High Pressure Synthesis of Ruddlesden-Popper Nickelates $R_{n+1}Ni_nO_{3n+1}$ (R = La, Pr, Nd, and Sm)

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Motivation

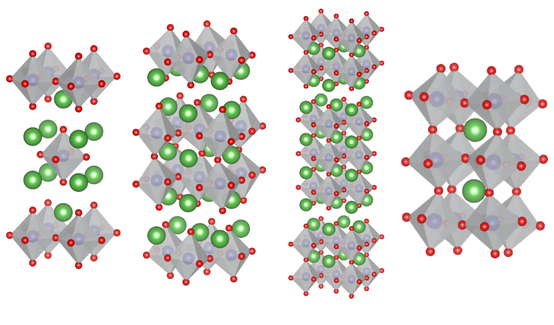
The search for room-temperature superconductors has been at the forefront of past and current research. In more recent years, the focus has shifted to mimicking the superconductivity of the cuprates in a similar material, the nickelates. In theory, the nickelates should have the same electronic properties since nickel is right next to copper in the periodic table. Specifically, there has been evidence of trace superconductivity found at 80 K in $La_3Ni_2O_7$, a Ruddlesden-Popper nickelate [1]. Therefore, the goal of this summer was to stabilize any Ruddlesden-Popper nickelate of La, Pr, Nd, and Sm in single crystal form.

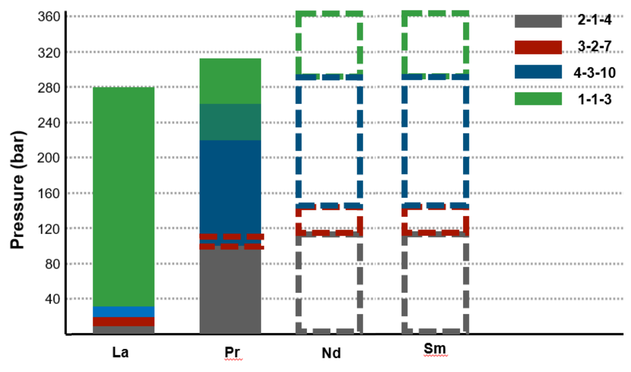
Ruddlesden-Popper Nickelates

Ruddlesden-Popper nickelates are layered materials with repeated layers of Ni-O separated by only rare-earth layers. To stabilize this crystal structure, high pressure during the synthesis is necessary. Current work has been done to stabilize the different phases for La and Pr but there is still work to be done for the remaining rare-earths Nd and Sm [2].

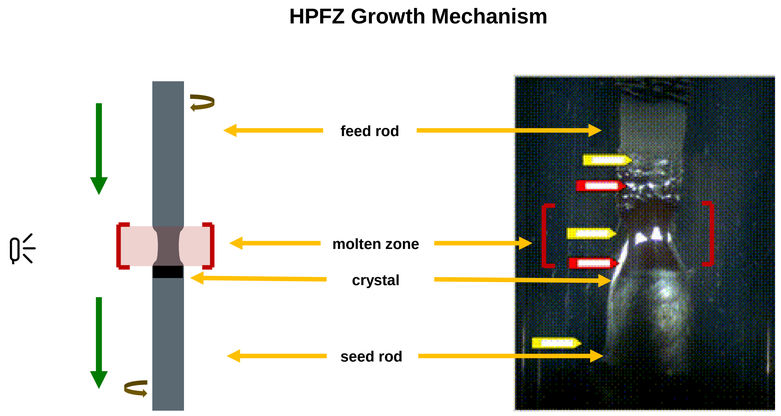
R Ni O

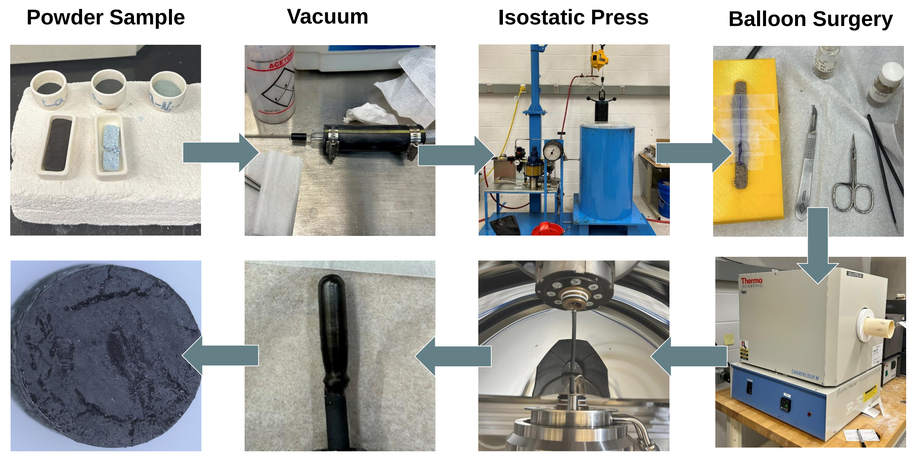
$R_{n+1}Ni_nO_{3n+1}$
R = La, Pr, Nd, Sm





High Pressure Optical Floating Zone Synthesis

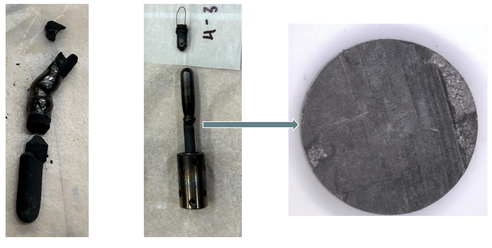


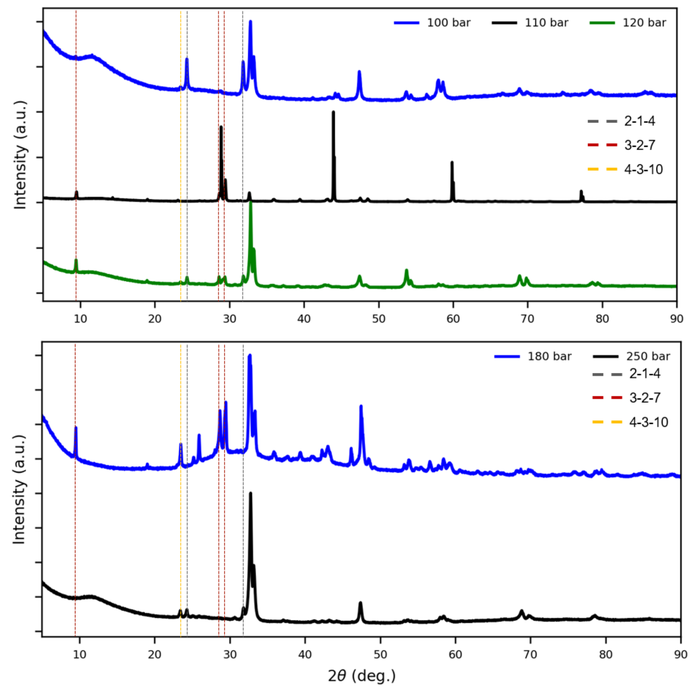


Results

$Nd_3Ni_2O_7$

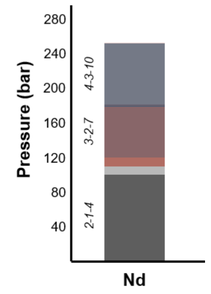
$Nd_4Ni_3O_{10}$





Conclusion

We attempted the high pressure synthesis of single crystal Ruddelesden-Popper nickelates $R_{n+1}Ni_nO_{3n+1}$ (R=La,Pr,Nd,Sm). Of the many growths attempted, we were only able to stabilize $Nd_3Ni_2O_7$ and $Nd_4Ni_3O_{10}$ phases under pressures of 110-120 bar and 180-250 bar respectively. Though we are not able to exclusively isolate each phase at specific pressures, their existence in the x-ray diffraction profiles is a promising step in the right direction. Future work will be done to further isolate single crystals and stabilize the failed growths attempted. Though there is still much work to be done, this work is a step in the right direction to stabilizing new rare-earth nickelate single crystals.



References

1. Sun, Hualei, Mengwu Huo, Xunwu Hu, Jingyuan Li, Zengjia Liu, Yifeng Han, Lingyun Tang, et al. “Signatures of Superconductivity near 80 K in a Nickelate under High Pressure.” Nature 621, no. 7979 (September 2023): 493–98. https://doi.org/10.1038/s41586-023-06408-7.
2. Zhang, Junjie, Hong Zheng, Yu-Sheng Chen, Yang Ren, Masao Yonemura, Ashfia Huq, and J. F. Mitchell. “High Oxygen Pressure Floating Zone Growth and Crystal Structure of the Metallic Nickelates R 4 Ni 3 O 10 (R = La , Pr).” Physical Review Materials 4, no. 8 (August 13, 2020): 083402. https://doi.org/10.1103/PhysRevMaterials.4.083402.