From spin- to charge-modulations in BaFe$_2$(As$_{1-x}$P$_x$)$_2$

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Introduction

The BaFe$_2$(As$_{1-x}$P$_x$)$_2$ compounds represent ‘122’ iron-pnictide superconductors with superconductivity induced by isovalent chemical doping of the BaFe$_2$As$_2$ parent compound (e.g. the partial substitution of As by P) with simultaneous suppression of the spin-density wave SDW magnetic order, see Fig. 1 [1, 2]. The samples with $x = 0$ (parent), $x = 0.10$ (under-doped), $x = 0.31$, 0.33, 0.53 (superconductors with $T_c = 27.3$ K, 27.6 K, 13.9 K, respectively) and $x = 0.70$, 0.77 (over-doped) have been studied by the $^{57}$Fe Mössbauer spectroscopy versus temperature. Representative spectra are shown at 4.2 K, 80 K and 300 K are shown in Fig. 2. Decreasing value of the average spectral shift $<\Delta\beta>$ with increasing substitution level indicates that phosphorus atoms increase the electron charge density on the Fe nuclei in BaFe$_2$(As$_{1-x}$P$_x$)$_2$ system.

Results and discussion

$x = 0.10$ (under-doped, $T_{SDW} = 106$ K)

The BaFe$_2$(As$_{0.9}$P$_{0.1}$)$_2$ sample presents strongly perturbed SDW magnetic order with $T_{SDW} = 106$ K received on the basis of the anomaly in the electrical resistivity [3]. The average magnetic field of the SDW $<\beta>$ = 4.14 T (at 4.2 K) is significantly reduced relative to the value for parent compound BaFe$_2$As$_2$ with $<\beta>$ = 5.30 T. The residual magnetic order is observed for the nematic phase in the temperature range up to 135 K, about 30 K higher than coherent SDW order and orthorhombic distortion, see Fig. 3 and Fig. 4. The nematic phase seems to be a region of incoherent spin density wavelets typical for a critical region. Nematic phase is characterized by electronic anisotropy in the crystallographic a-b plane with broken rotational symmetry, but preserved translational symmetry (tetragonal structure) [1].

$x = 0.31$ (superconductor, $T_c = 27.3$ K)

The BaFe$_2$(As$_{0.7}$P$_{0.3}$)$_2$ sample presents traces of the magnetic order below 50 K, so within the superconducting state, see Fig. 4 and Fig. 5. The coexistence of magnetism and superconductivity is due to vicinity of the quantum critical point for this composition. No change in the average magnetic field $<\beta>$ at the critical temperature is observed. Spectra above 50 K are described by the distribution of the electric field gradient.

$x = 0.33$ and $x = 0.53$ (superconductors, $T_c = 27.6$ K and 13.9 K, respectively)

The BaFe$_2$(As$_{0.7}$P$_{0.3}$)$_2$ and BaFe$_2$(As$_{0.5}$P$_{0.5}$)$_2$ sample display distribution of the electric field gradient (EFG) in the whole temperature range. A distribution is caused by perturbation of the iron surrounding in the Fe-As layer by the phosphorus atoms. It was found that the average quadrupole splitting $<\Delta\beta>$ varies at the critical temperature for optimally doped superconductor probably due to the superconducting gap opening and subsequent formation of the Cooper pairs, see Fig. 5 and Fig. 6. The similar effect was observed previously for others iron-based superconductors [4, 5], wherein the perturbation of the spatial modulization of the EFG being a consequence of the incommensurate modulization of the electron charge density on the Fe nuclei. No change in the charge modulations is observed for the over-doped samples.

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References