	Experiment title: Uniaxial strain study of the charge density wave and the electron-phonon coupling in underdoped cuprates	**Experiment number**: HC3414
Beamline:	**Date of experiment**: from: 18.10.2017 to: 24.10.2017	**Date of report**: 19.02.2018
Shifts:	**Local contact(s)**: S.M. Souliou	*Received at ESRF:*

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Report:

The purpose of the current experiment was to complete and extend our earlier investigations of the effect of uniaxial compression on superconducting cuprates. More specifically, we used large uniaxial pressures to tune the well-established competition between high-temperature superconductivity and charge ordering in $YBa_2Cu_3O_{6.6}$.

As in our previous experiment [1], we have successfully used a tailor-made piezoelectric-based apparatus [2] which fits in the continuous flow He-cryostat of ID28. Moreover, we have prepared needle-shaped samples (1.3 mm x 120 μm x 200 μm) of high quality detwinned $YBa_2Cu_3O_{6.6}$ crystals (T_c = 65 K) which were further thinned down to ~50 μm on their central part using a plasma focused ion beam setup. This served the double purpose of having sample thicknesses matching the absorption length at the used x-rays energy (17.794 keV) and of reaching a maximum compression without the breaking or buckling of the sample. The strain was applied along the needle axis which coincided with the crystallographic *a*-axis and was calibrated using a capacitance sensor and following the angular shift of the Bragg reflections.

We collected inelastic spectra in the energy range from -5 to 25 meV, following the acoustical and optical phonon dispersions along the [010] and [001] directions. The reference spectra that we collected at unstrained conditions were in excellent agreement with our previous results, showing a low temperature enhancement of the central quasi-elastic peak intensity maximized at T_c and a superconductivity-induced Kohn anomaly, both sharply localized around the 2D charge density wavevector $\boldsymbol{q}^{2D}$ = (0, 0.31, 6.5) [3].

Starting from the elastic part of the spectra, the uniaxial strain-dependence of the quasi-elastic line intensity below T_c across $\boldsymbol{q}^{2D}$ and along the [010] direction is shown in Fig. 1A. The quasi-elastic peak at $\boldsymbol{q}^{2D}$ continuously increases under a-axis uniaxial compression, as was also observed in our previous experiment [1]. The much higher uniaxial compressions that we reached in the current experiment (up to -1.3 %) led to a doubling of the intensity at $\boldsymbol{q}^{2D}$.

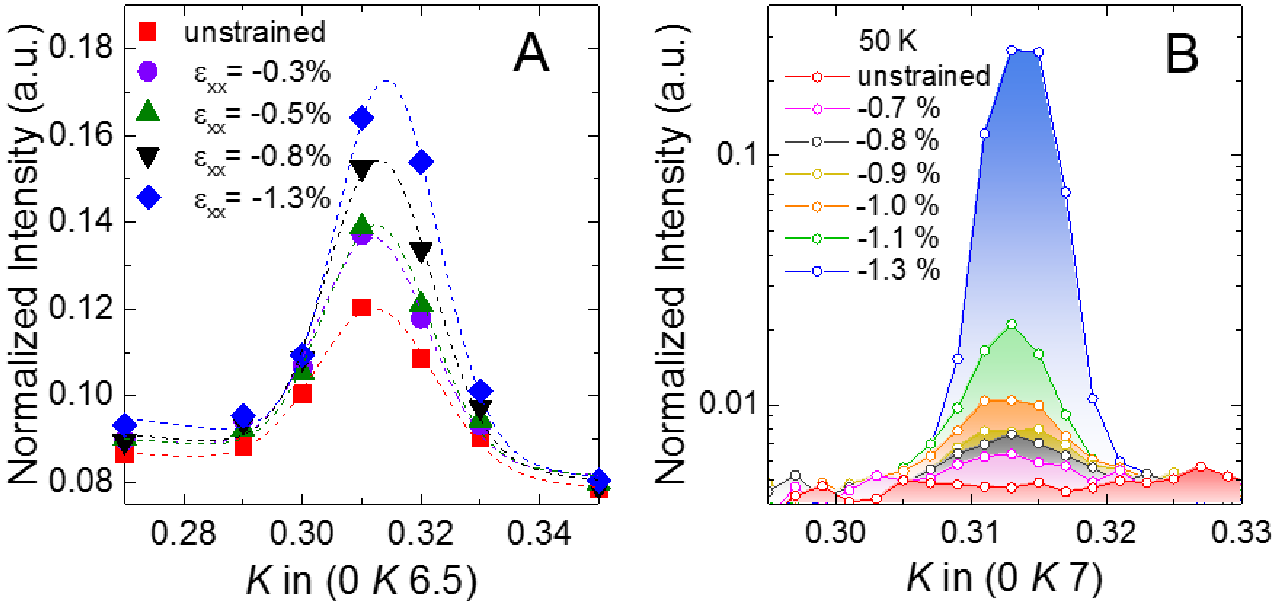

Fig. 1. Strain-dependence of the quasi-elastic line intensity recorded (A) below T_c across $\boldsymbol{q}^{2D}$ along the (0 *K* 6.5) direction and (B) at T= 50 K along the (0 *K* 7) direction.

Most notably, for compressions higher than -1 % we observed a modulation at $\boldsymbol{q}^{3D}$ = (0, 0.31, 7), which unlike the one at $\boldsymbol{q}^{2D}$, is long-ranged and 3D. The new modulation observed under uniaxial compression is reminiscent to the one previously observed under magnetic fields large enough to sufficiently weaken superconductivity (> 20 T) [4-6]. The quasi-elastic intensity at T = 50 K along the (0 K 7) direction as function of a-axis compression is plotted in Fig. 1B. The available beamtime, which was further reduced by ~30% due to a failure of the ESRF water network system during the experiment, did not allow for a detailed mapping of the temperature-uniaxial strain phase diagram. We are currently developing a piezoelectric apparatus suitable for fitting in the cryostat of the ID28 diffuse scattering side station, which will allow us to perform such an investigation in the future.

Moving on to the inelastic part of the spectra, we plot in Fig.2 the phonon spectra across $\boldsymbol{q}^{3D}$ along the [010] direction recorded below T_c under -1.3 % a-axis compression, together with the results of a fit to damped harmonic oscillator profiles. Away from $\boldsymbol{q}^{3D}$ the observed phonons are in agreement with the results of ab-initio calculations: they correspond to an acoustic phonon mode at ~8 meV, two experimentally unresolved optical modes centered at ~11 meV and an optical mode at ~15 meV. Around $\boldsymbol{q}^{3D}$ we observe some additional low energy spectral weight below ~7 meV (blue arrows in Fig.2) originating from an optical phonon mode which sharply softens and crosses the acoustic phonon dispersion. The pressure and temperature dependence of this mode reveals that it eventually softens completely and drives the formation of the 3D long-range order. Our results clearly demonstrate the leading role played by electron-phonon interaction (EPI) in the formation of the long-range CDW order and its competition to high temperature superconductivity.

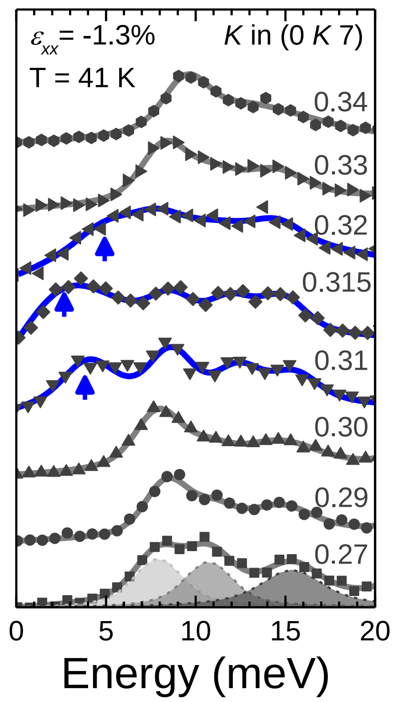

Fig. 2. Inelastic x-ray scattering intensity recorded across $\boldsymbol{q}^{3D}$ along the (0 *K* 7) direction under uniaxial compression -1.3% at T = 41 K. The spectra have been vertically shifted for clarity. The solid grey/blue lines show the total fit of the inelastic intensity to damped harmonic oscillator profiles and the dashed grey lines show the individual phonon profiles. The blue arrows indicate the additional spectra weight appearing around $\boldsymbol{q}^{3D}$.

References:
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