

The effect of lanthanum dilution on the anomalous behaviour of CeRu₂ superconductor

An application using Oxford Instruments Superconductivity's cryostat and variable temperature insert

Understanding the structural, electronic and magnetic properties of intermetallic rare earth (RE) and 4d transition metal (M) compounds is important because of their many applications in, for example, permanent magnets, polishing agents, new phosphors, and rechargeable batteries.

Cerium (Ce) is the least expensive of all the RE elements, but, when present in a trivalent state, leads to a large magnetic anisotropy. Most Ce-based RE compounds are, therefore, able to absorb large external magnetic fields without changing their spin direction, rendering them non-magnetic, and unsuitable for applications as permanent magnets.

In recent years, however, several investigations have shown a change in the Ce electronic state caused by interstitial doping, opening a new route towards the development of Ce-based permanent magnetic materials.

The large class of REM₂ type Laves phases offers a good opportunity to study the correlation between the structural and electronic modifications associated with interstitial doping. Of particular interest is the widely known anomalous behaviour of CeRu₂ and LaRu₂, which retain their superconducting properties following the introduction of magnetic elements (Figure 1), unlike similar compounds which become magnetic.

To try to understand this behaviour Dr Battisti and colleagues investigated the solid dilution La_{1-x}Ce_xRu₂ using both X-ray absorption spectroscopy and thermodynamic techniques.

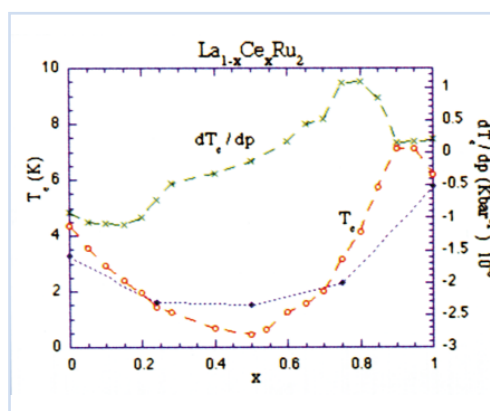


Figure 1: T_c and T_c/dp versus Ce concentration in the La_{1-x}Ce_xRu₂ series. [1] (closed diamond); data taken from [2] (x,o).

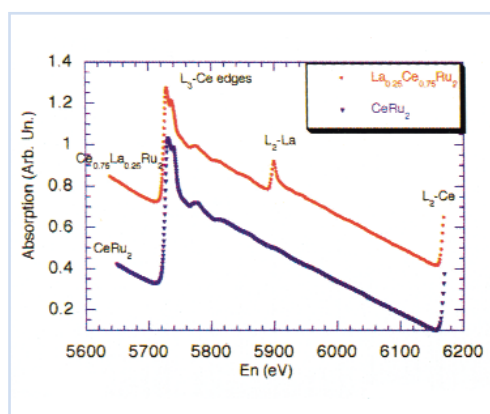


Figure 2: L₃ Ce edges of CeRu₂ and La_{0.25}Ce_{0.75}Ru₂ compounds.

Dr. Maurizio Battisti and colleagues at INFN-Laboratori Nazionali di Frascati-Italy, have been investigating the effect of interstitial doping on the magnetic behaviour of cerium based intermetallic compounds.

Comparison of results from X-ray absorption spectroscopy and thermodynamic measurements at very low temperatures, using Oxford Instruments Superconductivity's cryostat and variable temperature insert, has revealed details of the underlying interactions.

References:

- [1] R.N. Shelton, A.C. Lawson, K. Baberschke, Sol. State Commun. 24 (1977) 465
- [2] M. Battisti, A. Marcelli, S. Chudinov, L. Bozukov, C. Piquer, J. Chaboy, Journ. Magn. Mat. 196-197 (1999) 888

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X-ray absorption spectra were obtained at the Ru K-edge and the L-edges of La and Ce (Figure 2), for $x = 0, 0.25, 0.5, 0.75,$ and $1,$ at room temperature, 10 K, and 4 K.

From the X-ray absorption fine structure spectra the Ce valence was estimated (~ 3.3 in all compounds) together with the interaction between the hybridization and correlation effects among the 4f, 5d and 4d electrons. The spectra also show doping-induced distortion of the local environment around each atomic species (Figure 3). These results were then compared with the thermodynamic properties of the same solid dilution from measurements of heat capacity (>1.2 K), magnetoresistance (<2 T), resistivity (>1.8 K) and susceptibility (>1.8 K).

Analysis demonstrates that the dilution does not promote a localised 4f magnetic moment on the Ce site and the superconductivity of the whole $\text{La}_{1-x}\text{Ce}_x\text{Ru}_2$ series can mainly be ascribed to the Ru linear chain. Moreover, the dilution does not change the cubic (Fd3m) symmetry, but the interstitial doping affects the interplay between localization (due to f states) and hybridization (between f states and 5d and/or 4d extended states). As a consequence large changes in electronic and magnetic behaviour may be observed due to the dilution of intermetallic systems.

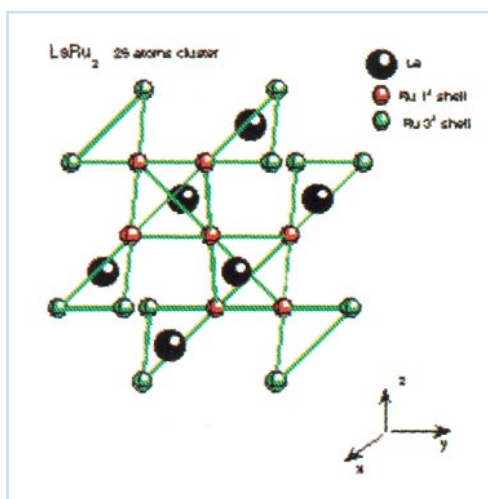


Figure 3: The crystallographic structure of the C15 Laves phases LaRu_2 showing a cluster of 25 atoms around the Ru atom.

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