Research Highlights

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Physical Trend for Critical Temperature in $Bi_2Sr_2CaCu_2O_8$ High-temperature Superconductors

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Abstract: Superconductivity is extremely interesting and important in condensed matter physics and material science. Currently, many types of materials exhibit superconductivity with a critical temperature (T_C) located in a large range under normal pressure. Compared with the successful Bardeen-Cooper-Schrieffer (BCS) theory for low-T_C metals, there are no effective model and theory for high-temperature superconductors. In this work, taking Y-doped $Bi_2Sr_2CaCu_2O_8$ as an example, a power law relationship is obtained for T_C and hole concentration. A large hole concentration is beneficial to realize a high T_C. This work provides useful guidance for the future discovery of high T_C superconductors.

Key words: superconductivity; critical temperature; physical trend; $Bi_2Sr_2CaCu_2O_8$

A material with electrical superconductivity can be called a superconductor, in which the zero electrical direct current (DC) resistance is observed when the temperature is lower than the critical temperature, T_C[1]. It is one of the most interesting and important fields in condensed matter physics and material science for both basic research and industry applications. Superconductivity was first found in metals with a history longer than 100 years[2]. However, the T_C in the metals is usually around several Kelvin, which only can be used for practical applications in liquid-helium temperature[3]. Later, high T_C above dozens of Kelvins[4] has been discovered in ceramic oxides. Thus, they are called high-temperature superconductors. Today, there are many different types of materials to have superconductivity under normal pressure, such as various metals[3], cuprates[5], and iron-based superconductors[6], *etc*. These materials not only enrich the family of superconductors but also greatly push the applications from liquid-helium temperature to liquid-nitrogen temperature. In contrast, the study on theoretical model for superconductivity is quite limited. The Bardeen-Cooper-Schrieffer[7] (BCS) theory is useful for low T_C metals, but it does not work for high-temperature superconductors[8]. In fact, until today, there is no successful theory for high-temperature superconductors, making the study on superconductivity quite difficult for fundamental research and practical applications[8].

1 Results and discussion

BSCCO (Bi-Sr-Ca-Cu-O) is a family of layered material with the general formula of $Bi_2Sr_2Ca_{n-1}Cu_nO_{2n+4+x}$, where n = 1, 2, or 3, and x represents the content of oxygen deviated from the stoichiometric composition[9]. Changing n gives different chemical compositions, leading to different types of materials. The main members of this family materials are Bi-2201, Bi-2212, and Bi-2223, in which the four numbers correspond to the number of Bi, Sr, Ca, and Cu, respectively. The basic structural framework in this family materials is similar. The only difference is the number of CuO_2 layers within the crystal structure. Among this family materials, Bi-2212 and Bi-2223 are of particular interest because they show relatively high superconducting transition temperatures with a T_C in the range of 20–110 K, making them standing on the top of high-temperature superconductors.

Yttrium (Y) doping is usually used to tune hole concentration (p) in BSCCO[10]. In the Bi-2212 material (the crystal structure is shown in Fig. 1[11]), Y partially substitutes Ca sites to reduce the hole concentration in the CuO_2 planes and thus to change the superconducting behavior[12]. For example, when increasing Y content, the material can change from a superconductor to a non-superconductive semiconductor with the T_C dramatically decreased to 0 K[10]. Herein, we carefully search the literature and list the T_C values of pure and Y-doped BSCCO in Fig. 2 and Table 1[10]. Clearly, when the room temperature p is decreased, the T_C is quickly decreased too. We then use different formulas to fit the experiment data. As shown in Fig. 2, we found that the experiment data follow well along the dashed line, with a curve representing the relationship of $p^{-1/6}$. Then the formula for T_C of BSCCO can be written as Eq. (1).

$$T_C = A - Bp^{-1/6} \tag{1}$$

where A and B are the fitted parameters with the corresponded values of 353.92 K and 1.112×10^7 K·m$^{-1/2}$. Eq. (1) suggests that larger A and p values are helpful for a higher T_C.

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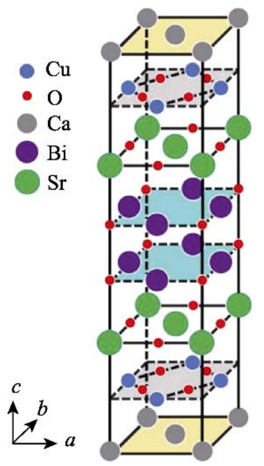

Fig. 1 Crystal structure of the Bi-2212[11]

Table 1 Physical parameters of pure and Y-doped Bi-2212 (the data are taken from the Ref. [10])

Y content	p (300 K)/(×10^{27}, m^{-3})	T_C/K
0.45	0.83	0
0.40	1.25	20
0.30	2.08	30
0.20	2.71	60
0.10	3.90	82
0	4.46	75

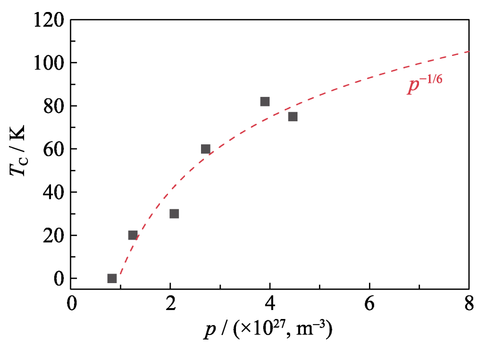

Fig. 2 T_C as a function of hole concentration (p) for pure and Y-doped Bi-2212 superconductors

The experiment data are taken from Ref. [10]

2 Conclusions

In conclusion, taking pure and Y-doped BSCCO as examples, a power law relationship is obtained for T_C and p. A large p is required for high T_C superconductors. This work thus provides a useful insight for future study on superconducting materials.

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$Bi_2Sr_2CaCu_2O_8$高温超导体中临界温度的变化规律

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摘 要：超导是凝聚态物理和材料科学领域极具研究价值且至关重要的方向。目前，已有多种材料在常压下展现出超导特性，其超导临界温度(T_C)分布范围极广。传统的 BCS 理论(Bardeen-Cooper-Schrieffer theory)成功解释了低临界温度金属的超导特性，但目前尚缺乏针对高温超导体的有效理论模型。本工作以钇(Y)掺杂的$Bi_2Sr_2CaCu_2O_8$为例，研究发现 T_C 与空穴浓度之间存在显著的幂律关系，较高的空穴浓度有利于实现高 T_C。本研究为未来新型高温超导体的研究提供了有益的理论指导。

关 键 词：超导；临界温度；物理趋势；$Bi_2Sr_2CaCu_2O_8$

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