Superconductivity and magnetism in $La_3Ni_2O_7$ and $Pr_4Ni_3O_{10}$

Meng Wang
School of Physics, Sun Yat-Sen University

Since the discovery of superconductivity at 80 K in single crystals of $La_3Ni_2O_7$ at pressures above 14.0 GPa, extensive efforts have been made to understand the properties of the bilayer nickelate system at both ambient and high pressure *(1-3)*. Density-wave-like orders, structural transition, strange metal behavior, oxygen vacancies, and orbital-dependent correlations were observed in the pressure-dependent phase diagram of $La_3Ni_2O_7$ *(4-9)*. However, their connections to the high-T_c superconductivity are still under debate. In this talk, we will discuss the determination of bulk superconductivity in single-crystal samples and the possible magnetic ground states and magnetic excitations measured by inelastic neutron scattering. In addition, we will introduce the discovery of superconductivity in $Pr_4Ni_3O_{10}$ *(10)*.

Reference:

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(10) X. Huang, H. Zhang, J. Li, *et al*., arXiv:2410.07861.

Biography:

Meng Wang is a professor at the School of Physics at Sun Yat-sen University. He graduated from Jilin University and then completed his Ph.D. in condensed matter physics at the Institute of Physics, Chinese Academy of Sciences. He was a postdoctoral research associate at the University of California, Berkeley, from 2013 to 2016. Professor Wang studies high-T_c superconductivity and quantum magnetism using neutron scattering, high-pressure, and various single-crystal growth techniques.

Unconventional lattice architecture in Ruddlesden-Popper nickelate polymorphs

Matthias Hepting
Department for Solid State Spectroscopy, Max Planck Institute for Solid State Research

The recent discovery of superconductivity in the bilayer (BL) Ruddlesden-Popper nickelate $La_3Ni_2O_7$ under high pressure has sparked considerable interest. However, in highly pure $La_3Ni_2O_7$ single crystals grown by the optical-floating zone method, a competing structural phase emerges across macroscopic length scales, characterized by alternating monolayer (ML) and trilayer (TL) NiO_6 units stacked along the *c*-axis direction. This unconventional lattice architecture contrasts sharply with the conventional $La_3Ni_2O_7$ and $La_4Ni_3O_{10}$ Ruddlesden-Popper phases, exhibiting monotonic BL and TL stacking, respectively. In this talk, I will discuss our comprehensive investigation of the ML-TL polymorph structure of $La_3Ni_2O_7$, using high-resolution synchrotron x-ray diffraction (XRD) alongside scanning transmission electron microscopy (STEM). In addition, we employed density functional theory (DFT) to analyze the contributions of the ML and TL structural units to the electronic band structure of the $La_3Ni_2O_7$ polymorph, revealing a unique Fermi surface topology distinct from that of monotonic BL or TL stacks. This characteristic Fermiology was similarly observed in recent angle resolved photoemission spectroscopy (ARPES) experiments on our ML-TL $La_3Ni_2O_7$ crystals, prompting further evaluations of the potential of the ML-TL polymorph for hosting high-temperature superconductivity.

Biography:

Matthias Hepting is a group leader for neutron spectroscopy in the Department for Solid State Spectroscopy at the Max Planck Institute for Solid State Research. From 2017 to 2018, he was a postdoctoral fellow at Stanford University and SLAC National Accelerator Laboratory. In 2016, he received his PhD degree from the Max Planck Institute for Solid State Research and the University of Stuttgart. His research focuses on the investigation of strongly correlated electron systems using a variety of inelastic photon and neutron scattering techniques as well as the synthesis of novel quantum materials.

Changes in low-temperature mean valence of nickel ions in pressurized $La_3Ni_2O_7$

Liling Sun[1,2]

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[2] *Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China*

The discovery of high critical temperature (T_c) superconductivity in pressurized $La_3Ni_2O_7$ has sparked new excitements for exploring novel high-T_c superconducting compounds with 3*d* transition metals, after the finding of copper-oxide and Fe-based superconductors at ambient-pressure. However, understanding the mechanism underlying the pressure-induced superconductivity in this material poses more substantial challenges compared to those encountered with the above two ambient-pressure superconductors, the mechanism of which has been recognized as one of the greatest challenges for the contemporary field of condensed matter physics. A commonly fundamental issue lies in unraveling the impacts of the mixed valence state of the cations with 3*d* orbital electrons on the development of high-T_c superconductivity. Here, we are the first to employ high-pressure (P) and low-temperature synchrotron X-ray absorption spectroscopy to investigate the influence of pressure on the change in mean valence (ν) of Ni ions in $La_3Ni_2O_7$. Our results demonstrate that at a low-temperature of 20 K, ν exhibits a steady increase across the pressures range from 1 atm to 40 GPa. Significantly, as ν approaches about 2.62^+, the ambient-pressure ordered phases disappear, and both the structural and the superconducting phase transition occur. The correlation established between $\nu(P)$ and $T_c(P)$, consistent with the pressure-induced structure transition from an orthorhombic phase to a tetragonal phase, provides new information for a more comprehensive understanding on pressure-induced superconductivity in $La_3Ni_2O_7$.

* This work was in collaboration with HL Sun, K Jiang, M Wang, Y. Ding, WG Yang, QY Kong, Q Wu, JP Hu, T Xiang and HK Mao.

Biography:

Liling Sun specializes in strongly correlated electron systems, with a particular emphasis on elucidating the mechanisms of unconventional superconductivity using high-pressure methods. She served as a full professor at the Institute of Physics, Chinese Academy of Sciences from 2005 to 2023 before joining to the Center for High Pressure Science & Technology Advanced Research (HPSTAR). She has published over 150 papers in scientific journals, including Nature, Nature Physics, Nature communications, PNAS, Reports on Progress in Physics, Physics Review Letters and Advanced Materials *etc*, and delivered over 60 invited talks. Professor Sun is a Fellow of the American Physical Society.

ARPES on Electronic Structures of Double-Layer Nickelate $La_3Ni_2O_7$

Xingjiang Zhou
National Lab for Superconductivity, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

We will report our direct measurement of the electronic structures of $La_3Ni_2O_7$ by high-resolution angle-resolved photoemission spectroscopy (ARPES) *(1)*. The Fermi surface and band structures of $La_3Ni_2O_7$ are observed and compared with the band structure calculations. A flat band is formed from the Ni-$3d_{z^2}$ orbitals around the zone corner which is ~50 meV below the Fermi level. Temperature dependence of the flat band is measured. Strong electron correlations are revealed which are orbital- and momentum-dependent. These observations provide key information to understand the origin of high temperature superconductivity in $La_3Ni_2O_7$.

Reference:

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Biography:

Xingjiang Zhou is currently a professor in the Institute of Physics, Chinese Academy of Sciences, Beijing. He received his B.S. and M.S. degrees from Tsinghua University and his Ph. D degree from the Institute of Physics, Chinese Academy of Sciences, Beijing. He developed a series of high-resolution vacuum ultra-violet laser-based angle-resolved photoemission systems. His research focuses on studying high temperature superconductors and other quantum materials. He has published more than 270 papers. He got the Achievement in Asia Award in 2014 and the TWAS Prize in Physics in 2015. He is a Fellow of American Physical Society.

<u>Destructive effect of structural disorders on the high-T_c superconductivity of pressurized bilayer nickelates</u>

Jinguang Cheng
Institute of Physics, Chinese Academy of Sciences

The recent report on the signature of high-temperature superconductivity (HTSC) in pressurized bilayer nickelate $La_3Ni_2O_7$ has sparked tremendous interest in the long-sought-after nickelate superconductors. Although zero resistance and diamagnetism have been achieved in the pressurized bilayer nickelates, there remain contradictory reports from different laboratories regarding the nature of HTSC. Accumulating experimental results have indicated an extreme sensitivity for the observed HTSC to structural imperfections and/or oxygen vacancies in the bilayer nickelates, while a comprehensive investigation on this point remains lacking. In this talk, I will present our recent effort of revealing the destructive effect of structural disorders on the HTSC of bilayer nickelates. The structural disorders include the intrinsic intergrowth of different Ruddlesden-Popper phases, the dislocations produced by shear stress/strain in solid pressure transmitting medium, and the site disorders introduced via chemical substitutions at the Ni sites. We believe these data can not only clarify some current contradictory results but also facilitate further investigations on the underlying mechanism of HTSC in bilayer nickelates.

Acknowledgement:
This work is in collaboration with Ningning Wang, Gang Wang, Xiaoling Shen, Jun Hou, Xiaoping Ma, Huaixin Yang, Rui Zhou, Zhian Ren, Stuart Calder, Jiaqiang Yan, Yoshiya Uwatoko, supported by MOST, NSFC, and CAS through projects.

Biography:
Jinguang Cheng is a professor at the Institute of Physics, Chinese Academy of Sciences (IOPCAS). He obtained the Ph.D. in Materials Science from University of Texas at Austin in 2010. Following two-year postdoctoral research at Austin, he joined IOPCAS and became the ground leader of EX6 in the Laboratory of Extreme Conditions Physics since 2014. His research interest focuses on the explorations of novel quantum materials and phenomena under high-pressure extreme conditions. He has published over 240 peer-reviewed journal papers and received the Sir Martin Wood China Prize in 2016.

Scanning near-field optical microscopy study on $La_3Ni_2O_7$ single crystals

Zengyi Du
Hefei National Laboratory/University of Science and Technology of China

In this talk, I will present our scanning near-field optical microscopy (SNOM) study on $La_3Ni_2O_7$ single crystals[1], revealing nanoscale structural phase separation. The near-field map shows enhanced optical conductivity in stripes that run diagonally relative to the Ni-O-Ni bond directions in the a-b plane. This pattern rules out impurity phases, such as the '1313', '214', or '4310' structures, and suggests the coexistence of orthorhombic Amam and Fmmm phases. As a contrast, $La_4Ni_3O_{10}$ displays uniform and higher optical conductivity with no evidence of phase separation. Our findings demonstrate SNOM as a powerful tool for investigating nanoscale low-energy physics in correlated quantum materials.

Reference:

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Biography:

Zengyi Du, a research fellow at Hefei National laboratory and University of Science and Technology of China in Prof. Donglai Feng's group. His research focuses on STM studies of high-temperature superconductors and developing scanning near-field optical microscopy (SNOM) technology under the extreme conditions to explore light-matter interaction at the nanoscale in quantum materials. As the first author, he has published articles in journals such as *Nature*, *Nature Physics*, *Nature Communications*, and *Physical Review X*.

Electronic structure and ultrafast dynamics of bilayer and trilayer nickelate superconductors

Lexian Yang

State Key Laboratory of Low Dimensional Quantum Physics, Department of Physics, Tsinghua University, Beijing 100084, China.

High-temperature superconductivity (HTSC) remains one of the most challenging and fascinating mysteries in condensed matter physics. Recently, superconductivity with transition temperature exceeding liquid-nitrogen temperature is discovered in $La_3Ni_2O_7$ at high pressure, which provides a new platform to explore unconventional HTSC. In this work, using high-resolution angle-resolved photoemission spectroscopy and ultrafast reflectivity spectroscopy, we systematically investigate the electronic structures and ultrafast dynamics of $La_3Ni_2O_7$ and $La_4Ni_3O_{10}$ at ambient pressure. The measured electronic structures agree with *ab-initio* calculations after considering an orbital-dependent band renormalization effect. The strong electron correlation effect pushes a flat band of d_{z^2} orbital component below the Fermi level (E_F), which is predicted to locate right at E_F under high pressure. Moreover, the $d_{x^2-y^2}$ band shows a pseudogap-like behavior with suppressed spectral weight and diminished quasiparticle peak near E_F. While the electronic structures of $La_3Ni_2O_7$ and $La_4Ni_3O_{10}$ are very similar, their ultrafast dynamics are radically different. We will also discuss the different electron-phonon coupling effects in the two compounds. Our findings provide important insights into the electronic behaviors of $La_3Ni_2O_7$ and $La_4Ni_3O_{10}$, which will shed light on the understanding of the unconventional superconductivity in nickelates.

Key words: Nickelate superconductor, electronic correlation, pseudogap, ultrafast dynamics

Biography:

Lexian Yang has been an associate professor at the Department of Physics, Tsinghua University since 2019. He received his B.S. and Ph.D. degrees from Fudan University. He is mainly interested in the electronic structure of various quantum materials, including the topological quantum materials, strongly correlated materials, low-dimensional materials, and advanced functional materials.

Superconducting gap features revealed by point contact tunneling spectroscopy in pressurized $La_3Ni_2O_7$

Hai-Hu Wen
School of Physics, Nanjing University, China

The discovery of superconductivity with T_c above 77 K in pressurized $La_3Ni_2O_7$ has stimulated enormous interests in the field of unconventional superconductivity. A recent experiment in $La_2PrNi_2O_7$ has shown that the superconducting volume is close to 100%. Because the superconductivity can only be achieved under high pressures, many intrinsic properties, such as the superconducting gaps, have not been measured yet. In this paper, we report the Andreev reflection measurement of the pressurized $La_3Ni_2O_7$ with the onset superconducting transition temperature at about 77 K. Our data reveal a clear peak of differential conductivity near zero bias in the tunneling spectrum, and appear also are some temperature-dependent steps which may reflect other superconducting gaps. Calculations based on the Blonder-Tinkham-Klapwijk model with three components can roughly fit the data: the central peak can be fitted with a *d*-wave gap with a magnitude of about 9 meV, and other two *s*-wave gaps at about 16 and 26 meV. Our results reveal possible evidence of a sign-reversal gap and multi-component features of the superconducting gaps in the nickelate 327 systems.

In collaboration with Cong Liu, Mengwu Huo, Huan Yang*, Qing Li*, Yingjie Zhang, Zhening Xiang, Meng Wang*

Biography:
Hai-Hu Wen, a senior professor of physics in School of Physics, Nanjing University, Director of Center for Superconducting Physics and Materials of Nanjing university, Winner of the Outstanding Youth Foundation of China (1998), Yangtze River Scholarship Professor (2012), American Physical Society Fellow (2013). Interests cover exploration of new superconducting materials, unconventional pairing mechanism of cuprates and iron based superconductors, mixed state properties, correlation effect and non-Fermi liquid behavior, etc. Has made several important contributions in the field of superconductivity. Published more than 460 scientific papers in internationally recognized journals, received over 14000 citations, h-index 60. Delivered more than 100 speeches or invited talks at international conferences.

Probing Density Wave Instability in $La_4Ni_3O_{10}$ with Ultrafast Optical Spectroscopy

Jian-Qiao Meng
School of Physics, Central South University

We investigate the density wave instability in the trilayer nickelate $La_4Ni_3O_{10}$ using ultrafast optical spectroscopy. At ambient pressure, three distinct coherent phonon modes are observed at 3.87, 5.28 and 5.63 THz. Temperature-dependent relaxation dynamics at low pump fluence reveal a phonon bottleneck effect associated with the opening of an energy gap near the density wave transition temperature ($T_{DW} \sim 135$ K). Furthermore, we find that the density wave order is significantly suppressed with increasing pump fluence.

Biography:
Jianqiao Meng obtained his B.S. from Hunan Normal University (2004) and his Ph.D. from the Institute of Physics, Chinese Academy of Sciences (2009). Following postdoctoral work at UCSC and LANL, he joined Central South University as a professor in 2014. His research focuses on the electronic structure and ultrafast dynamics of complex materials, including high-temperature superconductors, heavy fermions, and topological materials. He employs time-resolved and angle-resolved photoelectron spectroscopy, along with ultrafast pump-probe spectroscopy, to investigate these systems.

Superconductivity in pressurized trilayer nickelate single crystals

Jun Zhao
Department of Physics, Fudan University

The search for new high-temperature superconductors beyond the copper-based paradigm offers exciting opportunities to deepen our understanding of superconductivity mechanisms and explore new applications. In this talk, I will present our successful synthesis of high-quality trilayer nickelate $La_4Ni_3O_{10-\delta}$ single crystals with minimal oxygen deficiency, achieved through the high-pressure optical floating zone technique. Our results show that applying pressure effectively suppresses spin and charge order in $La_4Ni_3O_{10-\delta}$, leading to the emergence of superconductivity with a maximum T_c of around 30 K at 69.0 GPa. Susceptibility measurements reveal a strong diamagnetic response below T_c, confirming bulk superconductivity. In the normal state, we observe 'strange metal' behavior, marked by linear temperature-dependent resistance up to 300 K. This system's layer-dependent superconductivity suggests a distinct interlayer coupling mechanism, distinct from cuprates. These findings offer insights into the mechanisms of superconductivity and introduce a new material platform to study the interplay between various electronic phenomena, including spin/charge order, flat band structure, interlayer coupling, strange metal behavior and superconductivity.

Biography:
Jun Zhao is a Professor in the Department of Physics at Fudan University, where he has been a faculty member since 2012. Before joining Fudan, he was a Miller Research Fellow at UC Berkeley. His research primarily focuses on utilizing various neutron scattering techniques to investigate phase transitions and spin dynamics in strongly correlated electron systems. Additionally, he works on the growth of large-scale, high-quality single crystal samples and the measurement of their thermodynamic and transport properties. His work aims to advance the understanding of high-temperature superconductivity and quantum magnetism.

Discovery of new Superconductor $La_4Ni_3O_{10}$ Under High Pressure

Yoshihiko TAKANO[1,2]
[1] *Frontier Superconducting Materials Group, National Institute for Materials Science*
[2] *University. of Tsukuba*

Recent discovery of superconductivity in layered perovskite nickelate $La_3Ni_2O_7$ (T_c ~ 80 K) attracts much attention due to its high superconducting transition temperature (T_c) and similarity of crystal structure to high-T_c cuprate *(1)*. And its mechanism of superconductivity was already predicted in 2017 by Kuroki's group *(2)*. $La_3Ni_2O_7$ corresponds to the n=2 case of the Ruddlesden-Popper phase represented by the general formula of $La_{n+1}Ni_nO_{3n+1}$, and it has two layers of NiO_2 plane. In general, Ruddlesden-Popper phase has two-dimensional crystal and electric structure which is suitable for appearance of superconductivity for instance Li intercalated $KCa_2Nb_3O_{10}$ *(3)*. Particularly, $La_4Ni_3O_{10}$, is corresponding to n = 3 case of the Ruddlesden-Popper phase having three layers of NiO_2 plane. Due to the similarity between these materials, we expect the possibility of superconductivity in $La_4Ni_3O_{10}$ under high pressure*(4)*.
We synthesized polycrystalline samples, $La_3Ni_2O_7$ and $La_4Ni_3O_{10}$ with different oxygen contents, via solid-phase reaction and Hot Isostatic Pressing process from La_2O_3 and NiO *(4)*. Samples are characterized by powder X-ray diffraction and thermogravimetry. High pressure was generated with original Diamond Anvil Cell with boron-doped diamond electrodes designed for four-terminal resistance measurements *(5)*.
$La_4Ni_3O_{10}$ displays metallic behavior across all measured pressures, with a slight upturn observed at temperatures below approximately 100 K. A drop in resistance corresponding to superconductivity suddenly appears ~5 K at 32.8 GPa,. With increasing pressure beyond 46.2 GPa, the drop of resistance becomes significant and the T_c elevated up to 23 K at 79.2 GPa. This is the first discovery of superconductivity in $La_4Ni_3O_{10}$. In case of the sample with high oxygen contents, $La_4Ni_3O_{10.04}$ shows superconductivity at ~5 K around 20 GPa and increase up to T_c=36 K at ~48 GPa which is the record of T_c in $La_4Ni_3O_{10.04}$ up to now *(6)*.

References:

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(2) M. Nakata et al., Phys. Rev. B 95, 214509 (2017).
(3) Y. Takano et al., Solid State Commun., 103, 215 (1997).
(4) H. Sakakibara et al., arXiv: 2309.09462.
(5) R. Matsumoto et al., Rev. Sci. Instrum. 87, 076103 (2016).
(6) H. Nagata et al., J. Phys. Soc. Jpn 93, 095003 (2024).

Biography:

Y. Takano is a group leader at the Frontier Superconducting Materials Group, National Institute for Materials Science (NIMS), Tsukuba, Japan. His main research field is experimental condensed matter physics in general, and superconductivity in particular. He obtained his Ph. D from Yokohama-City University in 1995. He then joined the Institute for Solid State Physics, the University of Tokyo, as a post-doctoral researcher. In 1999, he obtained a permanent position at NIMS. Among his research achievements are: the discovery of a new superconducting material, namely a Lithium doped Niobium Oxide layered compound $KCa_2Nb_3O_{10}$, the development of a cross-whisker Josephson junction using d-wave high-T_c superconductors, and the successful synthesis of high-quality Magnesium Diboride superconductor by high pressure sintering, which consequently lead the direct observation the two-gap nature of the superconducting order parameter in this material for the first time in the world. In 2004, he successfully synthesized boron doped diamond thin films by the chemical vapor deposition (CVD) method, and pioneered the demonstration of superconductivity in these films. He organized an international conference on this topic in 2005. In 2008, He discovered strong pressure enhancement of T_c in FeSe superconductor and T_c elevated up to 37 K under pressure. Red wine inducement of superconductivity in Fe-based material is also his work. Recently, he is working in the field of high-pressure using original diamond anvil with boron doped diamond electrode.

Density wave collapse and superconductitivy-like signal emerging in pressurized $La_4Ni_3O_{10}$ revealed by ultrafast spectroscopy

Tao Dong

International Center for Quantum Materials, Peking University

We employed optical spectroscopy and ultrafast reflectivity measurements to investigate the pressure evolution of density wave instability of trilayer nickelate $La_4Ni_3O_{10}$. At ambient pressure, our optical spectroscopy and pump-probe measurements observe a gap opening with 61 meV in $La_4Ni_3O_{10}$ below the density wave transition. By comparing the measured plasma frequency with the first-principles calculation, we categorize $La_4Ni_3O_{10}$ as a moderately electronic correlation material, similar to the parent compound of iron-based superconductors. However, it is weaker than the bilayer nickelate $La_3Ni_2O_7$. With application pressure, the density wave instability is suppressed with increasing pressure and completely collapses around 14 GPa. A superconductivity-like signal emerges in the pump-probe spectroscopy at low temperatures when pressure exceeds 14 GPa.

Biography:

Tao Dong is now a research associate professor at the International Center for Quantum Materials, Peking University. He got his Ph.D. from the Institute of Physics (IOP), Chinese Academy of Science, in January 2014. He then worked at IOP as a research assistant professor. One year later, he moved to Peking University and worked as a research assistant professor. From 2018 to 2020, he did this postdoc research in Prof. Jure Demsar's lab at the Johannes Gutenberg University in Mainz as a Humboldt postdoctoral fellow.

Zurab Guguchia
TBD

Electronic and magnetic excitations of $La_3Ni_2O_7$

Donglai Feng

National Synchrotron Radiation Laboratory, Univ. of Sci. and Tech. of China, Hefei, China

The recent striking discovery of high-temperature superconductivity of 80 K in a bilayer nickelate $La_3Ni_2O_7$ under a moderately high pressure of about 14 GPa ignited a new wave of studying HTSC in nickelates. Using X-ray absorption spectroscopy and resonant inelastic X-ray scattering, we studied $La_3Ni_2O_7$ at ambient pressure and found that Ni $3d_{x^2-y^2}$, Ni $3d_{z^2}$, and ligand oxygen $2p$ orbitals dominate the low-energy physics with a small charge-transfer energy. Remarkably, well-defined optical-like magnetic excitations were found to soften into a quasi-static spin-density-wave ordering, evidencing the strong electronic correlations and rich magnetic properties. Our results on this parental phase may contain key information on basic interactions therein and bosons that may mediate pairing *(1)*.

Reference:

(1) X. Y. Chen et al. Nat. Commun. 15, 9597 (2024).

Biography:

Donglai Feng is a Yan-Jici chair professor at University of Science and Technology of China, and the president of ShanghaiTech University. He has been studying complex quantum materials and their microstructures, and published over 200 papers. He is currently leading the construction of a 4th generation synchrotron light source, the Hefei Advanced Light Facility. Donglai Feng is an academician of the Chinese Academy of Sciences, and a fellow of American Physical society (APS).

High-temperature superconductivity with zero-resistance and strange metal behaviour in $La_3Ni_2O_7$

Huiqiu Yuan
Center for Correlated Matter and Department of Physics, Zhejiang University

Recently signatures of superconductivity were observed close to 80 K in $La_3Ni_2O_7$ under pressure *(1)*. This discovery positions $La_3Ni_2O_7$ as the first bulk nickelate with high-temperature superconductivity, but the lack of zero resistance presents a significant drawback for validating the findings. In this presentation, we will report measurements of the electrical resistance, Hall resistance, I-V curves up to a pressure over 30 GPa using a liquid pressure medium and show that $La_3Ni_2O_7$ does exhibit high-temperature superconductivity with zero resistance *(2)*. We find that $La_3Ni_2O_7$ remains metallic under applied pressures, suggesting the absence of a metal-insulator transition proximate to the superconductivity. Analysis of the normal state T-linear resistance suggests an intricate link between this strange metal behavior and superconductivity, whereby at high pressures both the linear resistance coefficient and superconducting transition are slowly suppressed by pressure, while at intermediate pressures both the superconductivity and strange metal behavior appear disrupted, possibly due to a nearby structural instability. The Hall coefficient undergoes a change near the pressure-induced structure phase transition.

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(2) Y. N. Zhang et al., arXiv: 2307.14819; Nat. Phys. 20, 1269 (2024).

Biography:
Prof. Huiqiu Yuan is a Qiushi Professor in the School of Physics, and the executive deputy director of the Center for Correlated Matter at Zhejiang University. He is an APS fellow and the awardee of Ye Qi-Sun Prize of the Chinese Physical Society.
Prof. Yuan has been working on the emergent quantum phases and phenomena in correlated electron systems. He synthesizes materials and probes their physical properties under multiple extreme conditions of low temperature, high pressure and high magnetic field. He has published over 190 peer-reviewed articles, including a few articles published in Nature, Science, RMP, and delivered over 100 invited conference talks.

Evidence of Spin Density Waves in $La_3Ni_2O_{7-\delta}$ and $La_{1.9}Pr_{1.1}Ni_2O_7$

Lei Shu
Department of Physics, Fudan University

The recently discovered superconductivity with critical temperature T_c up to 80 K in the double-layer Nickelate $La_3Ni_2O_{7-\delta}$ under pressure has drawn great attention. Superconductivity was also discovered in $La_2PrNi_2O_7$ with similar transition temperature and larger superconducting volume fraction. We report the positive muon spin relaxation (μ^+SR) study of polycrystalline $La_{1.9}Pr_{1.1}Ni_2O_7$, $La_3Ni_2O_{6.92}$ and $La_3Ni_2O_{6.63}$ under ambient pressure. Zero-field μ+SR experiments reveal the existence of long-range magnetic order below T_N = 154 K in $La_3Ni_2O_{6.92}$, and T_N = 161 K in $La_{1.9}Pr_{1.1}Ni_2O_7$. On the other hand, the long-range magnetic order is completely disrupted in the highly-oxygen-deficient $La_3Ni_2O_{6.63}$, which exhibits short-range magnetic correlation below T_N = 30 K. The weak transverse-field μ^+SR measurements reveal the bulk nature of magnetism in all three samples. Our μ^+SR experiment results provide a comprehensive view of the correlation between magnetism and structure perfection in double-layer Nickelate under ambient pressure.

Biography:
Lei Shu is a professor in the Department of Physics, Fudan University. She received her PhD in Condensed Matter Physics from University of California, Riverside, USA in 2007, and was a postdoctoral fellow at University of California, San Diego, USA from 2008 to 2011. She is an experimental condensed matter physicist using muon as a probe to study the emergent phenomena in correlated *d*- or *f*-electron quantum materials, including superconductivity, magnetism, and heavy fermion behavior. She has published more than 90 SCI papers on journals such as Science Advances, Nature Reviews Methods Primers, Physical Review Letters, Physical Review B, etc.

Structural defects and their correlations with the superconductivity in high-T_c nickelate superconductors

Zhen Chen
Institute of Physics and University of Chinese Academy of Sciences

The discovery of the high-temperature $La_3Ni_2O_{7-\delta}$ superconductor under pressure has stimulated widespread interest in these Ruddlesden-Popper stacking nickelates. Superconductivity has been observed in both bilayer and trilayer phases. A common challenge is the relatively low superconducting volume fraction due to the stacking disorders and chemical off-stoichiometry. In this talk, I will present a comprehensive structural investigation of $La_3Ni_2O_{7-\delta}$ using our newly developed electron ptychography technique in scanning transmission electron microscopy *(1)*. We find that oxygen vacancies are mainly located in the inner apical oxygen sites between the two NiO_2 layers. We achieve the first atomic level quantification of the oxygen vacancies and find that oxygen vacancies vary significantly on the sub-100 nm length scale, even in what are generally considered to be high quality single crystal samples *(2)*. This may be the main reason for the low superconducting volume estimated from magnetic susceptibility. The structural inhomogeneities are also directly correlated with the ligand holes from O-K edge electron energy loss spectroscopy. We will also show the microstructural investigations in Pr-doped $La_3Ni_2O_7$ and $La_4Ni_3O_{10}$ phases. These results provide important guidelines for further improvement of sample quality and facilitate the understanding of superconductivity in nickelates.

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(2) Z. Dong, *et al*., Nature 630, 847 (2024).

Biography:

Zhen Chen is an Associate Professor at the Institute of Physics, Chinese Academy of Sciences. His major interests include the development of new electron microscopy techniques and applications in condensed matter systems. He has been selected as Innovators under 35 (China) by MIT Technology Review. His works broke twice the Guinness World record for image resolution and 'top 10 science and technology progress in the world in 2021' selected by the Chinese Academies of Science and Engineering. He has published more than 50 journal papers including those in Science, Nature and its sister journals.

Resolving the electronic ground state of $La_3Ni_2O_{7-\delta}$ films

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The recent discovery of a superconductivity signature in $La_3Ni_2O_{7-\delta}$ under a pressure of 14 GPa, with a superconducting transition temperature of around 80K, has attracted considerable attention. An important aspect of investigating electronic structures is discerning the extent to which the electronic ground state of $La_3Ni_2O_{7-\delta}$ resembles the parent state of the cuprate superconductor, a charge transfer insulator with long-range antiferromagnetism. Through X-ray absorption spectroscopy, we have uncovered the crucial influence of oxygen ligands on the electronic ground states of the Ni ions, displaying a charge transfer nature akin to cuprate but with distinct orbital configurations. Both in-plane and out-of-plane Zhang-Rice singlets associated with Ni $d_{x^2-y^2}$ and d_{z^2} orbitals are identified with a strong interlayer coupling through inner apical oxygen. Using resonant X-ray scattering measurements in $La_3Ni_2O_{7-\delta}$ films, we have also detected a superlattice reflection (1/4, 1/4, L) at the Ni L_3 absorption edge. Further examination of the resonance profile indicates that the reflection originates from the Ni *d* orbitals. By evaluating the reflection's azimuthal angle dependence, we have confirmed the presence of collinear antiferromagnetic spin ordering and charge-like anisotropy ordered with the same periodicity. Notably, our findings reveal a microscopic relationship between these two components in the temperature dependence of the scattering intensity of the reflection. This investigation enriches our understanding of high-temperature superconductivity under high pressure in $La_3Ni_2O_{7-\delta}$ bulk crystals.

Biography:
He obtained his Ph. D. in 2016 from the University of Connecticut in the USA. He is currently an Associate Professor at the Institute of Physics, Chinese Academy of Sciences. Dr. Zhu’s research focuses on correlated-electron physics in transition metal oxides (TMOs). His study is materials and problem-based, tackling the full spectrum of a problem from material synthesis (PLD, OMBE) to advanced measurements (resonant elastic/inelastic x-ray scattering), often at large-scale facilities at national labs.