	Experiment title: Effect of uniaxial strain on CDW in underdoped YBCO	Experiment number: HC-2792
Beamline: ID-27	Date of experiment: from: 2016.11.16. to: 2016.11.18	Date of report: 03/03/2017
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Report:

The principal aim of this proposal was to determine the response to uniaxial strain of charge density wave (CDW) in $\text{YBa}_2\text{Cu}_3\text{O}_{6.67}$ superconductor using single crystal X-ray diffraction (XRD) technique.

In particular we were interested to clarify if the reported bi-axial CDW structure in 123-type underdoped cuprates comes from a genuine 2D checkboard modulation or is generated by a similar distribution of orthogonal uniaxial domains in the Cu-O planes.

In fact, uniaxial strain is expected to affect in very different ways the two possible electronic orders: applied along one of the charge modulation direction should in principle align (or partially detwin) the uniaxial charge domains, whereas it would affect marginally a 2D checkboard structure.

To address this objective, we used a recently developed piezoelectric-based strain device [1] carefully designed to fulfill the transmission geometry of ID-27 beamline (large opening of $\sim 160^\circ$ that allow to access a considerable fraction of the reciprocal space, see (c) in **Fig. 1**). Was also designed and prepared an adapter to suitably fit the device inside the high-pressure He-flow cryostat in ID-27 and guarantee a good thermal contact between the strain apparatus, the adapter and the cryostat itself (see (a) and (b) in **Fig. 1**). In this way we were able to control both temperature and applied strain in order to investigate the dependence of Bragg's reflections and (incommensurate) CDW modulation peaks with respect to these two parameters.

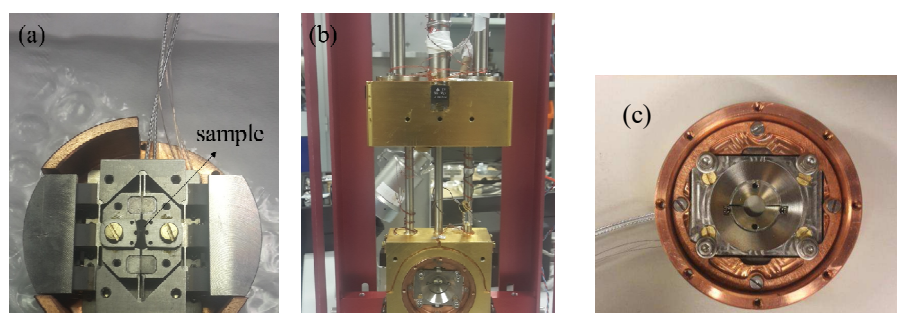


Fig. 1: (a) The piezoelectric based strain device mounted on the adaptor ring of the cryostat. The sample position in indicated. (b) The device mounted on the continuous flow He-cryostat of ID-27. (c) Back prospective of the strain device and adaptor.

We have produced needles from a high quality detwinned $\text{YBa}_2\text{Cu}_3\text{O}_{6.67}$ ($p=0.12$, $T_c=61$ K) single crystal, in order to both allow the mounting and increase the strain homogeneity [1]. The sample was mounted on the device using an epoxy glue so that the bc -plane was surface exposed to the X-rays.

The strain was then applied along the b -axis (needle-length). We decided to focus our studies on compressive strain at first because tensile strain makes more likely to break the sample. Next to the primary sample in the device we glued another piece from the same single crystal ($\text{YBa}_2\text{Cu}_3\text{O}_{6.67}$ and bc -plane perpendicular to the beam) to be used as unstrained reference.

For the experiment we used a 33 keV X-ray beam and initially we opted for a CCD detector which allows to access a wide range of reciprocal space (see Fig. 2). For the analysis of detector images we used the Dioplas software, to rapidly calculate and compare many integrated diffraction patterns, and CrysAlis software, to perform structural refinements and the extraction of the reciprocal space images.

The device inserted in the cryostat was mounted on the ID-27 goniometer and cooled the sample down to 70 K (close to the temperature that maximizes the CDW signal at this doping level).

Unfortunately, it was not possible to detect the very weak CDW signal above the strong background level using this detector. This did not prevent us on the other hand to map out the reciprocal space and to characterize the operation of the device, by measuring the lattice parameters vs. strain on different positions along the sample. Incidentally we also tried to use a smaller but more sensitive Pilatus detector to look for CDW features, this was also unsuccessful, very likely due to the high energy of the photons.

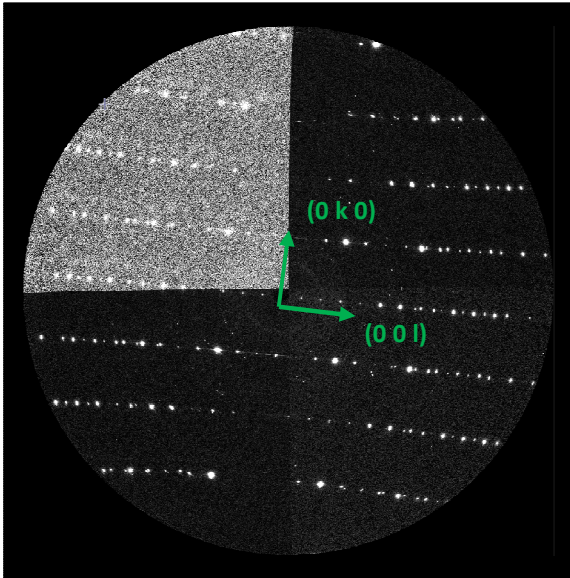


Fig. 2: Diffraction image from **CCD detector** with sample not rotated (b -axis normal to the lab plane) at 70 K.

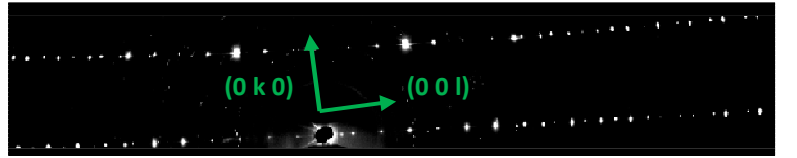


Fig. 3: Diffraction image from **Pilatus detector** with sample not rotated (b -axis normal to the lab plane) at 55 K.

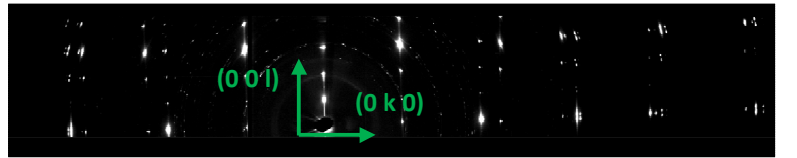


Fig. 4: Diffraction image from **Pilatus detector** with sample rotated by 90° (b -axis parallel to the lab plane) at 300 K.

In the low temperature characterizations we applied different compressive strains along b -axis and we measured the b -parameter variations extracted from the shift of $(0 k l)$ peaks with respect to their unstrained positions (notice that it was impossible to find pure $(0 k 0)$ reflections for all these diffraction patterns). The b -parameter was obtained (from lattice constants relation for an orthorhombic system) using the c -parameter evaluated from high order $(0 0 l)$ reflections at different applied strains and positions along the sample. We found that in this range of low temperatures the strain device successfully and efficiently transmit the strain on the sample. Comparing the expected strains, evaluated from the capacitance, and the measured b -parameter variations, we estimated that more than 95 % of the strain was transferred to the sample (see (c) in Fig. 5) with reasonably uniform distribution along its length (see (a) in Fig. 6). Moreover, in the hypothesis of linear elastic regime, from the evaluation of the c -parameter expansion at different compressive strains (along b -axis) we were able to calculate an average value of 0.27 for the in-plane/out-of-plane Poisson's ratio (c/b strain) (see (c) in Fig. 5).

At room temperature, on the other hand, we found instead that the strain transmission efficiency of the device is greatly reduced. From the 2θ positions of the $(0 4 0)$ peak we calculated the b -parameter at different points along the sample at various compressive strains (up to -0.3 %). The results in Fig 6 show that the measured b -strain distribution is not homogeneous along the sample length, with higher values at the center, and it is only

25 % of the expected compressive strain. This reduction of the efficiency can be attributed to lower rigidity of the Stycast 2850FT epoxy at higher temperatures. Finally, when we applied tensile strain the sample did not show any clear response (even up to 0.63 % of strain) probably because this load caused its fracture.

We can conclude that the strain device can be successfully used to apply homogenous strain with transmission efficiency on the sample close to 100 % at low temperatures. Moreover, we can trust the values estimated from the capacitance variation, a crucial information for future experiments where is impossible to measure directly the lattice parameters deformation.

Problems arise at higher temperature, where the epoxy used for the samples mounting loses part of its efficiency and the strain on the crystal is inhomogeneous and lower than the expected one. Future more careful calibration of the setup and of the Pilatus detector will hopefully allow to observe also the signal from the CDW.

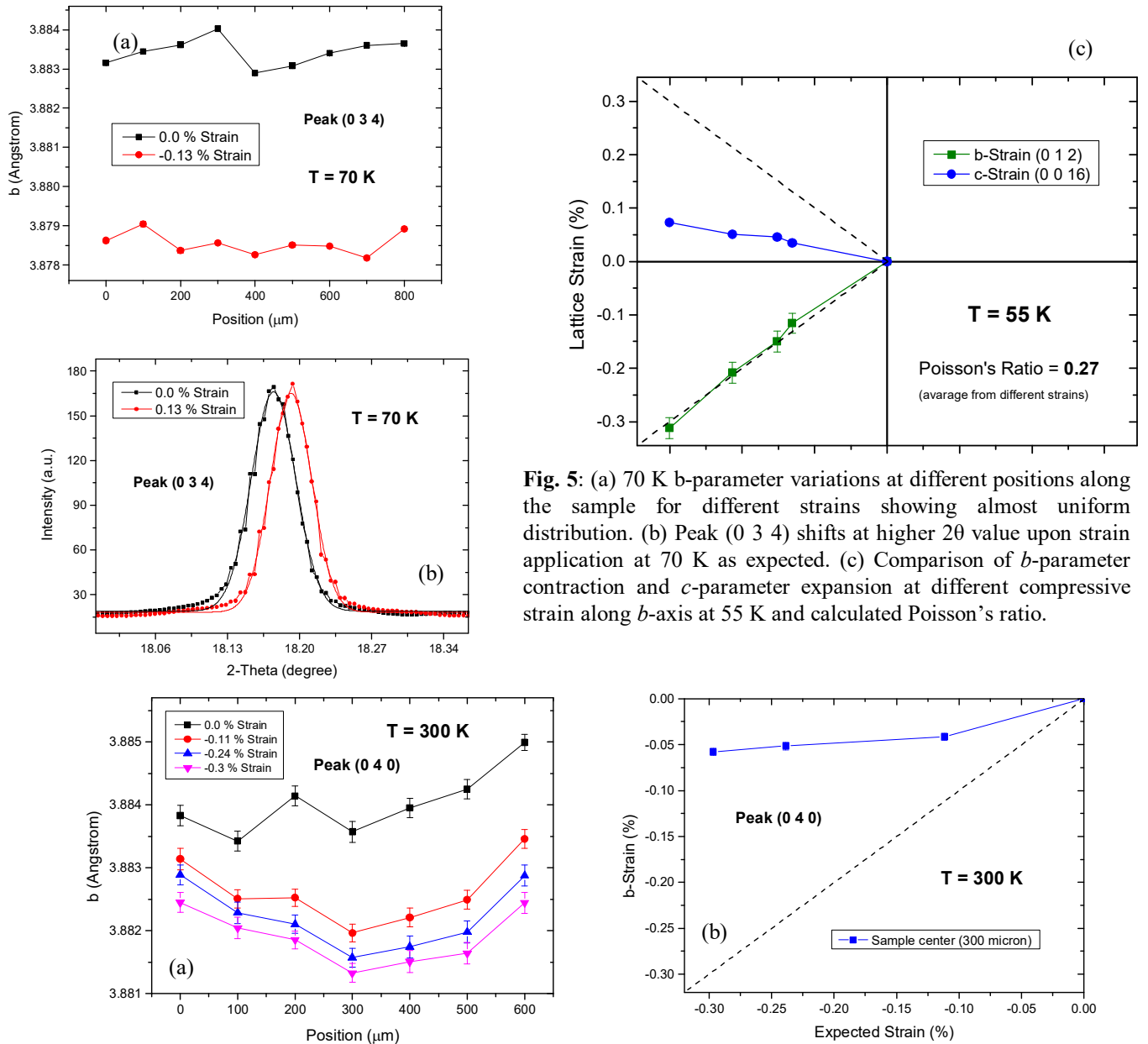


Fig. 6: (a) Room temperature b -parameter variations at different positions along the sample for different strains. (b) Comparison between expected strain along b -axis and measured b -strain in the sample centre from (0 4 0) peak at room temperature.