Doping dependence of spin excitations in $BaFe_{2-x}Ni_xAs_2$

H. Q. Luo[1], Z. Yamani[2], Y. C. Chen[1], S. L. Li[1], T. A. Maier[3] and P. C. Dai[4,1]

[1] Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
[2] NRC Canadian Neutron Beam Centre, Chalk River Laboratories, Chalk River, ON, Canada K0J 1J0
[3] Computer Science and Mathematics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831 USA
[4] Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996-1200, USA

Magnetic fluctuations are thought to be responsible for electron pairing in copper oxide and iron pnictide superconductors as their low energy spin dynamic behavior appears to be directly connected with superconductivity [1, 2]. Thus a detailed derivation of magnetic excitations is required to fully understand the underlying mechanism in these novel superconductors. Similar to cuprates, the parent compounds of iron pnictides exhibit long range antiferromagnetic (AF) order below a Néel temperature (T_N) and superconductivity rises when the AF order is gradually suppressed by electron or hole doping [2].

In order to gain insight on the relation between magnetic and superconductivity in electron doped $BaFe_{2-x}Ni_xAs_2$, we extensively explored low energy spin excitations throughout its phase diagram (see Fig. 1(a) from Ref. [3]). High quality $BaFe_{2-x}Ni_xAs_2$ single crystals were grown by FeAs self-flux method as described previously [3]. Neutron scattering experiments were performed on C5 thermal neutron triple-axis spectrometer at Canadian Neutron Beam Center. The final neutron energy was set to E_f =14.56 meV with pyrolytic graphite (PG) as vertically focusing monochromator and flat analyzer. The collimations were set to [none, 0.8°, 0.85°, 2.4°]. We define the wave vector **Q**(H, K, L) = ($2\pi H/a$, $2\pi K/b$, $2\pi L/c$) where **Q**(H, K, L) is given in reciprocal lattice units (r.l.u.) using the orthorhombic unit cell, with a = b = 5.62 Å, and c = 12.77 Å. In this configuration, the AF vector in reciprocal space is $\mathbf{Q}_{AF}$ = [H, 0] or [0, K]. Six doping levels are studied in this experiment as indicated by arrows in Fig. 1(a):

- x = 0.03 (slightly underdoped, T_N = 107 K and non-superconducting),
- x = 0.065 (underdoped, T_N = 72 K and T_C = 8 K),
- x = 0.092 (nearly optimal doped, T_N = 40 K and T_C = 19 K),
- x = 0.12 (slightly overdoped, without long-range AF order and T_C = 19 K),
- x = 0.15 (overdoped, T_C = 14 K), and
- x = 0.18 (overdoped, T_C = 9 K).

To increase the sample volume, for each doping several crystals were co-aligned in the [H, 0, H] and [0, -K, 0] scattering plane with ~23.5° between c-axis and the vertical direction. Thereby momentum transfers both along transverse (TR) and longitudinal (LO) directions with L = 0 and 1 were accessible (as shown by the labels in Fig. 1(b), see also [5]).

We find that unlike the parent compounds which exhibit resolution-limited AF spin waves dominated by local moments [4], the momentum distribution of the spin excitations is transformed to an anisotropic ellipse in [H, K] plane upon doping electrons into the system (Fig. 1(b)). This suggests additional contribution from the itinerant magnetism. The observed peak widths in both transverse and longitudinal directions have a linear doping dependence (Fig. 1(c)), displaying a slight enhancement of anisotropy upon doping (Fig. 1(d)). Although larger peak width and incommensurability are predicted by the RPA calculation based on a rigid band shift model in pure itinerant magnetism picture [5], the magnitude of in-plane anisotropy generally agrees with the experimental results. Furthermore, the low energy spin excitations in the overdoped sample with x = 0.15 seem to form two incommensurate peaks with small deviation about δ = 0.1 (r.l.u.) along K direction which is found to be favored by superconductivity at low temperatures. We also find evidence for a clear spin resonance which appears below T_c for samples with doping around x = 0.10 (optimal doping for superconductivity) consistent with previous studies [6]. The peak intensity of low energy spin excitations decreases by further electron doping and vanishes near the overdoped border of superconducting dome (Fig. 1(e)). These results strongly suggest that the superconducting electron pairing in iron-pnictide is mediated by itinerant AF fluctuations at low energies [7].

References

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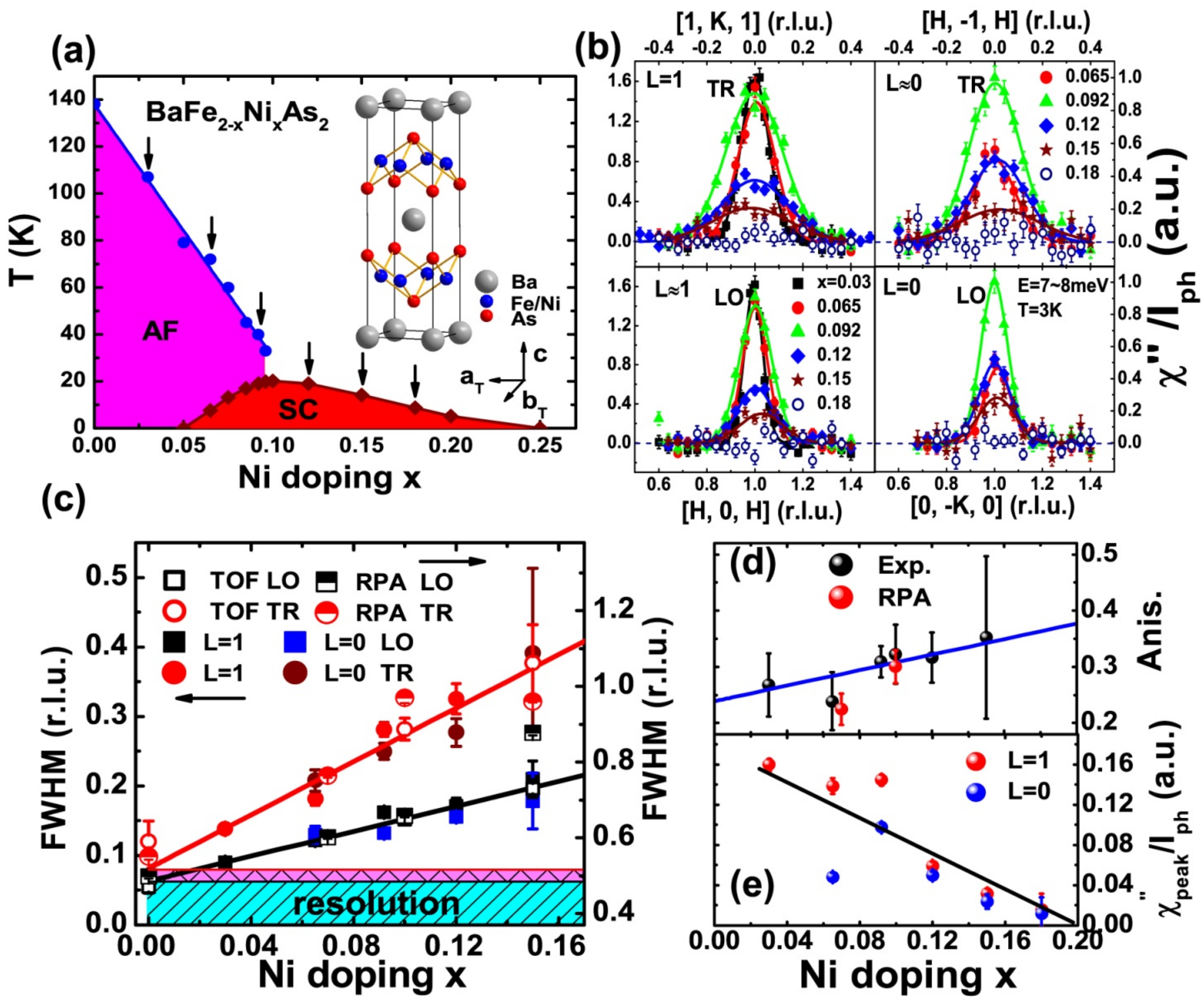

Fig. 1 (a) Phase diagram and crystal structure of $BaFe_{2-x}Ni_xAs_2$. (b) Transverse and longitudinal Q-scans for different dopings. (c-e) Doping dependence of peak width, anisotropy and peak intensity of spin excitations at E = 7 to 8 meV.