Experimental report

04/02/2019

Proposal: CRG-2434 **Council:** 4/2017

Title: Evolution of critical order parameter fluctuations close to a structural quantum critical point in Lu(Pt,Pd)2In

Research area: Physics

This proposal is a new proposal

Main proposer: **Stefan LUCAS**

Experimental team: Jaehyeon KWON
Stefan LUCAS
Oliver STOCKERT
Thomas GRUNER

Local contacts: Karin SCHMALZL

Samples: Lu(Pt0.2Pd0.8)2In

Instrument	Requested days	Allocated days	From	To
IN12	4	3	21/09/2018	25/09/2018

Abstract:

The intermetallic alloying series Lu(Pt,Pd)2In is one of the rare examples showing a structural quantum critical point (QCP), i.e. a continuous phase transition occurring at T=0. In contrast to usual magnetic QCPs, critical fluctuations of the crystal structure instead of magnetic fluctuations play an important role for the evolution of exotic phases like superconductivity. In the case of pure LuPt2In a Peierls transition occurs at Ts=490K, which is continuously suppressed to Ts=0 by substituting Pd for Pt. At a Pd content of about 55%, a QCP is approached and remarkably, superconductivity is clearly enhanced, indicating a strong influence of the low-energy quantum fluctuations on the electron-phonon coupling.

Having already investigated 2 samples of the alloying series being located close to the QCP we could nicely track the phonon softening and observe enhanced phonon intensities close to the structural phase transition. However, to distinguish the effect of critical quantum fluctuations from the softening and to find out from which initial energy scale the softening sets in, we propose to measure a third sample being located in the overcritical regime to complete the dataset.

The study of quantum critical points, i.e., continuous phase transitions occurring at absolute zero temperature, continues to be one of the most exciting research topics in solid state physics. So far, most work has been devoted to magnetic quantum critical points. In contrast, only very little is known about structural quantum criticality.

Recently we started our investigation of the alloying series Lu(Pt$_{1-x}$Pd$_x$)$_2$In. In the parent compound LuPt$_2$In, a transition from a cubic Heusler structure (space group 225) towards a cubic superstructure (space group 197) occurs at $T_s \approx 490$ K by a doubling of the lattice parameters [1]. When substituting Pd for Pt, the structural transition in Lu(Pt$_{1-x}$Pd$_x$)$_2$In is linearly suppressed with Pd content with a critical Pd concentration $x_c \approx 0.6$ where the transition has been fully vanished and a quantum critical point has been approached. In the vicinity of the quantum critical point, anomalies in transport and thermodynamic properties point to an enhanced electron-phonon coupling in the quantum critical regime. The most prominent feature around the quantum critical point in Lu(Pt$_{1-x}$Pd$_x$)$_2$In is the appearance of a superconducting dome around the quantum critical point with an enhancement of the superconducting transition temperature by more than a factor of 2 in comparison to the parent compound LuPt$_2$In (LuPd$_2$In does not exhibit superconductivity at all).

In a previous experiment (see experimental report to proposal CRG-2377 [2]) we studied the phonon softening at the structural transition in Lu(Pt$_{1-x}$Pd$_x$)$_2$In with Pd concentrations of $x = 0.4$ and 0.5. In those measurements we detected a full softening of the relevant low-energy phonon at (0.5 0.5 0) at the transition with a strong increase in intensity. In the present experiment we extended our measurements to the overdoped regime, i.e. for $x > 0.6$ and compared the results with the largely underdoped regime. In particular, we now investigated single crystals of the two parent compounds, LuPd$_2$In ($x = 1$) and LuPt$_2$In ($x = 0$). We performed our experiment again on the triple-axis spectrometer IN12 using a fixed final neutron wavevector $k_f = 1.8\,\text{Å}^{-1}$ and a $(h\ k\ 0)$ horizontal scattering plane. This allowed us to record the low-energy phonons around the first strong superstructure peak at $(2.5\ 1.5\ 0)$ (in high-temperature notation). In order to follow the phonon softening from highest temperature on, we used an cryofurnace to have access to temperatures beyond 500 K. Data have been taken between 534 K and 2 K.

Fig. 1 displays energy scans across the low-energy phonons along $[110]$ around $(2.5\ 1.5\ 0)$ in both, LuPd$_2$In and LuPt$_2$In, taken at $T = 534$ K, i.e. in the high-temperature phase (only LuPt$_2$In undergoes a structural transition at $T_s \approx 490$ K, while LuPd$_2$In remains in the high-temperature Heusler phase down to lowest temperatures). Nicely dispersing phonons are visible in both compounds. While the phonon energy steadily increases with momentum transfer in LuPd$_2$In, a pronounced minimum can be seen in PuPt$_2$In for $\mathbf{Q} = (2.5\ 1.5\ 0)$. The phonons have been fitted using peaks with Lorentzian lineshape convoluted with the Gaussian energy resolution of 0.3 meV (FWHM) of the IN12 spectrometer at $k_f = 1.8\,\text{Å}^{-1}$ (solid lines in Fig. 1). As a result of the fits the dispersion $\omega(\mathbf{Q})$ and the phonon intensity (susceptibility) are shown in Figs. 2 (a) and (b). As expected a pronounced phonon softening at $(0.5\ 0.5\ 0)$ is visible in LuPt$_2$In at 534 K, i.e. 44 K above the phase transition. Together with the softening a strong increase in the phonon intensity is observed at $(0.5\ 0.5\ 0)$. This indicates the vicinity of LuPt$_2$In to the structural instability being present at slightly lower temperature. Surprisingly, although LuPd$_2$In does not exhibit any phase transition dow to lowest temperatures, a slight dip in the phonon dispersion exists also in this parent compound at 534 K. Together with a little hump in the phonon intensity this can be seen as a precursor of the structural transition occurring only in samples with much lower Pd content.

Detailed measurements of the full phonon softening in LuPt$_2$In around the structural transition are highly desired to get a deeper understanding of the underlying mechanism.

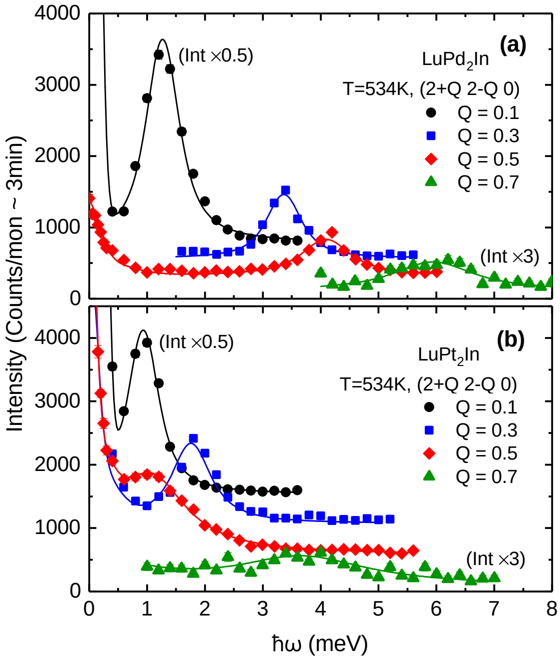

Fig. 1: Phonons in (a) $LuPd_2In$ and (b) $LuPt_2In$ along $[110]$ recorded at $T = 534\,\mathrm{K}$.

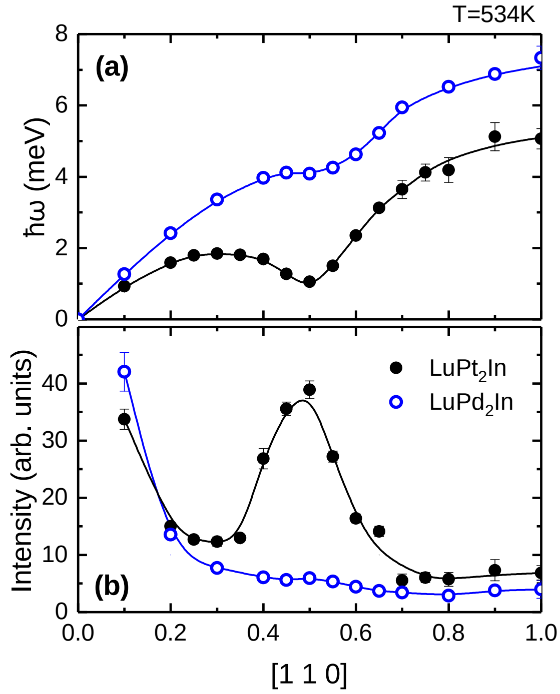

Fig. 2: (a) Dispersion and (b) intensity of the phonons along $[110]$ in $LuPd_2In$ and $LuPt_2In$ at $T = 534\,\mathrm{K}$.

References:

[1] T. Gruner, D. Jang, Z. Huesges, R. Cardoso-Gil, G. H. Fecher, M. M. Koza, O. Stockert, A. P. Mackenzie, M. Brando, C. Geibel, Nature Physics **13**, 967 (2017)

[2] S. Lucas et al., JCNS-Experimental Report to Proposal CRG-2377 (2017)