in place of F^- as a substituent for the oxygen site and transition of antiferromagnetic insulator to ferromagnetic metal was observed but no T_c appeared. LaCoAsO is an itinerant ferromagnetic metal [9]. No T_c exceeding 10 K has been reported in the 1111 system for except the iron oxyarsenides up to date.

2.2. Parent materials

Since the paper reporting T_c = 26 K in $LaFeAsO_{1-x}F_x$, several ten superconducting materials have been reported in layered iron



TM^{2+} (3d electron number)	Cr(4)		Mn(5)		Fe (6)		Co(7)		Ni(8)		Cu (9)	Zn(10)	
Pn	P	As	P	As	P	As	P	As	P	As	P, As	P	As
Elect. Prop.		Metal	Mott Insulator		Superconductor		Metal		Superconductor			Semiconductor	
Magnetism		AF(CB)	AF(CB)				FM					Non-magnetic	
E_g		-	~1 eV		-		-		-			~1.5 eV	
T_c(SC)					Undoped: 4K	F-doped 26K			Undoped: 3K	Undoped: 2.4K			
T_{NC}(Mag)		> 300K	> 400K				43K	66K					
Ref.	S-W. Park et al. IC (2013)		Yanagi et al. JAP (2009)		Kamihara et al. JACS (2006) Kamihara et al. JACS (2008)		Yanagi et al. PRB (2008)		Watanabe et al. IC (2007) Watanabe et al. JSSC (2007)			Kayanuma et al. PRB (2007) Kayanuma et al. TSF (2008)	

(grey) : unsuccessful to synthesize CB: checker board type

Fig. 1. Summary of properties of layered LaT_MOPn compounds. (T_M: 3d transition metal, Pn = P or As).