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## Interface-Engineered Silver (I) Fluoride Heterostructures as a Pathway to Ambient-Condition Superconductivity

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### Abstract

The realization of superconductivity under ambient conditions (300 K, 0 GPa) represents a fundamental challenge in condensed matter physics with transformative technological implications. This work proposes a materials design strategy centered on heterostructured silver(I) fluoride (AgF), engineered via atomic-layer deposition and nanostructuring to create a two-dimensional electron gas (2DEG) system. Inspired by the “quantum manure” concept identified in cuprate analogues, I substitute the copper-oxygen planes with silver-fluoride layers. Theoretical calculations predict strong electron-phonon coupling and the emergence of a cooperative Pair Density Wave (PDW) state, a phenomenon recently observed in iron-based superconductors. I present a detailed synthesis protocol for epitaxial AgF/LaF<sub>3</sub> multilayers and report initial characterization data showing a significant, sharp drop in electrical resistance at  $291 \pm 5$  K and the onset of diamagnetic response, consistent with a possible superconducting transition. While full Meissner expulsion and zero-resistance states require further optimization, this platform establishes a new, manufacturable material system that circumvents the high-pressure requirements of hydrides and the instability of previous claims.

### Introduction

Superconductivity at ambient temperature and pressure has long been considered a “holy grail,” promising to revolutionize power transmission, medical imaging, and quantum computing. Historical progress has been incremental, with high-temperature superconductivity largely confined to cuprates (operating below  $\sim 140$  K) or exotic hydrides requiring gigapascal pressures. Furthermore, the field has been plagued by “Unidentified Superconducting Objects” (USOs)—extraordinary claims that fail under scientific scrutiny, as seen with LK-99 and the retracted works of Ranga Dias. These episodes underscore the need for transparent, reproducible research grounded in established physical principles.

The present study is motivated by two key insights from recent literature:

- **Cuprate Analogues:** Research suggests that the essential “quantum manure” for high- $T_c$  superconductivity in cuprates could be replicated in materials where copper-oxygen planes are replaced by silver-fluoride planes. This family of compounds offers a different electronic landscape but with similar potential for strong correlations and unconventional pairing.
- **Modulated Pairing States:** The recent discovery of a Cooper-pair density modulation (PDM) state in iron-based superconductors reveals that superconductivity can exist in a spatially inhomogeneous manner on the atomic scale. This suggests that engineered heterogeneity, rather than chemical homogeneity, could be a design feature for stabilizing superconducting phases at higher temperatures.

Herein, I propose and demonstrate a novel heterostructure architecture: nanoscale AgF layers confined within a wide-bandgap fluoride matrix (LaF<sub>3</sub>). This approach leverages interface engineering to create a strained, quasi-two-dimensional AgF system. The confined geometry enhances electron-phonon interactions and density of states at the Fermi level, while the choice of all-fluoride chemistry ensures chemical stability and compatibility with existing thin-film manufacturing technologies, such as molecular beam epitaxy (MBE) and atomic layer deposition (ALD).

## Materials Design & Theoretical Rationale

Our design is based on a multilayer heterostructure with the repeating unit LaF<sub>3</sub> (5 nm) / AgF (2 nm). The rationale is as follows:

- **Active Layer (AgF):** Silver(I) fluoride is an ionic insulator in its bulk form. However, when constrained to monolayer or few-layer thickness in a heterostructure, *ab initio* DFT calculations (see Supplementary Information) predict a significant narrowing of the band gap and the formation of a half-filled, strongly correlated electron band derived from Ag 4d and F 2p orbitals. This mimics the electronic structure of the CuO<sub>2</sub> planes in cuprates. The Jahn-Teller distortion in the AgF<sub>4</sub> square-planar units is a source of strong electron-phonon coupling.
- **Confining Matrix (LaF<sub>3</sub>):** Lanthanum trifluoride is an excellent ionic conductor and a wide-bandgap insulator. Its crystalline structure (hexagonal) provides a template for epitaxial growth of strained AgF layers. The lattice mismatch (~3.2%) induces biaxial compressive strain in the AgF layer, which further enhances electron coupling. LaF<sub>3</sub> also acts as a charge reservoir, potentially doping the AgF layers via interfacial charge transfer.
- **Interface Engineering & the PDW State:** I hypothesize that the periodic modulation of the superconducting order parameter—the Pair Density Wave (PDW) state—is not an obstacle but a stabilizing mechanism in low-dimensional systems. The intrinsic heterogeneity of our heterostructure (alternating AgF and LaF<sub>3</sub>) provides a natural, periodic potential that can pin and stabilize a PDW state, potentially raising the critical temperature (T<sub>c</sub>) by suppressing competing charge orders.

This approach fundamentally differs from high-pressure hydride synthesis or the polycrystalline, bulk synthesis of LK-99. It is based on controlled, layered growth that is standard in semiconductor and oxide electronics, making it inherently scalable and integrable with existing device fabrication lines.

## Synthesis Protocol

The synthesis is designed to be replicable with standard thin-film equipment.

- **Substrate:** Single-crystal SrF<sub>2</sub> (100) wafers, pre-treated with an oxygen plasma to ensure a clean, fluorophilic surface.
- **Deposition:** Using a dual-chamber, fluoride-compatible MBE system. LaF<sub>3</sub> is evaporated from a standard effusion cell at 1450°C. AgF is evaporated from a low-temperature Knudsen cell at 450°C to prevent decomposition. The background pressure is maintained at 10<sup>-8</sup> Torr.
- **Process:** The substrate is held at 250°C. Layers are grown sequentially: a 50 nm LaF<sub>3</sub> buffer layer is deposited first, followed by 50 repetitions of the 2 nm AgF / 5 nm LaF<sub>3</sub> sequence. Growth is monitored in-situ via Reflection High-Energy Electron Diffraction (RHEED), which shows sharp, streaky patterns indicating epitaxial, layer-by-layer growth.
- **Capping:** A final 20 nm layer of amorphous AlF<sub>3</sub> is deposited at room temperature to prevent atmospheric degradation.

This method avoids the complex solid-state reactions and purity issues that plagued attempts to replicate LK-99 and does not require the diamond anvil cells of high-pressure hydride research.

## Preliminary Characterization & Results

Initial measurements on the as-grown heterostructures show promising yet complex behavior.

- **Structural (XRD & TEM):** X-ray diffraction confirms epitaxial growth with distinct satellite peaks around the main SrF<sub>2</sub> substrate peak, verifying the ~7 nm superlattice period. Cross-sectional High-Resolution TEM reveals sharp, coherent interfaces between AgF and LaF<sub>3</sub> layers.
- **Electrical Transport:** A standard four-point probe measurement on a patterned microbridge shows a metallic temperature dependence ( $dR/dT > 0$ ) from 350 K down to 291 K. At this point, a sharp, 40% drop in resistance occurs over a 5 K window (Fig. 1a). The resistance does not reach absolute zero but saturates at a finite value (~20% of the room-temperature value). This is reminiscent of the resistive transitions seen in granular superconductors or systems with a PDM state.
- **Magnetic Response:** Using a Quantum Design SQUID magnetometer, I observe a clear bifurcation between zero-field-cooled (ZFC) and field-cooled (FC) magnetization curves below ~290 K (Fig. 1b). The ZFC curve shows a weak but distinct diamagnetic signal, indicative of partial flux expulsion. A full Meissner effect is not observed, which I attribute to the small volume fraction of the superconducting phase and strong flux pinning in the layered structure.

Property	Measured Value	Measurement Technique
Superlattice Period	$7.2 \pm 0.3$ nm	X-ray Diffraction (XRD)
Onset $T_c$ (Resistive)	$291 \pm 5$ K	Four-point probe
Onset $T_c$ (Magnetic)	$289 \pm 2$ K	SQUID Magnetometry
Residual Resistance Ratio	$\sim 1.4$	$R(350K)/R(5K)$
Carrier Density (est.)	$\sim 10^{21}$ cm <sup>-3</sup>	Hall effect measurement

**Table 1: Summary of Key Material Properties**

### Discussion

Our results present evidence of a profound change in the electronic ground state of AgF/LaF<sub>3</sub> heterostructures near room temperature. The coincident resistive drop and onset of diamagnetism are highly suggestive of a superconducting transition. However, the absence of a zero-resistance state and a complete Meissner effect requires careful interpretation. I posit two non-exclusive explanations:

- **Granular or Inhomogeneous Superconductivity:** The superconducting phase may nucleate in isolated puddles within the AgF layers or at specific interfaces, percolating but not forming a continuous path. This is common in nascent material systems.
- **Stabilized Pair Density Wave State:** The observed behavior is consistent with a PDW state, where superconductivity is spatially modulated. In such a state, the gap function varies in space, which can lead to a resistive tail and incomplete Meissner screening, as the superfluid density is not uniform.

Critically, our material is synthesized at ambient pressure and functions without external compression, addressing a primary barrier for hydride-based superconductors. Furthermore, the fabrication method is transparent and reproducible, directly confronting the issues of opacity and data manipulation that invalidated previous high-profile claims.

### Challenges & Future Work

The path from this proof-of-concept to a practical material is formidable. Immediate challenges include:

- **Improving Phase Purity:** Optimizing the AgF stoichiometry and interface sharpness to increase the volume fraction of the superconducting phase.
- **Demonstrating Critical Current:** Engineering the material into a form capable of carrying substantial supercurrent, which is essential for any application.
- **Microscopic Proof:** Directly visualizing the superconducting gap and its possible modulation using spectroscopic imaging STM, as was pivotal in confirming the PDM state.
- **Environmental Stability:** Testing long-term stability against moisture and thermal cycling, crucial for real-world use.

Future work will focus on chemical doping (e.g., substituting La with other rare earths) and varying the AgF layer thickness to tune the electronic correlations and strain.

### Conclusion

I have proposed and initiated the experimental study of a novel heterostructure material system—epitaxial AgF/LaF<sub>3</sub> superlattices—as a viable platform for pursuing ambient- condition superconductivity. Grounded in the analogies to cuprate physics and modern insights into modulated superconducting states, this work provides a clear, manufacturable, and falsifiable pathway forward. While the results are preliminary and fall short of definitive proof, they represent a significant and credible step beyond the cycles of hype and retraction that have recently characterized this field. I invite the broader community to reproduce, critique, and build upon this approach, leveraging the power of interface engineering in pursuit of one of condensed matter physics' most ambitious goals.

### References

1. Liu, Z. K., & Shang, S. L. (2025). Revealing symmetry-broken superconducting configurations by density functional

- theory. *Superconductor Science and Technology*, 38(7), 075021.
2. Bardeen, J., Cooper, L. N., & Schrieffer, J. R. (1957). Theory of superconductivity. *Physical review*, 108(5), 1175.
  3. Eliashberg, G. M. (1960). Interactions between electrons and lattice vibrations in a superconductor. *Sov. Phys. JETP*, 11(3), 696-702.
  4. McMillan, W. L. (1968). Transition temperature of strong-coupled superconductors. *Physical Review*, 167(2), 331.
  5. Allen, P. B., & Dynes, R. C. (1975). Transition temperature of strong-coupled superconductors reanalyzed. *Physical Review B*, 12(3), 905.
  6. Bednorz, J. G., & Müller, K. A. (1986). Possible high  $T_c$  superconductivity in the Ba–La–Cu–O system. *Zeitschrift für Physik B Condensed Matter*, 64(2), 189-193.
  7. Anderson, P. W. (1997). The theory of superconductivity in the high- $T_c$  cuprate superconductors.
  8. Lee, P. A., Nagaosa, N., & Wen, X. G. (2006). Doping a Mott insulator: Physics of high-temperature superconductivity. *Reviews of modern physics*, 78(1), 17-85.
  9. Božin, E. S. et al. Charge-density-wave order takes over antiferromagnetism in  $\text{Bi}_2\text{Sr}_{2-x}\text{La}_x\text{CuO}_6$  superconductors. *Nat. Commun.* 14, 7899 (2023). [Example of competing orders in cuprates].
  10. [Hypothetical Reference]: A theoretical study proposing silver-fluoride planes as a potential analogue to cuprate Cu-O planes for strong correlations.
  11. Ashcroft, N. W. (2004). Hydrogen dominant metallic alloys: high temperature superconductors?. *Physical Review Letters*, 92(18), 187002.
  12. Drozdov, A. P., Eremets, M. I., Troyan, I. A., Ksenofontov, V., & Shylin, S. I. (2015). Conventional superconductivity at 203 kelvin at high pressures in the sulfur hydride system. *Nature*, 525(7567), 73-76.
  13. Somayazulu, M., Ahart, M., Mishra, A. K., Geballe, Z. M., Baldini, M., Meng, Y., ... & Hemley, R. J. (2019). Evidence for superconductivity above 260 K in lanthanum superhydride at megabar pressures. *Physical review letters*, 122(2), 027001.
  14. Snider, E. et al. Room-temperature superconductivity in a carbonaceous sulfur hydride. *Nature* 586, 373–377 (2020).
  15. [Hypothetical Reference]: A review on “chemical precompression” as a strategy to stabilize high-frequency hydrogen lattices without external pressure.
  16. Scott, T., Walsh, A., Anderson, B., O'Connor, A., & Tasse, G. (2021). High-tech infrastructure and economic growth: The Materials Genome Initiative. *Science and Public Policy*, 48(5), 649-661.
  17. Curtarolo, S. et al. AFLOW: An automatic framework for high-throughput materials discovery. *Comput. Mater. Sci.* 58, 218–226 (2012).
  18. [Hypothetical Reference]: A high-throughput computational screening of over 20,000 metals for electron-phonon coupling, analyzing the trade-off between  $\lambda$  and  $\omega_{\text{log}}$ .
  19. [Hypothetical Reference]: A machine-learning model predicting superconducting properties for over 100 million compounds, identifying unstable but high- $T_c$  candidates.
  20. [Hypothetical Reference]: Identification of  $\text{Li}_2\text{AgH}_6$  and  $\text{Li}_2\text{AuH}_6$  as materials approaching the practical ambient-pressure limit for conventional superconductivity.
  21. Larkin, A. I., & Ovchinnikov, Y. N. (1965). Nonuniform state of superconductors. *Soviet Physics-JETP*, 20(3), 762-762.
  22. Larkin, A. I. & Ovchinnikov, Y. N. Nonuniform state of superconductors. *Zh. Eksp. Teor. Fiz.* 47, 1136–1146 (1964).
  23. Agterberg, D. F., Davis, J. S., Edkins, S. D., Fradkin, E., Van Harlingen, D. J., Kivelson, S. A., ... & Wang, Y. (2020). The physics of pair-density waves: cuprate superconductors and beyond. *Annual Review of Condensed Matter Physics*, 11(1), 231-270.
  24. Wang, Y. et al. Discovery of a Cooper-pair density wave state in a transition-metal dichalcogenide. *Science* 372, 1447–1452 (2021). [Key experimental discovery of PDW].
  25. [Hypothetical Reference]: A study on PDW states in iron-based superconductors, highlighting their role in stabilizing superconductivity near competing orders.
  26. Ohtomo, A., & Hwang, H. Y. (2004). A high-mobility electron gas at the  $\text{LaAlO}_3/\text{SrTiO}_3$  heterointerface. *Nature*, 427(6973), 423-426.
  27. Reyren, N., Thiel, S., Cavaglia, A. D., Kourkoutis, L. F., Hammerl, G., Richter, C., ... & Mannhart, J. (2007). Superconducting interfaces between insulating oxides. *Science*, 317(5842), 1196-1199.
  28. Gozar, A., Logvenov, G., Kourkoutis, L. F., Bollinger, A. T., Giannuzzi, L. A., Muller, D. A., & Bozovic, I. (2008). High-temperature interface superconductivity between metallic and insulating copper oxides. *Nature*, 455(7214), 782-785.
  29. Uchihashi, T. Two-dimensional superconductivity at the surfaces of  $\text{KTaO}_3$  gated with ionic liquid. *Phys. Rev. B* 103, L100503 (2021).
  30. Saito, Y., Nojima, T. & Iwasa, Y. Highly crystalline 2D superconductors. *Nat. Rev. Mater.* 2, 16094 (2017).
  31. Hoppe, R. Die Kristallstruktur des Silber(I)-fluorids,  $\text{AgF}$ . *Naturwissenschaften* 57, 534 (1970).
  32. Sobczyk, M. & Lis, T. Crystal structure of silver(II) fluoride. *J. Fluor. Chem.* 128, 1257–1263 (2007).
  33. [Hypothetical Reference]: A study on the electronic structure and Jahn-Teller effect in  $\text{AgF}_4$  square-planar units.
  34. [Hypothetical Reference]: Research on  $\text{LaF}_3$  as a wide-bandgap insulator and ionic conductor for epitaxial templates.
  35. Eckstein, J. N., & Bozovic, I. (1995). High-temperature superconducting multilayers and heterostructures grown by atomic layer-by-layer molecular beam epitaxy. *Annual review of materials science*, 25(1), 679-709.
  36. Farrow, R. F. (1995). *Molecular beam epitaxy: applications to key materials*. Elsevier.
  37. Arthur, J. R. (2002). *Molecular beam epitaxy*. *Surface science*, 500(1-3), 189-217.
  38. [Hypothetical Reference]: A protocol for the MBE growth of fluoride films, addressing challenges with fluorine

volatility.

39. [Hypothetical Reference]: Use of RHEED for in-situ monitoring of epitaxial fluoride superlattice growth.
40. van der Pauw, L. J. A method of measuring specific resistivity and Hall effect of discs of arbitrary shape. Philips Res. Rep. 13, 1–9 (1958).
41. [Standard reference on SQUID magnetometry].
42. Tinkham, M. Introduction to Superconductivity. 2nd Ed., Dover Publications (1996).
43. [Hypothetical Reference]: A paper discussing resistive transitions and partial Meissner effects in granular superconductors or systems with inhomogeneous order parameters.
44. [Hypothetical Reference]: An analysis showing that compounds with higher predicted  $T_c$  values are increasingly thermodynamically unstable, making synthesis challenging.
45. Sun, W., Dacek, S. T., Ong, S. P., Hautier, G., Jain, A., Richards, W. D., ... & Ceder, G. (2016). The thermodynamic scale of inorganic crystalline metastability. *Science advances*, 2(11), e1600225.
46. [Hypothetical Reference]: A review on the synthesis of metastable materials using techniques like MBE and ALD.
47. Onnes, H. K. (1911). The superconductivity of mercury. *Comm. Phys. Lab. Univ. Leiden*, 122, 124.
48. Nagamatsu, J., Nakagawa, N., Muranaka, T., Zenitani, Y., & Akimitsu, J. (2001). Superconductivity at 39 K in magnesium diboride. *nature*, 410(6824), 63-64.
49. [Hypothetical Reference]: A critical review of "Unidentified Superconducting Objects" (USOs) and the importance of reproducibility, referencing cases like LK- 99 and high-pressure hydrides.
50. [Hypothetical Reference]: A perspective article on the fundamental question of the upper limit for the critical temperature ( $T_c$ ) of superconductors