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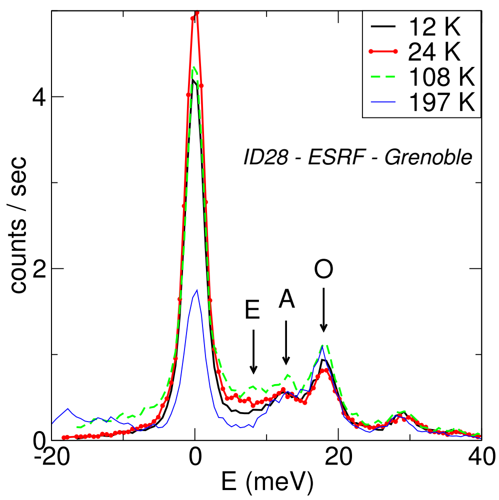
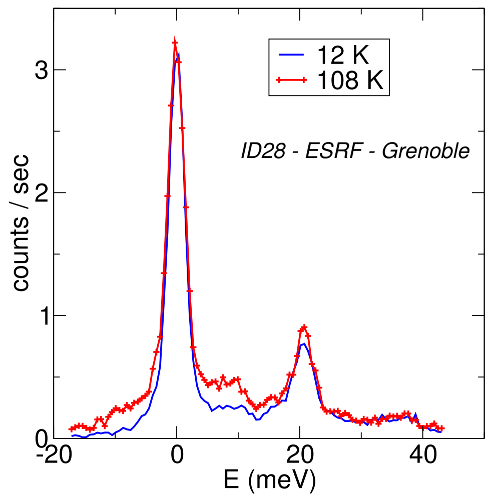
Report:
It is believed that the Cu-O planes in cuprates for example in $La_{2-x}Sr_xCuO_{4+\delta}$ high temperature superconductors (HTS) are in a particular quantum state, with separation between charge and spin. One may then expect to observe excitations associated to this new phase, which could eventually develop a Goldstone mode, if the phase condenses in an ordered charge (and spin) modulation. This has been recently claimed on the basis of the Raman response of $La_{2-x}Sr_xCuO_{4+\delta}$ [1, 2, 3]. The authors of Ref. [1] observe a mode at about 30 cm^{-1} for $T < 50K$, which has been further confirmed by Sugai and co-workers [3]. The latter observe also a second mode at higher energy ($\approx 80\ cm^{-1}$), and interpret the two modes in a framework of the charge density wave theory as, respectively, the phason and amplitudon modes associated with the charge modulation. More recently, another group claimed, in contradiction with the work mentioned above, that the dynamical excitation associated with the stripe modulation can be observed as a sharp softening, similar to a Kohn anomaly, in the dispersion of the phonon mode associated with the copper-oxygen bond-stretching mode [4].
In a recent experiment [5, 6] on the Cu-O bond-stretching mode in $La_{2-x}Sr_xCuO_{4+\delta}$ ($x = 0.08$), we found some additional intensity at about 10 meV ($\approx 80\ cm^{-1}$).

We investigated the origin of that intensity in the experiment reported here. The sample of $La_{2-x}Sr_xCuO_{4+\delta}$ with nominal $x = 0.08$ was superconducting with a measured $Tc = 21\ K$ consistent with the nominal doping. We note that for this concentration ($x = 0.08$), the authors of Ref. [3] measure the strongest Raman intensity for the supposed phason and amplitudon modes.
The most striking results we obtained are shown in Fig. 1, where we plot inelastic x-ray scattering (ixs) intensity as a function of energy for a reduced wave-vector $q = (0.25, 0, 0)$ measured for temperatures ranging from 12 to 197 K. At energies below the longitudinal acoustic (A, $\approx 13\ meV$) and first optic (O, $\approx 20\ meV$) modes, we observe additional intensity (E, $\approx 9\ meV$) for temperatures $T \leq 110K$.

Fig 1: Q = (3.25 0 0)



We note that the intensity in the $\sim 9\ meV$ energy (E) grows up from 12 to 108 K roughly of a factor 2, but then vanish for $T = 197\ K$. This is not compatible with any possible artifact like multiple-phonon scattering [7] or forbidden modes (like *e.g.* transverse acoustic in longitudinal configuration). These would become stronger with temperature according to Bose statistics, and would be strongest at room temperature. These changes with temperature of the intensity of mode E are also incompatible with a signal only due to the tail of the elastic line. Indeed, the intensity of the E mode at 108 K is significantly higher than the one at 24 K, while the elastic line intensity decreases by about 20%.
In Fig. 2 we show the intensity change at a reduced wave-vector $q \approx (0.4, 0, 0)$, from 12 to 108 K. The effect is even more obvious thanks to a very small dynamical structure factor for the acoustic line.

Fig. 2: Q = (3.387 -0.04 0)


Having excluded contributions from artifacts, we must account for the presence of a new excitation. After refinement, we found an energy position of about 74 cm^{-1}. This could be compared with the $\approx 80\ cm^{-1}$ found by Sugai and co-workers for the mode they interpret as an amplitudon. The temperature dependance confirms the Raman results, with the signal disappearing at room temperature. The initial increase of intensity from $\approx 10K$ to $\approx 100K$ could be due to the Bose factor. Note that while Raman scattering directly probes charge excitations, inelastic x-ray and neutron scattering [8] probe related density fluctuations. Finally, we point out that no signature of a similar dynamical contribution is described in neutron scattering investigations, despite the large number of experiments made on cuprates. This could be explained by the fact that inelastic neutron scattering background has a strong, temperature dependent contribution. In comparison, the nearly background-free nature of the ixs technique allow one to sort out additional contributions to the usual 1-phonon collective excitations, as pointed out in Ref. [7].

This is the first observation using IXS of the dynamical response of charge modulation in cuprates as reported by Raman experiments, [1, 3] and a publication [9] is in preparation. Given the flexibility of IXS to look at different areas of the BZ, this opens up exciting possibilities of investigation to confirm the validity of the interpretation in terms of dynamical response of charge modulations dues to phase separation. We propose to investigate systems where stripes are believed to be quasi-static as in $La_{2-x}BaxCuO_{4+\delta}$ for $x \approx \frac{1}{8}$ [4], as one would expect a stronger signal due to better ordering.

References

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