| ESRF | **Experiment title:** Mapping out the phase diagram of the strain-induced 3D long range order in YBCO | **Experiment number**: HC-4043 |
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**Report:**

The purpose of the current experiment was to investigate the effect of uniaxial compression in tuning the interplay between charge ordering and superconductivity in $YBa_2Cu_3O_{6.67}$. In particular, following our discovery of a uniaxial-strain induced long-range 3D charge density wave (CDW) in this system [1] - similar to the one earlier observed under very high magnetic fields [2] - we proposed to use x-ray diffuse scattering (DS) to map out its pressure/temperature dependence and its relation with the short-ranged, quasi-2D CDW observed already at unstrained conditions.

The motivation for pursuing this experiment in the ID28 side station stemmed from preliminary measurements under unstrained conditions during which incommensurate modulation peaks associated with the 2D-CDW were successfully observed using a nitrogen cryostream system (see Figure 1). For the experiment, the beamline was set to a non-standard energy of 12.4 keV in order to avoid fluorescence from the various atoms of the unit cell.

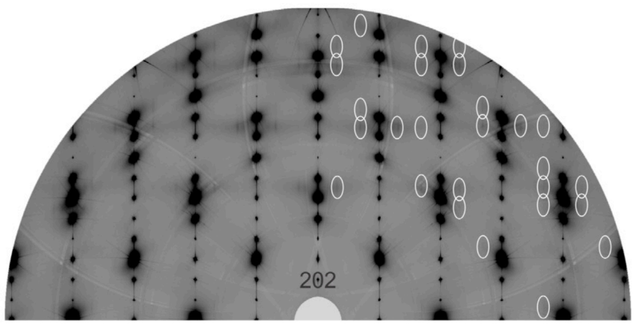


*Figure 1: The 2hl reciprocal space plane of $YBa_2Cu_3O_{6.67}$ at 85 K. The 2D-CDW modulation peaks are indicated by the white rings.*

For the application of uniaxial compression, we have introduced a newly designed piezoelectric-based apparatus (based on the one of [1,3]) in the closed cycle cryostat already available at the ID28 side station. The strain device was fitted inside the cryostat using a suitably designed adapter to allow for measurements both in transmission and in reflection geometry. A picture of the device mounted on the cryostat on the diffractometer of the ID28 side station is shown in Figure 2. The dimensions of the device did not allow the use of the existing cryostat windows, therefore we have designed and prepared a new frame to be used with Kapton windows and a dedicated internal rotating screen assembly. The scope of internal screen was to block the photons backscattered from the Kapton windows, aiming to minimize the contribution of the sample environment and facilitate the observation of the weak 2D-CDW superstructure reflections in the collected images.

In addition, we have prepared needle-shaped samples (2.5 mm x 150 µm x 150 µm) of high quality detwinned $YBa_2Cu_3O_{6.67}$ crystals ($T_c$ = 65 K) which were further thinned down to ~40 µm on their central part using a plasma focused ion beam setup. The strain was applied along the needle axis which coincided with the crystallographic *a*-axis and was calibrated using a dedicated built-in capacitive force sensor. Before the official start of the beamtime we have checked that the device works successfully inside the cryostat at low temperatures.

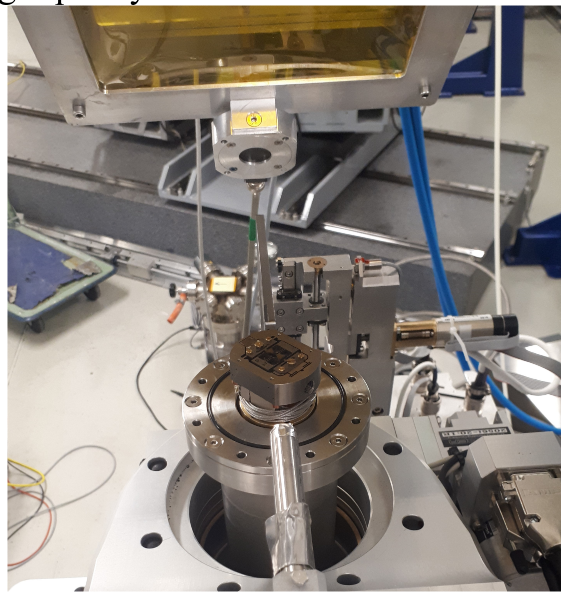

*Figure 2: The piezoelectic-based strain apparatus mounted on the cryostat of the Id28 side station. The beam collimator and the Pilatus detector used for the measurements are visible in the picture.*

Unfortunately, due to various technical reasons we did not manage to observe the 3D-CDW order during this beamtime. The major problem that we have encountered had to do with the rotating screen assembly which did not perform as expected based on the preliminary tests both in terms of the suitability of the motor and in terms of synchronization with the cryostat rotation. The measurements were further complicated by the formation of a thin layer of ice on the device and on the sample when the system was cooled, probably due to a leak on the rotation screen axis. Moreover, during the experiment we had a failure of the water cooling system of the main diamond monochromator and a subsequent instability of the incident beam. Thanks to the intervention and assistance of the beamline staff members both the cooling system and the rotating screen motor have been replaced during the experiment, but inevitably all these operations were time consuming. While, we managed to observe the peaks associated with the 2D-CDW order in the final one of the measured samples, it broke before we could reach a high enough strain for the emergence of the 3D-CDW. We are confident that with an improved version of the motorized screen assembly we will be able to get positive outcome in a future continuation experiment.

References:
[1] Kim et al., Science 362, 1040–1044 (2018)
[2] S. Gerber et al., Science 350, 949-952 (2015), H. Jang et al., PNAS 113, 14645-14650 (2016), J. Chang et al., Nat. Commun. 7, 11494 (2016).
[3] Hicks, C.W. et al., Rev. Sci. Instrum, 85, 065003 (2014)