EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

ESRF

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal:

https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Reports supporting requests for additional beam time

Reports can be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

<table>
<tr><td>ESRF</td><td>Experiment title:
Low energy phonon renormalizations in Bi-2212 superconducting cuprates</td><td>Experiment number:
HC-2827</td></tr>
<tr><td>Beamline:
ID-28</td><td>Date of experiment:
from: Feb. 9, 2017 to: Feb. 14, 2017</td><td rowspan="2">Date of report:
Feb. 28, 2017
Received at ESRF:</td></tr>
<tr><td>Shifts:
15</td><td>Local contact(s):
Alexey Bosak</td></tr>
<tr><td colspan="3">Names and affiliations of applicants (* indicates experimentalists):
Ming Yi*, UC Berkeley
Alex Frano*, UC Berkeley
Yu He*, Stanford University
Wei-Sheng Lee*, SLAC National Accelerator Laboratory
Matthieu Le Tacon*, Karlsruhe Institute of Technology
Zhi-Xun Shen*, Stanford University
Robert Birgeneau*, UC Berkeley</td></tr>
</table>

Report:

During this beamtime, we used inelastic x-ray scattering to map out the low energy acoustic phonon dispersion of an underdoped (UD32) $Bi_2Sr_2CaCu_2O_{8+\delta}$ cuprate superconductor, where a charge density wave is reported to exist around q = 0.3 [1]. In particular, we measured the inelastic signal from -5meV to 20meV at selected q points along the direction (2 0 0) to (3 0 0), with a focus in the energy range of -2meV to 10meV.

Figure 1 shows the phonon dispersion at selected q points taken at two temperatures, slightly below Tc (28K) and high temperatures where the charge density wave (CDW) is expected to have weakened somewhat (240K) [1]. A peak indicating the acoustic mode is seen to dispersion from 4meV from H=2.1 towards 6meV at H=2.5. More interestingly, the peak width, indicated by the gray shading, is observed to broaden between 2.25 to 2.32

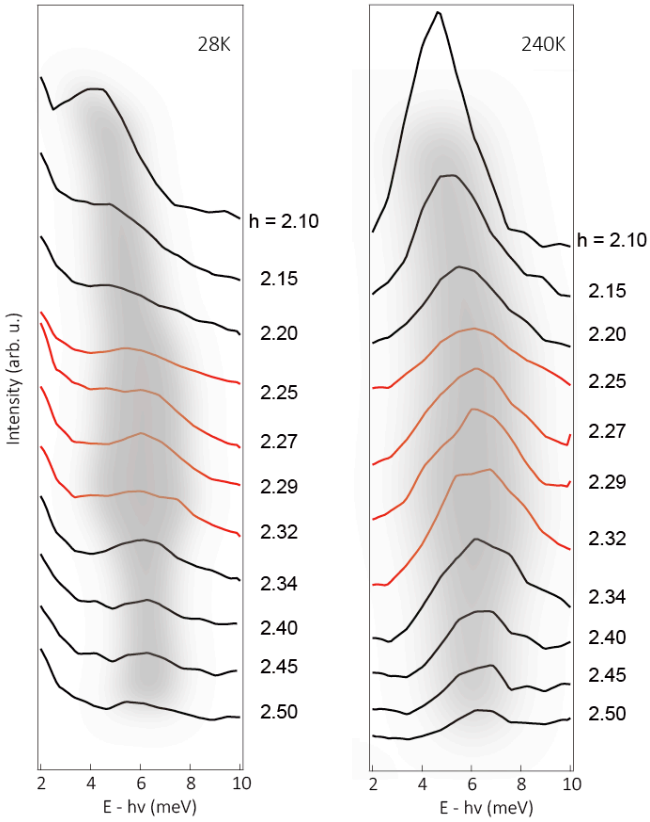

Figure 1 Measured acoustic phonon dispersion along (2 0 0) to (3 0 0) for 28K (left) and 240K (right). The peak width is indicated by gray shading. Broadened peak range is indicated by red color.

(shown in red)—a q range that straddles the expected CDW q-vector (0.3) (Fig. 2) [1]. Similar broadening is also observed at high temperatures. We note that the CDW, while weak, is still finite at this high temperature [1], hence may still explain the observed broadening.

The observed broadening is largely consistent with the phonon softening observed in YBCO [2-3], and may indicate electron-phonon coupling due to the CDW. However, as has been pointed out in a recent inelastic neutrons scattering paper [4], there exists a low energy optical mode around 6meV that crosses and hybridizes with this acoustic phonon branch at around the same q~0.3 (Fig. 3). To distinguish this possibility from intrinsic effects of the CDW, it is necessary to examine the behavior of another low energy phonon branch that does not cross the 6meV optical phonon. In this regards, we have also observed an optical phonon mode around 14meV. However, due to limited beamtime, we did not have enough time to obtain good statistics on this mode to make a conclusive statement. For this mode, we see a well-defined peak near 2.1 and 2.5, but strongly broadened features in intermediate q's. This hints at the possibility that there may also be a broadening of this phonon branch around 2.3. As this higher optical mode does not cross the 6meV optical mode reported, this broadening, if true, would be evidence that the broadening is due to intrinsic softening due to the CDW. It is thus imperative to gather sufficient quality data on this optical mode in a future beamtime. The results will give us important information on the universality of electron-phonon coupling in the CDW of the cuprate high temperature superconductors.

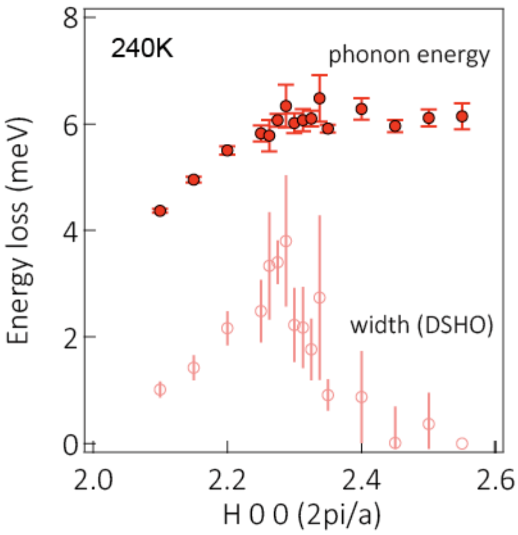

Figure 2. Fitted phonon width showing a broadening around q~0.3 (240K).

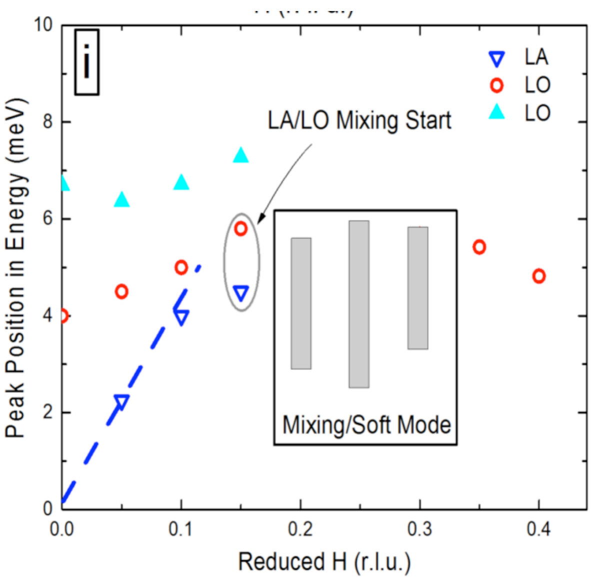

Figure 3. Reported crossing and hybridization of a ~6meV optical phonon mode with the low energy acoustic mode around q=0.3 [4].

References:

[1] da Silva Neto *et al. Science* **343**, 393 (2014).
[2] E. Blackburn *et al*. *Phys. Rev. B* **88**, 054506 (2013).
[3] M. Le Tacon *et al*. *Nat. Phys.* **10**, 52 (2014).
[4] A. M. Merritt et al., arXiv:1702.04331 (2017).