Solid State Communications 208 (2015) 29–33

Contents lists available at ScienceDirect

Solid State Communications

journal homepage: www.elsevier.com/locate/ssc

Paramagnon excitations' theory for resonant inelastic X-ray scattering in doped plane copper oxide superconductors

I.A. Larionov [a,b,*]

[a] Institute of Physics, Kazan Federal University, Kremlevskaya 18, 420008 Kazan, Russia
[b] National University of Science and Technology "MISIS", Leninskij avenue 4, 119049 Moscow, Russia

ARTICLE INFO

Article history:
Received 29 January 2015
Accepted 23 February 2015
Communicated by A.H. MacDonald
Available online 3 March 2015

Keywords:
A. Copper oxide superconductors
D. Paramagnons
E. Resonant inelastic X-ray scattering (RIXS)

ABSTRACT

A relaxation function theory with paramagnon excitations for doped $S=1/2$ two-dimensional Heisenberg antiferromagnetic system in the paramagnetic state is given in view of magnetic response of high-T_c copper oxide superconductors as obtained by resonant inelastic X-ray scattering (RIXS). The results of the theory on Nd(La)–Ba(Sr)–Cu–O and Y–Ba–Cu–O family compounds give fair agreement without especially adjusted parameters to RIXS data. It is shown that RIXS data analysis depends on paramagnon damping and thus affected by approximations made for dynamic spin susceptibility.

1. Introduction

The major part of research to understand the mechanism of high-temperature superconductivity has been focused on evolution of spin excitations' spectrum from antiferromagnetic (AF) state to superconducting (SC) state of layered cuprate high temperature superconductors (high-T_c) [1–4] with doping. In the carrier free regime the elementary excitations in high-T_c's are spin waves (magnons in the quasiparticle language) [5–7], and this concept has been widely used for description of two-dimensional (2D) (anti-)ferromagnets and thoroughly investigated in the past [8]. Therefore it is tempting to consider the doped 2D Heisenberg AF (2DHAF) systems in terms of magnon excitations (strictly speaking, paramagnon excitations, a notation used for spin fluctuations in representation of *damped* spin waves or, if we want to be cautious, paramagnon-like excitations). The motion of charge carriers even in the optimally doped (maximum T_c) high-T_c's is known to take place in the presence of strong AF fluctuations [9,10] and spin waves in 2DHAF systems persist even without long range order in the paramagnetic state [5–8,11]. Thus the concept of damped spin waves, paramagnons in the quasiparticle language, appears to be the clue in explaining the spin dynamics in normal, non superconducting, state of plane copper oxide high-T_c's [1,12,13] and shall be accounted for in studies down to the superconducting state.

Because of technique limitations the experimental research of doped cuprates has been focused mainly on low energy elementary excitations in narrow range of wave vectors of the Brillouin zone. Recent Resonant Inelastic X-ray Scattering (RIXS) experiments [13,14] gave information about the imaginary part of dynamic spin susceptibility along the [100] direction and are complementary to neutron scattering (NS) studies that are focused mainly on the wave vectors around the AF wave vector $\mathbf{Q}=(\pi,\pi)$. The general theory of RIXS by collective magnetic excitations is given by Haverkort [15].

Evidence for spin waves in underdoped $YBa_2Cu_3O_{6.35}$ with $T_c=18$ K, where the magnetic excitations are very similar to that of carrier free 2DHAF systems, was reliably obtained from NS studies [16] in the nearly optimally doped $YBa_2Cu_3O_{6.85}$ showed that AF spin excitations of copper oxide high-T_c emanate in the overall doping range from those of the parent insulator, i.e., the spin waves [17].

RIXS data confirmed the existence of damped paramagnon excitations [13,14] in the majority of superconducting cuprates, and properties that correspond to the presence of damped spin excitations (paramagnons) with dispersion that is close to magnons in cuprates without charge carriers – AF insulators. Experimental spectra for all studied systems covered a wide range of compounds and doping levels: AF carrier-free $Nd_{1.2}Ba_{1.8}Cu_3O_6$, heavily underdoped $Nd_{1.2}Ba_{1.8}Cu_3O_7$ and $YBa_2Cu_3O_{6.6}$ (with $T_c=65$ K and 61 K, respectively), underdoped $YBa_2Cu_4O_8$ ($T_c=80$ K) and lightly overdoped $YBa_2Cu_3O_7$ ($T_c=90$ K), and $La_{2-x}Sr_xCuO_4$ from underdoped, $x=0$, to heavily overdoped $x=0.4$ regimes, that proves the existence of damped paramagnons, that is, clearly well-defined magnetic excitations of cuprates with various doping levels.

* Correspondence address: Institute of Physics, Kazan Federal University, Kremlevskaya 18, 420008 Kazan, Russia.
E-mail address: Larionov.MRSLab@mail.ru

http://dx.doi.org/10.1016/j.ssc.2015.02.016
0038-1098/