Field, Temperature and Composition Dependence of Electrical Resistance in the Superconducting Ferromagnetic Rutheno-Cuprates (Ru$_{1-x}$Nb$_x$)Sr$_2$(Eu$_{1.5}$Ce$_{0.5}$)Cu$_2$O$_{10}$, [Ru,Nb)-1222]

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Introduction
Rutheno-cuprates provide a natural superconducting (Cu-O$_2$ planes) + ferromagnetic (Ru-O$_2$ planes) multilayer system at atomic level [1]. The rutheno-cuprates present a broad (bulk) superconducting transition associated to significant granularity. In the Ru-1222 system a frequency shift in the AC susceptibility characteristic of spin glasses was observed, and its magnetization scales with the applied magnetic field [2] which is typical for interacting magnetic particles. Some important aspects that are still open are: the interaction of charge carriers with Ru magnetic moments (including a negative magnetoresistance), the role of the crystal lattice (low dimensionality, presence of coherent rotation domains, non optimal atomic distances and angles for superexchange interactions along the c-axis of the tetragonal structure), the localized vs itinerant character of the Ru magnetic sublattice, the understanding of how the superconducting and magnetic order parameters interact with each other and how the Cooper pairs manage to cross the ferromagnetic planes in the crystal structure. In this project we made samples substituting the magnetic Ru ion for a non-magnetic ion like Nb with the same valence and similar ionic ratio with the aim to clarify magnetic mechanism involved.

Experimental
Precursor oxides were initially mixed and grinded, followed by three calcinations at different temperatures with intermediate grindings. Afterwards the samples were pressed and sintered in an oxygen atmosphere. Resistance as a function of temperature and composition was measured in applied magnetic fields up to 14 T.

Results and Discussion
Figure 1 shows resistance as function of temperature (T) for three different magnetic fields in the superconducting transition region for Ru-1222 (x=0). The inset shows the entire T range. One can observe a broad superconducting transition region characteristic for rutheno-cuprates that shifts to lower temperatures with increasing magnetic field. The same general trend is also observed for other compositions. The resistance derivative with respect to temperature allows to determine intra- and inter-grain superconducting transition temperatures as shown in fig. 2 and 3 for x=0.2 and 0.6 respectively, at zero applied field. The two observed maxima in the derivative curves correspond to the inter- and intra-grain superconducting transition temperatures for the higher and lower temperatures respectively. Both transition temperatures are reduced with increasing Nb content. Table 1 reports the transition temperatures for x=0. Additional work is under progress.

<table>
<thead>
<tr>
<th>H (T)</th>
<th>$-T_{\text{inter}}$ (K)</th>
<th>$-T_{\text{intra}}$ (K)</th>
<th>$-T_{R-e}$ (K)</th>
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<tr>
<td>0</td>
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<td>26.08</td>
<td>10.95</td>
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<td>14</td>
<td>28.87</td>
<td>7.04</td>
<td>N.R.</td>
</tr>
</tbody>
</table>

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References