Stripes and superconductivity in the HTSC copper oxides

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Abstract

Powder diffracttion using synchrotron radiation and high pressure cell has been performed for the HTSC compound $Hg_{0.8}Tl_{0.2}Ba_2Ca_2Cu_3O_{8.15}$ in the temperature range 100 –300 K and external pressure 0 – 35 GPa. Observed structural anomalies at $T_2 \sim 240$ K and $T_1 \sim 160$ K have been attributed with stripe domain structure. A negative thermal expansion coefficient in a wide temperature range was observed at P=1 GPa. Analysis of crystal structure shows a suppression of lattice distortions connected with stripe structure by pressure. As external pressure leads to increase of T_c for investigated material, we suppose that superconductivity and stripe structure may have the same origin, but their interactions are competing. EXAFS (Cu K-edge) measurements support this conclusion.

Key words: high temperture superconductivity; stripe structure; Rietveld refinement; EXAFS spectroscopy

The influence of stripe structure on superconductivity in HTSC remains unclear from the time of the experimental observation of stripe structure, see for example [1] and references therein. Various approaches exist which consider enhancement of pair formation or pair movement due to stripe structure. The development of local lattice distortions in the CuO_2 - plane of HTSC materials at low temperature, determined by polarized Cu K-edge EXAFS measurements (see, for example, [2]) gives a significant support for these models. For HTSC copper oxides, and particularly for $Hg_{0.8}Tl_{0.2}Ba_2Ca_2Cu_3O_{8+x}$ (Hg,Tl-1223), few structural anomalies have been observed: $T_0 \sim T_c+15$ K, $T_1 \sim 160$ K and $T_2 \sim 240$ K. We connect these structural features with stripe structure [3]. External pressure leads to increase of temperature of superconductivity T_c of HTSC compounds, underdoped or nearly optimally doped by charge carriers, because of both intrinsic pressure induced structural change and increase of charge carriers concentration in "superconducting" CuO_2-planes due to charge transfer. To investigate an influence of these factors on structural anomalies the study of crystal structure of Hg,Tl-1223 at high pressure and low temperature has been undertaken.

Sample preparation and characterisation are described in ref [3]. The sample contained Hg,Tl-1223 phase (∼95%) and $BaCuO_2$ (∼5%). The superconducting transition temperature determined by ac-susceptibility measurements is 125 K, so the state of sample is underdoped by charge carriers. The high pressure/low temperature synchrotron diffraction experiment at pressure range 0-35 GPa and temperature interval 100-300 K was carried out on beamline BL10XU at SPring8, Japan. The diamond anvil cell was used as a high-pressure cell, low temperature measurements were performed using helium cryostat. The imaging plate (R-AXIS IV, 0.10 mm resolution, 300*300 mm area size) was used as the x-ray diffraction detector, λ=0.4959 A. The exposure time of each measurement was 1-2 min. The measurements at room temperature have been performed at P= 1, 3, 12, 15, 20, 35 GPa. At P= 1 and 20 GPa the measurements

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have been performed in the range 100-300 K with 5K step at cooling. GSAS program [4] was used for calculation of structural parameters, the structure model obtained in [3] was applied as initial, obtained discrepancy indexes were the following: $wR_p \sim 3 - 5\%$, $R_p \sim 3 - 4\%$, $\chi^2 \sim 3 - 5$.

Lattice volume as function of temperature at P=1 and 20 GPa is shown in Fig. 1 (the behaviour of a and c-parameters is the same), a and c as function of pressure at room temperature in whole are similar with literature data [5], Fig. 2. The standard deviations are about size of symbols. We see that compressibility for our sample is slightly less than for optimally doped one [5]. The atomic coordinates for P= 1 and 20 GPa almost do not change at temperature decrease. The BaO-layer is situated between Hg,Tl-O and CuO_2-planes and its splitting is controlled by difference of electric charge in surrounding plans. We have calculated this splitting as $\delta = c^*(z_{Ba}\text{-}z_{O3})$. This parameter for P=1 GPa and ambient pressure has the same value $\sim 0.70(5)$ A, while for P=20 GPa increases up to 1.6(1) A. This splitting has not a change by temperature, so we can conclude that the charge transfer does not occur at temperature decrease.

All structural anomalies are suppressed for P=20 GPa, while for P=1 GPa the T_0 anomaly is very weak but still noticeable and its temperature is the same as for ambient pressure. The increase of lattice volume between T_1 and T_2 (Fig. 1) is more surprised fact we observe. Together with very small calculated splitting of CuO_2-planes (for P=1 GPa this value is the same as for ambient pressure) it means that small external pressure suppress formation of stripes and leads to some intrinsic change of the material, which causes a negative thermal expansion.

EXAFS spectroscopy has been performed in Novosibirsk center of synchrotron radiation, VEPP-3 station. Magnitude of the Fourier transform of the Cu K-edge EXAFS at T= 300, 150 and 110 K, corrected for phase shift, is plotted in Fig. 3. For all peaks, except first one, where Cu-O bonds into CuO_2-plane give a contribution, there is a usual growth of intensity at temperature decrease due to Debye-Waller factor. But for Cu-O in-plane bonds the most disordered state is observed for 150 K, near T_1. We connect this feature with development of stripe structure. A decrease of temperature below T_c leads to growth of peak intensity, which we explain as suppression of stripe structure. Possibly, the difference in our EXAFS results and data described in ref. [2] may be explained by photo-domain effect [6].

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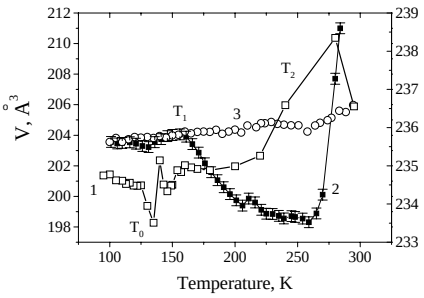

Fig. 1. Lattice volume as function of temperature for Hg,Tl-1223 (x=0.15) at ambient pressure (1, right) [3], 1 GPa (2) and 20 GPa (3).

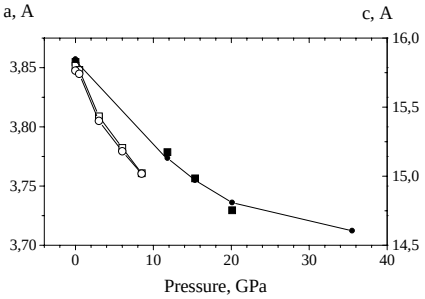

Fig. 2. Unit cell dimensions as function of pressure (data from [5] - light symbols).

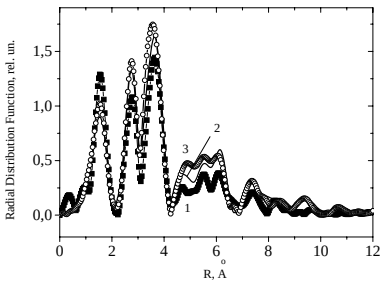

Fig. 3. The results of EXAFS spectroscopy at T=300 K (1), 150 K (2) and 110 K (3).

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