**Hyper-gap transparent conductor**

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An elusive conductor with perfect optical transparency holds revolutionary potential for fields such as optoelectronics and nanophotonics. This hypothetical metal possesses an unprecedented spectral gap[1,2], dubbed the “hyper-gap” in its absorption spectrum, separating the intra-band and inter-band absorptions, in which the optical losses could completely vanish — a property currently achievable only within the bandgap of insulators. However, realizing such a hyper-gap metal demands an exotic electronic structure, where the conducting bands have a bandwidth narrower than their energy separations from the remaining electronic states. Despite decades of searching[3], no evidence has yet surfaced on where this material might be found or if it is even possible. Here, we present the first observation of this long-sought-after hyper-gap in a family of organic metals, the Fabre charge-transfer salts[4], through first-principal predictions coupled with both electrical and optical measurements. A remarkable transparent window, spanning from visible red to near-infrared wavelengths, is identified in bulk single crystals that remain transmissive over thirty microns thick. The corresponding absorption coefficient is the lowest recorded among all known stoichiometric metals, rivaling that of commercial thin films of transparent conductive oxides. This discovery[5]  introduces a new path, beyond traditional doping strategies in insulators, to combine electronic conduction and optical transparency in intrinsic solids.

[1] Medvedeva, J. E. & Freeman, A. J. Combining high conductivity with complete optical transparency: a band structure approach. *Europhys. Lett.* 69, 583–587 (2005).

[2] Khurgin, J. B. & Sun, G. In search of the elusive lossless metal. *Appl. Phys. Lett.* 96, 181102 (2010).

[3] Hu, X. et al. High-throughput search for lossless metals. *Phys. Rev. Mater.* 6, 065203 (2022).

[4] Parkin, S. et al. Superconductivity in the organic charge transfer salts: (TMTSF)2X and (TMTTF)2X. *Mol. Cryst. Liq. Cryst.* 79, 605–615 (1982).

[5] Z. Wu, C. Li, X. Hu, K. Chen, X. Guo, Y. Li, and L. Lu, Hyper-gap transparent conductor, *Nat. Mater.* (2025). DOI: 10.1038/s41563-025-02248-0