Neutron scattering study of incommensurate scattering in lightly doped $La_{2-x}Ba_xCuO_4$ single crystals

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The discovery of high temperature superconductivity in 1986 by Bednorz and Muller has had a profound effect on the world of physics for the past two decades [1]. In particular, the study of cuprate superconductors, which includes materials such as $La_{2-x}Ba_xCuO_4$ (LBCO), $La_{2-x}Sr_xCuO_4$, $YBa_2Cu_3O_7$ and $Bi_2Sr_2Ca_2Cu_3O_{10}$, has been a very stimulating field of research. While $La_{2-x}Sr_xCuO_4$ has been well studied, experiments involving its sister material, $La_{2-x}Ba_xCuO_4$, have been relatively limited. This has been the case until the past decade during which advances have been made using the floating zone image furnace technique [2]. This method of crystal growth has yielded high quality single crystal samples appropriate for neutron studies. Neutron scattering experiments have been undertaken in order to understand the relationship between magnetism and superconductivity in these materials.

It has been demonstrated that these materials have complex phase diagrams that are extremely sensitive to dopant concentration [3]. Differences in the phase diagrams, however, indicate the sensitivity of the relationship between the chemical, magnetic and electronic phases in these materials [4]. In order to study the interplay of these properties, we have grown several high quality single crystal samples of LBCO. Previous studies have shown the evolution of a doping dependent incommensurate magnetic structure in the underdoped but superconducting region, which is consistent with the stripe ordering regime for the cuprates [5,6]. To extend this study to even lower doped region of the phase diagram, we performed neutron scattering experiments on non-superconducting underdoped LBCO single crystals with doping $p \leq pc$ (critical doping for superconductivity) to $p = 0$ (the undoped parent compound).

This study was conducted on the N5 triple axis spectrometer with flat PG-002 monochromator and analyser crystals. The measurements were performed with a fixed final energy of $E_f = 1.2363$ THz ($\lambda_f = 4$ Å). A liquid nitrogen cooled Be filter was used in the main beam to eliminate higher order wavelength neutrons. In order to be able to observe any incommensurability and hence achieve a high q-resolution, in addition to using cold neutrons (4 Å), we used a tight collimation setting of [none, 0.2°, 0.27°, 1.2°]. The crystals were oriented in the (HK0) plane in the tetragonal unit cell notion and cooled in a displex closed-cycle refrigerator with exchange gas. Elastic neutron scattering was performed to probe the evolution of static magnetic ordering as a function of doping and temperature. Samples ranged in doping from x = 0 to x = 0.025. Figure 1 shows typical scattering observed around the antiferromagnetic peak (½, ½, 0) as a function of temperature for an LBCO low-doped sample, x = 0.0125. The images on the left of this

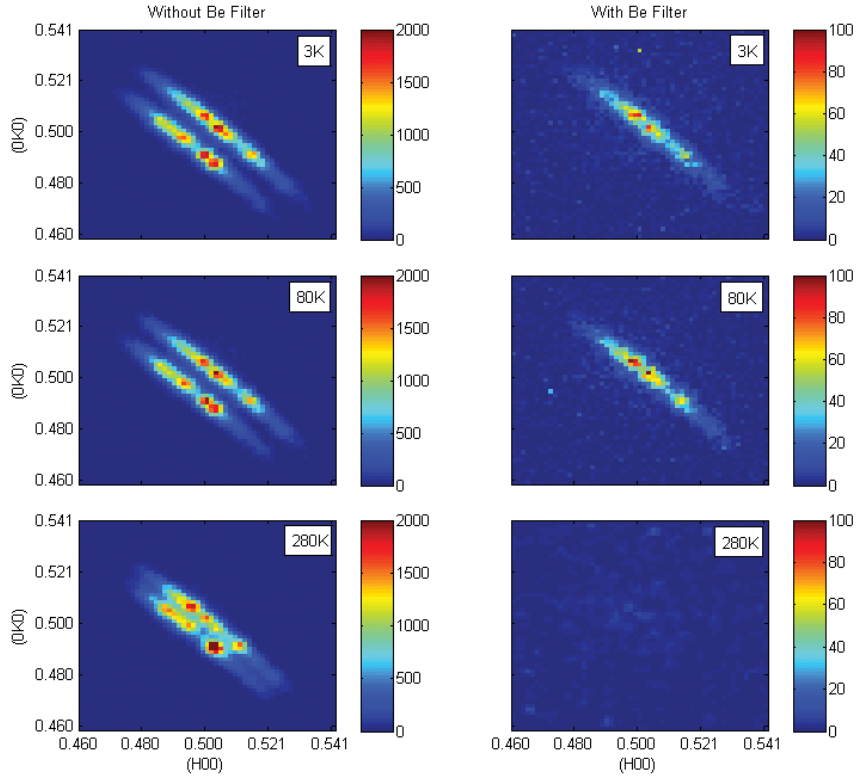

Fig 1. Observed scattering around the antiferromagnetic point (½, ½, 0) for LBCO x = 0.0125 at different temperatures without the filter (left panels) and with the filter (right panels).

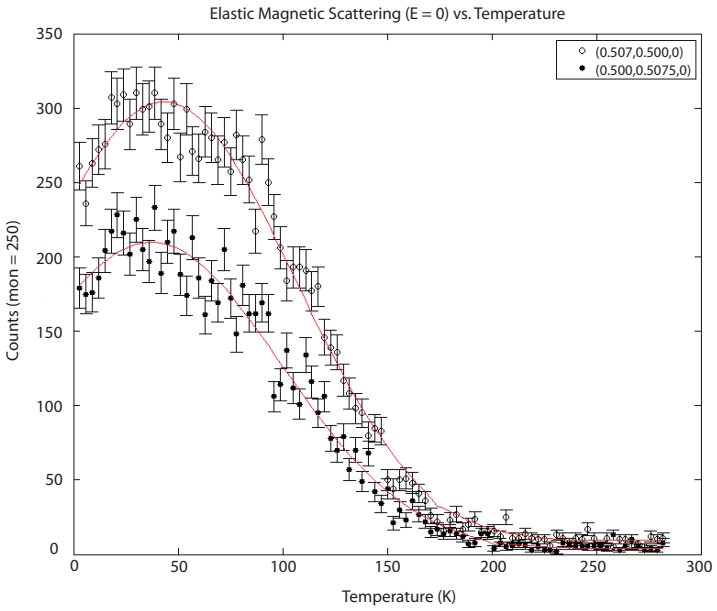

Fig 2. The temperature dependence of the intensity observed at two locations in the magnetic peak. A maximum is seen around 45 K.

figure show the scans taken prior to filtering. These panels clearly display higher order contamination of the scattering at (½ ½ 0) due to the (1 1 0) Bragg reflection. The two peaks are a result of the orthorhombicity of the material at this doping. The peak separation clearly increases as the temperature is decreased, showing the distortion of the lattice parameters upon cooling.

The panels to the right of figure 1 show the corresponding mesh scans taken with the cold beryllium filter in the main beam. The secondary peak is eliminated as the higher order scattering is filtered out. The magnetic scattering increases upon cooling to below ~ 200 K and is observed down to 3 K. The fact that the magnetic scattering is only observed on the high-q side of the Bragg position (½ ½ 0) indicates that the magnetic moments are aligned in the basal plane parallel to the longer axis in this plane. This is similar to the magnetic structure observed for pure $LaCuO_4$ [7].

Figure 2 shows the scattering intensity as a function of temperature for two positions on the peak. This figure clearly demonstrates the onset of magnetic ordering as the sample is cooled. The scattering gradually increases upon entering into the antiferromagnetic phase with a T_N ~ 180 K. This magnetic scattering continues to develop, reaching a maximum around T = 45 K below which it starts to decrease as the temperature approaches 3 K.

The trend seen in the data could indicate that the material enters the antiferromagnetic phase which is characterized by three-dimensional Bragg scattering which at very low temperatures evolves into a two-dimensional 'rod' of scattering along the L direction. The loss of intensity below 45 K would mark such a transition. In this case, the three-dimensional Bragg scattering is smeared along L as the antiferromagnetism becomes disordered in the c* direction. This phenomenon is observed for other doping levels as well. This result is unique in that there have been no observations of two-dimensional scattering in the barium doped system. Further experiments to study the behaviour of magnetic scattering along the L direction are required in order to confirm the result.

Our studies on samples with even lower doping levels than x = 0.0125 indicate that they also exhibit qualitatively similar behaviour. However, we find that the temperature at which the magnetic scattering appears is inversely scaled with doping (i.e. for lower doped samples the temperature scale is higher). In addition, we have also observed that the location of the magnetic scattering (incommensurability) changes with doping. The incommensurability becomes smaller as one moves towards the pure material. Peak width is also affected by changes in doping. A smaller width is observed for samples with smaller doping, indicating that the magnetic correlation length becomes larger as doping is reduced. Further quantitative analysis of the data is required to derive absolute values of the correlation lengths and incommensurability vs. doping.

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