Experimental Report

20/02/2014

Proposal:	**6-01-324**	**Council:**	4/2012	
Title:	High energy resolution density fluctuations spectrum in 4He hcp			

This proposal is continuation of: 6-01-321

Research Area: Physics

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Samples: Helium 4

Instrument	Req. Days	All. Days	From	To
IN5	5	5	18/03/2013	25/03/2013

Abstract:

Our recent successful measurement performed last December on IN5 of the density fluctuation spectrum of a single crystal of 4He at moderate energy resolution demonstrates the great interest of measuring the dynamic of such quantum crystal where anharmonicity plays a crucial role.
The full vision of the reciprocal space allowed by the IN5 instrument constitutes a formidable tool to investigate this dynamics.

In the proposed experiment we plan to extends the previous measurements with a higher energy resolution for the low energy range.
Both measurements will compose a set of data of invaluable quality to tackle mysteries such as the supersolidity in this material.

High energy resolution density fluctuations spectrum in ^{4}He hcp

Better data have become necessary in order to build firm basis to the theories about the simplest quantum solid, i.e., normal helium in its cryslalline form. This include questions arising from the concept of supersolidity [1, 2], now declined as "superplasticity" or "giant plasticity"[3]. It was also necessary because of emerging theories based on data of low quality[4, 5]; conclusions about these theories being potentially drawn from better quality data taken in similar conditions.

In all the previous measurements made on triple-axis instruments, the crystal growth was left free leading to an alignment of the c* axis always closer to scattering plane than to the vertical. The previous measurements were then all made in the (a*,c*) plane and no data were available, up to now, in the pure hexagonal basal plane.

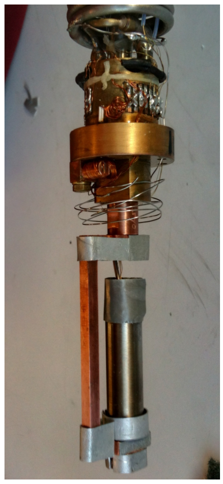

Figure 1: Sample cell on the dilution stick.

The present experiment is a continuation of a previous experiment[6] with a higher Q and energy resolutions while keeping the maximum Q-range to cover the interesting part of the reciprocal space and energy transfer.

Several technical improvements have been made since the last experiment however (see Fig. 1). An improved sample cell has been designed including a regulated heating and a thermometer on top of the sample cell to control accurately the temperature gradient between the two ends of the sample cell during the crystal growth.

This improved cell allowed to grow the crystal in a single operation, no need to anneal the crystallites grown on the cell wall to have a single crystal of the expected orientation. By growing the crystal by epitaxy on a graphite seed, the hexagonal axis (c axis) is perpendicular to the scattering plane within the accuracy of the graphite positioning in the cell, i.e., $\pm 1°$.

Data have been recorded at two incident wavelengths, firstly, at λ=4.0 Å with full chopper velocity (17000rpm) for a resolution around 0.1 meV to emcompass a large reciprocal space and, secondly, at λ=5.0 Å and full velocity to reach a resolution around 0.065 meV and to emphasize the low-Q region close to the real Γ point (0,0,0) where the long wave acoustic mode emerges. Using the symmetry of the crystal, one need theorically to span only 30° in angle of the

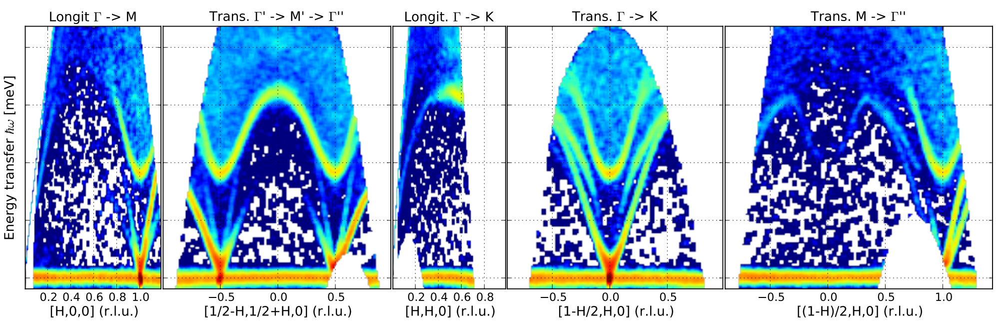

Figure 2: Phonon dispersions along several high symmetry directions taken with the best resolution ($\delta\hbar\omega \approx$0.065meV – incident wavelength λ = 4.8 Å).

(a*,b*) plane to measure all the phonons. In practise it is better to cover a larger angle to include 2 similar Bragg reflections, covering at least 60 degrees (extended to span the energy axis from zero to the max energy at each Q-point) in this hexagonal symmetry case. During acquisition the rotation of the crystal has been made always avoiding the thermal conducting yoke to cross neither the incident nor the scattered beam. After the standard transformations performed with the LAMP software, data have been mapped in the crystal reciprocal space using the HORACE software suite. Slices from the four-dimensional datasets have been extracted using the same software.

On figure 2 one can see the measured phonon branches in various symmetry directions in the reciprocal space. Depending on the scalar product $(Q.\zeta)$ where Q is the transfer wave vector and ζ the mode polarisation, one is restricted to see only the non-zeroed intensities. Along the Γ-M direction, only the longitudinal modes are in principle visibles, to see the transverse modes along the same symmetry axis, one has to cut along the Γ' - M - Γ'' axis, etc.

However, since the modes appear not to be pure modes along the Γ - M direction, some transverse modes are also visible on the figure although with a weaker intensity. The same hold for the other directions, except the Γ - K, i.e., (0,0,0) $\rightarrow$ (1,1,0), direction which is a pure direction for the acoustic modes. An enlarged view of the reciprocal space is given on

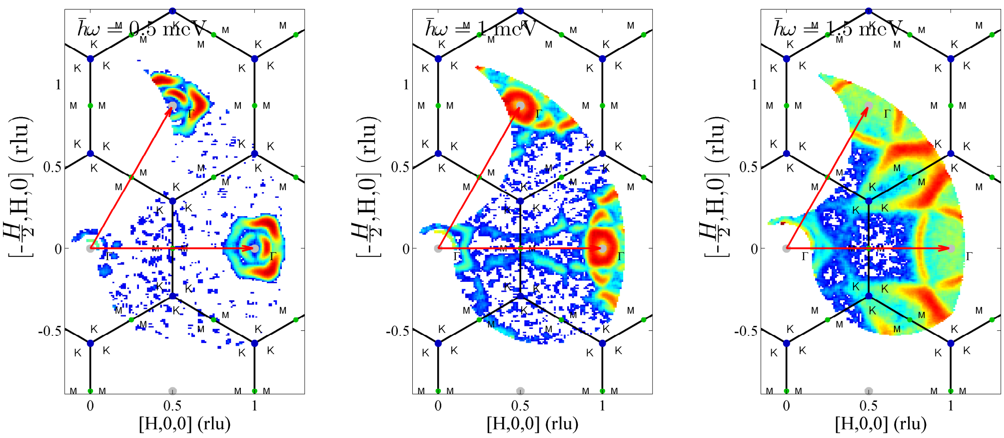

Figure 3: Iso-energy plots at $\hbar\omega$=0.5, 1.0 and 1.5 meV for λ =4.8Å.

figure 3. The iso-energy cuts at different energies show the phonons within the Brillouin zone as well as close to the origin zone center $\Gamma_\circ$ (0,0,0). The acoustic modes emerging from the $\Gamma_\circ$ are clearly visible above 0.5 meV. Above $\approx$ 1.75 meV the modes broaden and vanish. Similarly to the liquid phase, a substantial intensity remains above the optical mode everywhere in the reciprocal space. This multi-phonon like intensity merges with the recoil parabola at higher energies as was shown in the previous experiment with a shorter incident wavelength.

References

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[2] Syshchenko O.r and Day J. and Beamish J. *Physical Review Letters* **104**(2010)195301
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