Phonons in High-Temperature Superconductors by Inelastic X-Ray Scattering

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Investigation of the coupling of lattice vibrations to the electronic system (electron-phonon coupling, epc) in high-T_c superconductors is important both to understand the behavior of these highly correlated materials, and in its relevance to their superconducting properties. Meanwhile, meV-resolved inelastic x-ray scattering, with its unique ability to measure atomic-scale dynamics of small samples, allows systematic phonon studies in a way never before possible. We use inelastic x-ray scattering to extend phonon studies of superconductors into several new materials, allowing both common aspects and new features of their phonon spectra to be identified.

The high-energy in-plane longitudinal Cu-O bond-stretching mode behaves similarly in several hole-doped materials. This mode is known to anomalously soften from earlier neutron scattering studies [1] on $La_{2-x}Sr_xCuO_4$ (LSCO) and $YBaCu_2O_{7-\delta}$ (YBCO). We show similar softening exists in $HgBa_2CuO_{4+\delta}$ (Hg1201) [2] and $La_{1.8-x}Eu_{0.2}Sr_xCuO_4$ (LESCO) [3]. Also, in all cases, a change in character of the mode is visible at about 3/5 of the distance to the zone boundary. The doping dependence of this softening in LSCO seems to correlate with T_c [4], while in near optimally doped YBCO, *ab-initio* calculations [5] that show generally good agreement with our data, fail in the region of the bond-stretching mode [6]. Thus we provide evidence both for the unusual nature and the universality of the softening of this mode.

Other work focuses on the c-axis polarized modes. We confirm the unusual temperature dependence of the buckling mode in YBCO [6] seen previously in INS work [7], with softening and broadening of the mode observed below T_c. We then investigate the two-layer bismuth compound, $Bi_2Sr_2CaCu_2O_{8+y}$ (Bi2212) [8]. Here we find the equivalent buckling mode is not visible, but that another mode appears when the temperature is reduced below T_c. This is interesting both because the temperature dependence is relatively strong, and because the mode energy and q-dependence does not seem to correlate well with known (raman-active) phonon modes.

Finally, we consider a next generation IXS instrument [9]. The previously shown data clearly demonstrate that IXS measurements are severely flux limited. A suitably optimized insertion device operating at a long straight section at SPring-8 can provide an order of magnitude more flux than presently available. While such an optimized design includes an unprecedented 50 kW total power and 1.5 kW in the central cone, there appears to be a viable path through these difficulties [9].

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