Experimental report

17/01/2018

Proposal: **7-02-165** **Council:** 4/2016

Title: Investigation of phonon softening close to a structural quantum critical point in Lu(Pt0.6Pd0.4)2In

Research area: Physics

This proposal is a continuation of 7-02-162

Main proposer: **Stefan LUCAS**

Experimental team: Oliver STOCKERT
Stefan LUCAS

Local contacts: Michael Marek KOZA
Martin BOEHM

Samples: Lu(Pt0.6Pd0.4)2In

Instrument	Requested days	Allocated days	From	To
IN3	6	6	26/01/2017	30/01/2017
			31/01/2017	02/02/2017
IN8	4	6		

Abstract:

The substitution series Lu(Pt,Pd)2In is one of the rare examples showing a structural quantum critical point (QCP), i.e. a continuous structural phase transition at T=0. The Peierls transition from a cubic Heusler structure towards a cubic superstructure occurs at 490K in pure LuPt2In. By substituting Pd for Pt, the transition temperature is suppressed to zero at a Pd concentration of about 55%. Interestingly, a remarkable increase of superconductivity (Tc = 1K) is observed just in the vicinity to the QCP. Therefore, a strong connection between superconductivity and the occurring low-energy quantum fluctuations is expected.
In powder samples of LuPt2In we already observed enhanced low-energy fluctuations at the structural phase transition. The availability of single crystals now enables important investigations of the phonon dispersion. In the proposed experiment, the phonon softening and the corresponding low-energy fluctuations shall be investigated for a single crystal of Lu(Pt0.6Pd0.4)2In (Ts = 140K). A successful experiment will be an ideal starting point for further investigations of the concentration series, especially on approaching the structural QCP.

Investigation of phonon softening close to a structural quantum critical point in $Lu(Pt_{0.6}Pd_{0.4})_2In$

Stefan Lucas, Oliver Stockert, Martin Böhm, Michael Marek Koza
(Test on IN3 connected to Proposal 7-02-165)

Quantum critical points, i.e. continuous phase transitions occurring at absolute zero temperature, are one of the most exciting research topics in current solid state physics. Driven by a non-thermal tuning parameter like magnetic field, pressure or chemical substitution, exciting phenomena like superconductivity, metamagnetism and non-Fermi-liquid behavior often appear in the vicinity of a quantum critical point [1,2]. However, most of the quantum critical phenomena, which were theoretically described and experimentally investigated so far are based on magnetic systems [1,2]. Thereby, magnetic fluctuations are crucial for the evolution of the unusual properties. Recently, first materials were found, which reveal a structural quantum phase transition with strong indications for a quantum critical behavior caused by fluctuations of the crystal structure [3,4]. In particular, an enhancement of superconductivity right in the vicinity of the structural quantum critical point attracts special attention. The intermetallic alloying series $Lu(Pt_{1-x}Pd_x)_2In$ might be a model system for a detailed study of a structural quantum critical point. It undergoes a Peierls transition at $T_s = 490\,K$ in pure $LuPt_2In$ being connected to a phonon softening at certain points in reciprocal space (fcc crystal structure). By substituting Pd for Pt the phase transition is continuously suppressed to zero at a Pd concentration of about 55 % according to thermodynamic and transport measurements [4]. Exactly in this region of the phase diagram an enhancement of superconductivity by a factor of more than 2 as well as an anomalous behavior in specific heat and resistivity is observed indicating an enhanced electron-phonon coupling in this regime. To learn more about the general phonon dispersion in $Lu(Pt_{0.6}Pd_{0.4})_2In$ ($T_s = 130\,K$) along different directions, we performed a test experiment on the thermal triple-axis spectrometer IN3 at room temperature. This experiment was planned as a preliminary test for an experiment on IN8, where the dispersion should be investigated in more detail and at different temperatures.

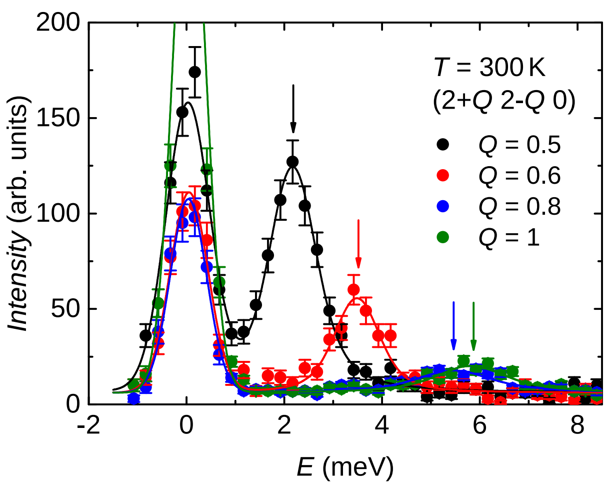

Figure 1: Typical energy scans along ($2{+}Q$ $2{-}Q$ 0) measuring the transverse acoustic phonon.

Using a (h k 0) scattering plane, we were able to measure the dispersion along the [100] and [110] direction around the strong nuclear peaks (4 0 0) and (2 2 0). From previous diffraction experiments, we knew the first strong superstructure peak to appear at

$\boldsymbol{Q_s} = (2.5\ 1.5\ 0)$. A fixed $k_f = 2.66\,\text{Å}^{-1}$ was chosen and an energy resolution of about 0.8 meV (FWHM) could be reached using collimation. Constant Q-scans were performed in an energy range between -0.8 to 8.4 meV.

Fig. 1 shows typical energy scans along $(2+Q\ 2-Q\ 0)$ measuring the transverse acoustic phonon. Both, the transverse and longitudinal acoustic (TA and LA, resprectively) phonon branches for the $[1\,\pm1\,0]$-directions are shown in Fig. 2 on the left hand side. Already at room temperature the softening has set in at $\boldsymbol{Q_s}$ in the TA phonon branch. The phonon dispersion along the [100]- and $[0\bar{1}0]$-direction is shown in Fig. 2 on the right hand side and was more difficult to measure due to weaker phonon intensities and an uncertainty about the actual number of phonons at high energies. Therefore, especially above $Q = 0.5$, the data is less trustful.

With the help of this test experiment on IN3 we gained useful information about the general phonon dispersions along typical directions in $Lu(Pt_{0.6}Pd_{0.4})_2In$. Further treatment of the data will show, if these information are already enough for some theoretical calculations of the phonon dispersion. However, for more reliable and especially temperature-dependent measurements, further experiments are required to get a deeper understanding of the phonon softening in $Lu(Pt_{1-x}Pd_x)_2In$ and what role the phonons play for the evolution of superconductivity.

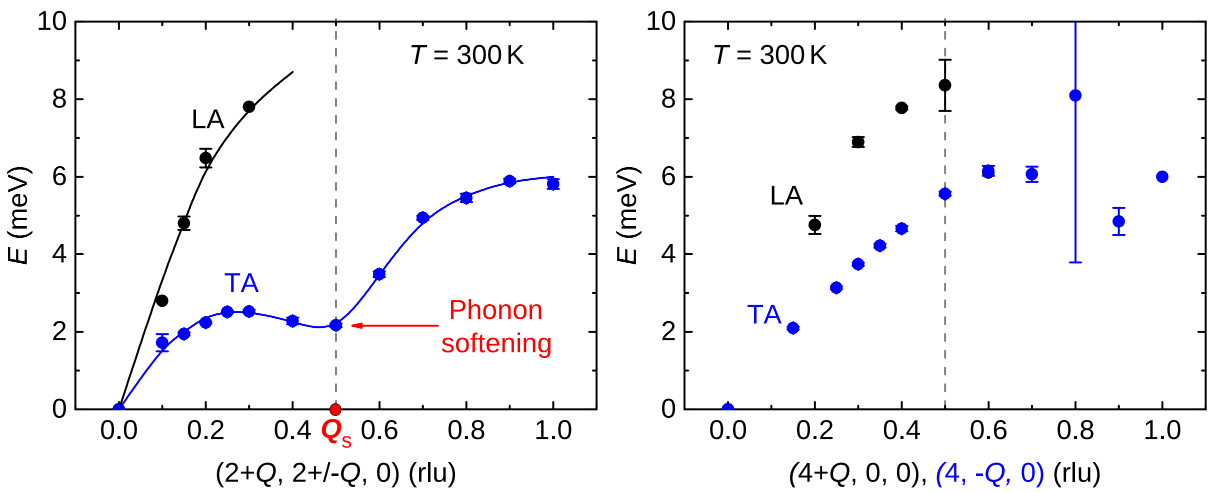

Figure 2: *Left:* Phonon dispersion along the $[1\,\pm1\,0]$-direction indicating the phonon softening at (2.5 1.5 0) for the transverse acoustic (TA) branch. *Right:* Longitudinal and transverse acoustig phonon dispersion along the [100]- and $[0\bar{1}0]$-direction, respectively. Above $Q = 0.5$ excitations were difficult to fit.

[1] H. v. Löhneysen et al., Rev. Mod. Phys. **79**, 1015 (2007); [2] Q. Si and S. Paschen, Phys. Status Solidi B **250**, 425 (2013); [3] L.E. Klintberg et al., Phys. Rev. Lett. **109**, 237008 (2012); [4] T. Gruner et al., Nat. Phys. **13**, 967972 (2017);