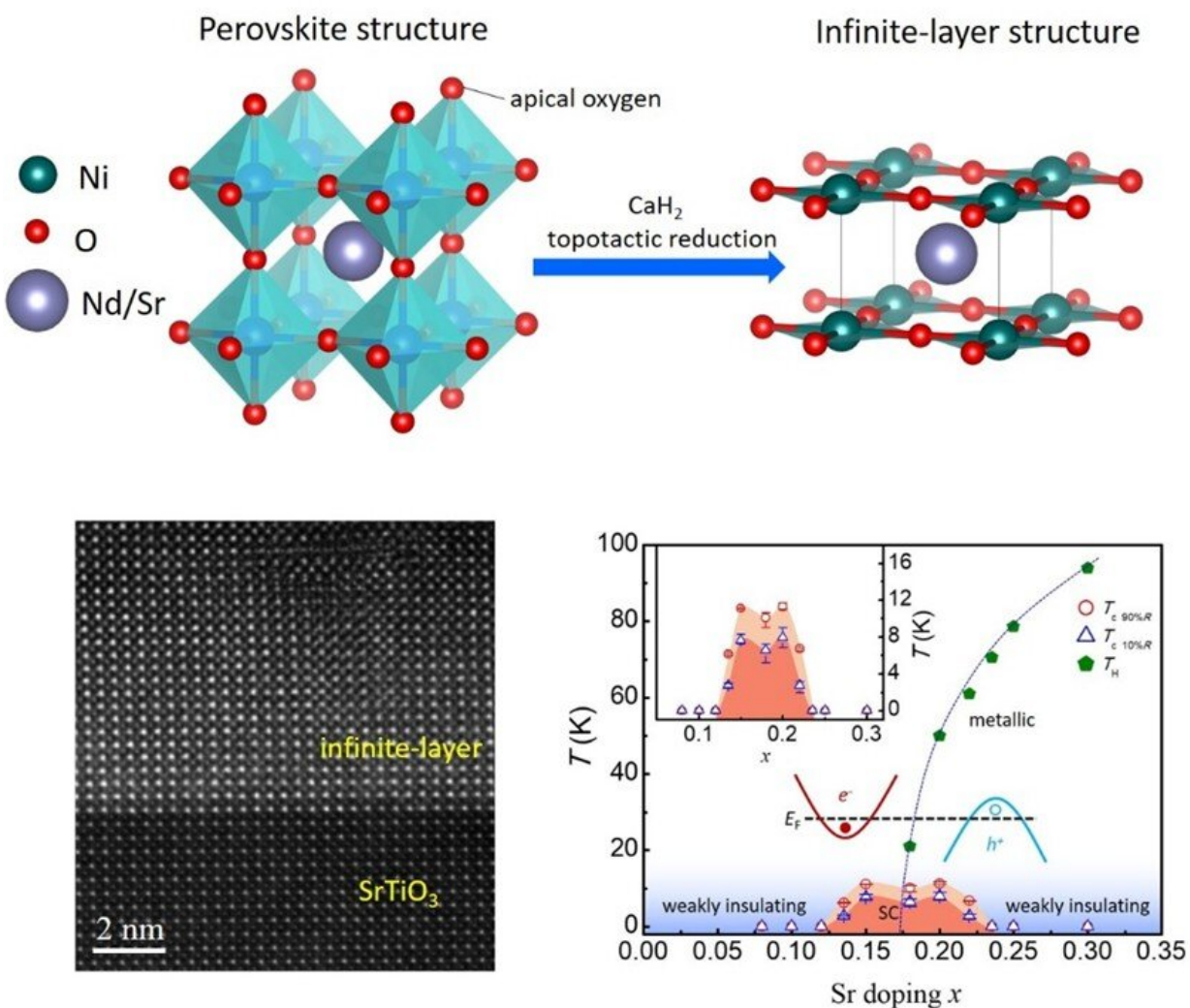


Phase diagram for infinite layer nickel superconductors

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(Top) Figure shows the transformation of the perovskite structure $\text{Nd}_{1-x}\text{Sr}_x\text{NiO}_3$ to the infinite-layer structure $\text{Nd}_{1-x}\text{Sr}_x\text{NiO}_2$ using calcium hydride (CaH_2). (Bottom) Figure shows the high-angle annular dark-field

scanning transmission electron microscopy (HAADF-STEM) image and the phase diagram of infinite-layer $\text{Nd}_{1-x}\text{Sr}_x\text{NiO}_2$ films on single crystalline SrTiO_3 substrate. The $T_{c90\%R}$ and $T_{c10\%R}$ are defined to be the temperature at which the resistivity drops to 90% and 10% of the value at 15 K (the onset of the superconductivity) respectively. The inset in the left upper corner of the plot is the enlarged view of the superconducting dome region. TH shows the temperature at which the majority of charge carriers changes from electrons to holes. Credit: Physical Review Letters

NUS physicists have developed a method to induce the transition of a rare-earth nickelate from their native perovskite form to infinite-layer structures. This allowed them to build a complete phase diagram of this nickelate superconductor.

A superconductor is a material system that can conduct [electrical current](#) with zero resistance when it becomes colder than a "[critical temperature](#)," known as the superconducting transition temperature T_c . Conventional superconductors usually have a T_c lower than the limit of around 30 K (268 degrees below room temperature) predicted based on the Bardeen–Cooper–Schrieffer (BCS) theory. This limits the use of superconducting devices in our daily lives. For decades, researchers have been trying to push this T_c higher by synthesizing [new materials](#). It is also important to understand the physical mechanism. The so-called [high temperature superconductivity](#) in compounds containing copper oxide layers (known as the cuprates), with T_c above the BCS limit and subsequently above the boiling point of liquid nitrogen (77 K), was discovered in late '80s. Since then the T_c has been stagnant and although important research outcomes have been made, the origin and mechanism of the high- T_c [superconductivity](#) is still a mystery. A new superconducting family with a similar crystal and electronic structure as the cuprate is one of the paths in the search for potentially higher T_c materials and to understand the underlying mechanism of high- T_c

superconductivity.

Recently, researchers have discovered the presence of superconductivity in rare-earth nickelate compounds, an analog of the cuprate. Studying this cuprate analog could potentially lead to a better understanding of high temperature superconductivity, and the possibility to predict, design and synthesize higher T_c superconductors. However, it became apparent that nickelate superconductors are more challenging to produce than initially thought. Nine months after this discovery, a research team led by Prof ARIANDO from the Department of Physics, NUS, became the first group to reproduce this result. More importantly, they successfully developed the phase diagram of the nickelate superconductor.

To achieve this, Prof ARIANDO's group developed a topotactic reduction technique to transform thin films of rare-earth nickelate (NdNiO_2) from its usual perovskite crystalline form to a new doped structural form, known as infinite-layer structures. In this material, superconductivity arises when the nickelate compound is doped with strontium (Sr) impurities and it exists in its infinite-layer structural form. The technique allowed the research team to study the superconductivity as a function of doping. They constructed the phase diagram for this material system, and found the presence of a superconducting dome region (doping dependent T_c) and weakly insulating regime by the side of the dome (See Figure).

In their experiments, the researchers used a pulsed laser deposition technique to synthesize Sr-doped nickelate $\text{Nd}_{1-x}\text{Sr}_x\text{NiO}_3$ thin films on strontium titanate (SrTiO_3) substrates. The as-grown thin film, together with a reagent, calcium hydride (CaH_2), was put into a vacuum chamber to induce a reduction reaction. During the reduction process, the apical oxygen atom in the NiO_6 octahedra is removed. This causes the perovskite $\text{Nd}_{1-x}\text{Sr}_x\text{NiO}_3$ to transform into the infinite-layer $\text{Nd}_{1-x}\text{Sr}_x\text{NiO}_2$. The researchers applied different levels of Sr doping

concentrations and found that superconductivity appears in the infinite-layer $\text{Nd}_{1-x}\text{Sr}_x\text{NiO}_2$ when the Sr composition is between $x = 0.135$ and 0.235 . This forms a superconducting dome-shaped region. More interestingly, they found that besides the superconducting region, weakly insulating behavior can be observed at low temperatures. This unique behavior is different from other high- T_c material systems such as cuprates.

Prof Ariando said, "By introducing suitable impurities to the insulating parent compound, the [nickelate](#) material system can exhibit high- T_c superconductivity. Our findings can provide further insights to better understand the doping-dependent properties in these material systems and to search for other superconducting materials in the 'nickel family.'"

More information: Shengwei Zeng et al. Phase Diagram and Superconducting Dome of Infinite-Layer $\text{Nd}_{1-x}\text{Sr}_x\text{NiO}_2$ Thin Films, *Physical Review Letters* (2020). [DOI: 10.1103/PhysRevLett.125.147003](https://doi.org/10.1103/PhysRevLett.125.147003)

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