Incommensurate structures in high-T_c superconducting crystals

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Incommensurate structures with modulation wave vectors $\mathbf{q}_1 = \delta_1\mathbf{c}^*$ and $\mathbf{q}_2 = \delta_2\mathbf{c}^*$ have been observed in $Bi_{2.2}Sr_{1.8}CaCu_2O_{8+x}$ crystals. The nature and behavior of the new and previously detected superstructures are discussed. It is concluded that the Bi–Sr–Ca–Cu–O system belongs to the family of incommensurate crystals.

During the past year, many papers have reported the observation of incommensurate superstructures in high-T_c superconductors of different types. In a Bi–Sr–Ca–Cu–O (2–2–1–2) system, for example, several types of long-period modulations in the *ab* plane have been observed simultaneously.[1–3]

Analysis of experimental data has shown that all these superstructures correspond to long-period structures with planar defects, such as oppositely phased boundaries and stacking faults, and the "incommensurability effects" are the result of combining *commensurate* (!) periods in various proportions.[2] To interpret the results, there is therefore no need in this case to resort to incommensurate structures which physically are entities of a different nature.[4] We have assumed elsewhere[5] that high-T_c superconductors have incommensurate structures, but in the correct sense of this word.

To look for incommensurate structures, we have conducted x-ray diffraction studies (Fe $K\alpha_1$ radiation) with single crystals of $Bi_{2.2}Sr_{1.8}CaCu_2O_{8+x}$. All the experimental results are shown in Figs. 1–3 (see the figure captions). The use of Fe $K\alpha_1$ radiation allowed us to detect the satellite reflections S_1 $(00l \pm \delta_1)$ of very low intensity I_{S1} $(I_B/I_{S1} \approx 10^3$–$10^4)$, which are situated on the "tails" of the Bragg reflections B with $l = 2n$ (Figs. 1 and 2). The mesh profile near the $(00l)$ reflections shows that the

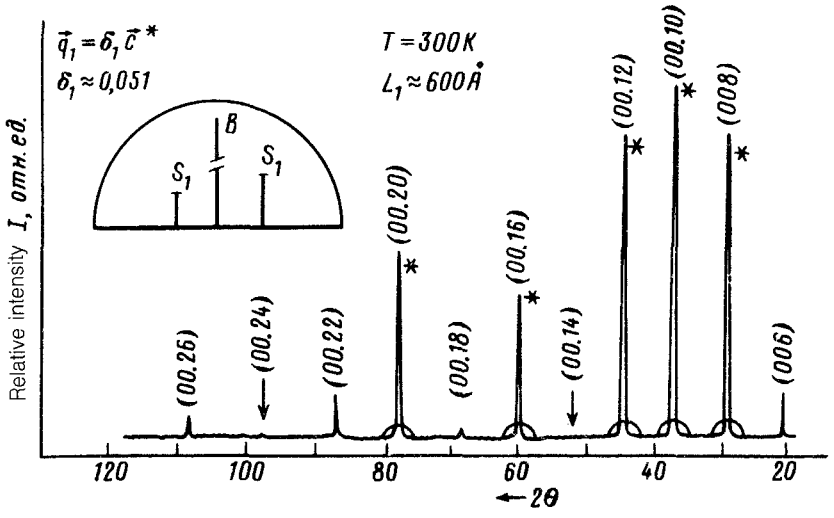

FIG. 1. The x-ray diffraction pattern of a $Bi_{2.2}Sr_{1.8}CaCu_2O_{8+x}$ crystal along the [00l] direction. The satellites S_1 ($00l \pm \delta_1$) are situated near the even reflections ($l = 2n$) represented by an asterisk. (The location of the satellites S_1 is shown schematically in the inset.) The arrows show the Bragg reflections of very low intensity. The odd reflections are absent. The delta (δ) is the incommensurability parameter and L is the modulation period.

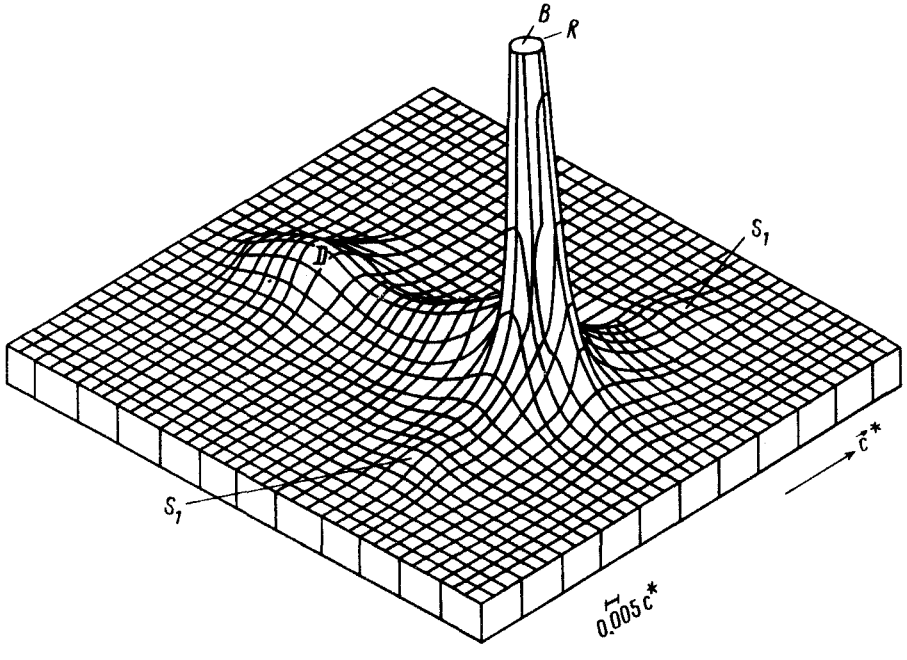

FIG. 2. Isometric representation of the profile of a reciprocal lattice point of $Bi_{2.2}Sr_{1.8}CaCu_2O_{8+x}$. S_1–Satellites; D–diffuse scattering; B–Bragg reflection; R–auxiliary reflections.

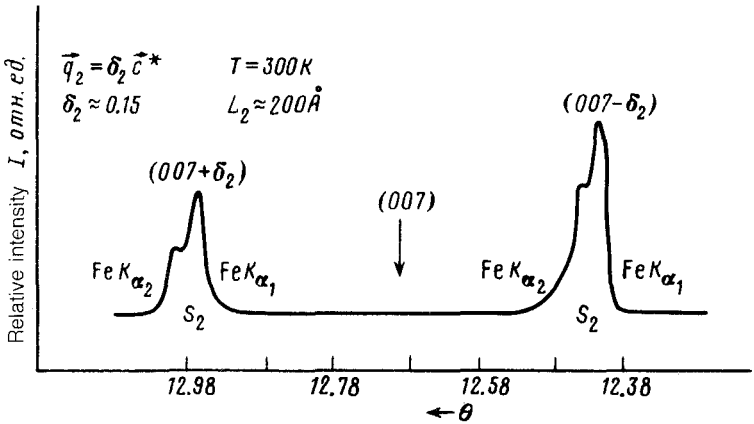

FIG. 3. Profiles of the satellites S_2 situated near the odd (forbidden) reflections ($l = 2n + 1$).

modulation wave vector is exactly parallel to the c axis, i.e., $\mathbf{q}_1 = \delta_1 \mathbf{c}^*$ ($\delta_1 \approx 0.051$ and $L_1 \approx 600$ Å, where L_1 is the modulation period) (Fig. 2).

Near the symmetry-forbidden 00l reflections ($l = 2n + 1$) we observed S_2 satellites ($00l \pm \delta_2$); $I_{S1}/I_{S2} \approx 10$, $\mathbf{q}_2 = \delta_2 \mathbf{q}^*$, $\delta_2 \approx 0.15$, and $L_2 \approx 200$ Å (Fig. 3). As the temperature is lowered, both S_1 and S_2 satellites move toward the center of the reciprocal-lattice point. The experimental results which we presented above allow us to conclude that the superstructures detected in $Bi_{2.2}Sr_{1.8}CaCu_2O_{8+x}$ are *truly* incommensurate structures. This conclusion suggests that the fundamental properties and particular features of incommensurate crystals are characteristic of high-T_c superconductors.

We note in conclusion (see Fig. 2) that in $Bi_{2.2}Sr_{1.8}CaCu_2O_{8+x}$ the Bragg reflections (00l) and their immediate neighborhood have a complex configuation: In very close proximity to the main reflection there are additional reflections R, whose nature so far is not known. A strong diffuse scattering has also been observed in this region. The answers to the questions raised here would require some temperature studies.

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[1]P. A. Abouy *et al.*, J. Phys. France **49**, 1987 (1988).
[2]R. Herrera *et al.*, Physica C **159**, 490 (1989).
[3]E. A. Hewat *et al.*, Physica C **155**, 619 (1988).
[4]R. Blinc and A. P. Levanyuk, Incommensurate Phases in Dielectrics, North-Holland, 1986, p. 402.
[5]V. V. Zaretskii *et al.*, XII European Cryst. Meeting, Moscow, August 20–29, 1989, Vol. 1, p. 540.

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