# Paramagnetically driven superconducting re-entrance in Eu-doped infinite layer Nd nickelate

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We investigate the synthesis and magnetic-field-driven electronic behavior of infinite-layer $Nd_{1-x}Eu_xNiO_2$ (NENO) thin films. The 112 superconducting phase is obtained from high-quality perovskite nickelate films through topotactic reduction [1]. Following the solid-state route proposed by W. Wei [2,3], metallic aluminium is deposited in situ onto the perovskite film and reacts according to $2Al + 3NdNiO_3 \rightarrow Al_2O_3 + 3NdNiO_2$, selectively removing apical oxygens and stabilizing the square-planar $NiO_2$ coordination. All films were synthesized by RF off-axis magnetron sputtering, with the aluminium layer deposited on-axis.

The 112 NENO phase was successfully obtained on LSAT and $NdGaO_3$ (NGO) substrates. We focus in particular on the response to applied magnetic fields, where superconductivity strongly interacts with the magnetic moments of $Eu^{2+}$ and $Nd^{3+}$ ions. Transport measurements reveal unusually high upper critical fields, requiring high-field experiments up to 30 T performed at the Laboratoire National des Champs Magnétiques Intenses (LNCMI-EMFL), CNRS, Université Grenoble Alpes.

Lower-$T_c$ samples display a striking re-entrant superconducting behavior, with distinct superconducting domes in the $H_{c2}$-$T_c$ phase diagram. This behavior is consistent with a Jaccarino-Peter-type compensation effect [7], arising from a negative exchange field between the magnetic rare-earth ions and the electron spins. Hall effect data are also described by including an anomalous Hall contribution proportional to the spin-paramagnetic response of the $Eu^{2+}$ and $Nd^{3+}$ ions.

[1] D. Li et al., Nature 572, 624-627 (2019)
[2] W. Wei et al., Physical Review Materials 7, 013802 (2023)
[3] W. Wei et al., Sci. Adv. 9, eadh3327 (2023)
[4] C. Domìnguez et al., Nat. Mater. 19, 1182–1187 (2020)
[5] L. Varbaro et al. APL Mater. 12, 081120 (2024)
[6] L. Varbaro et al., Adv. El. Mater. 9, 2201291 (2023)
[7] V. Jaccarino & M. Peter, Phys. Rev. Lett. 9, 290 (1962)