A new theory to explain the transparency of metallic oxides

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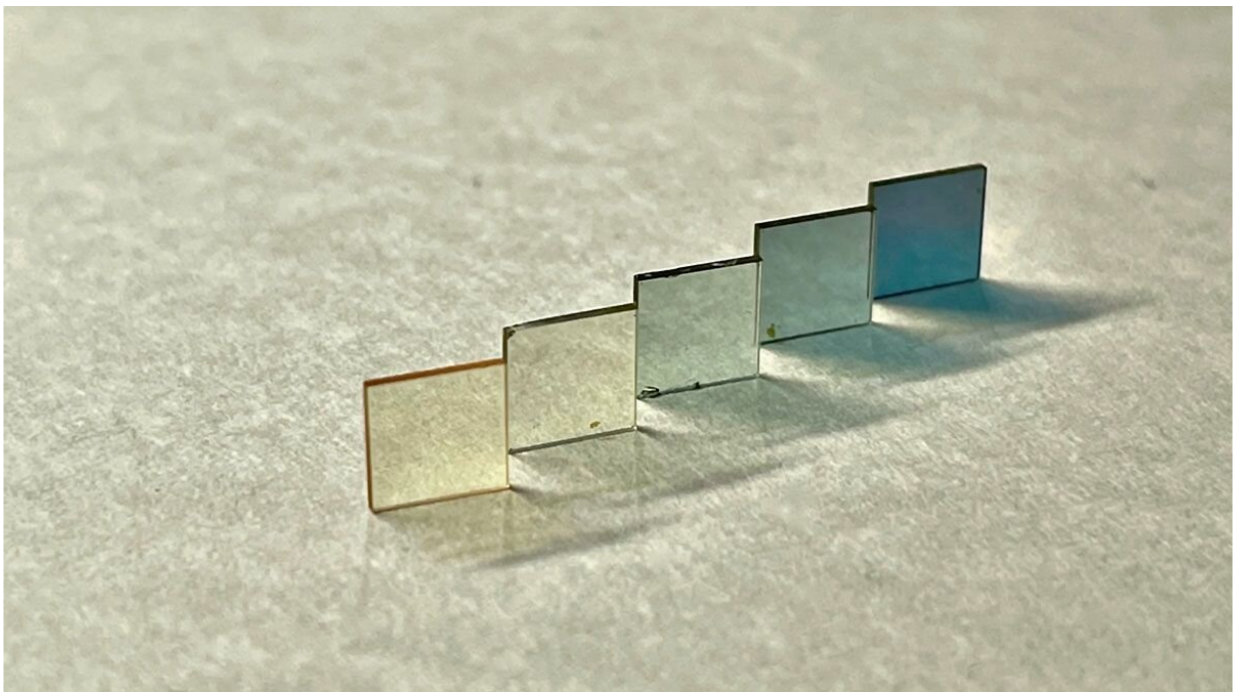


A collection of strontium and vanadium oxide (SrVO3) metallic films of increasing thickness. Credit: ICMAB-CSIC

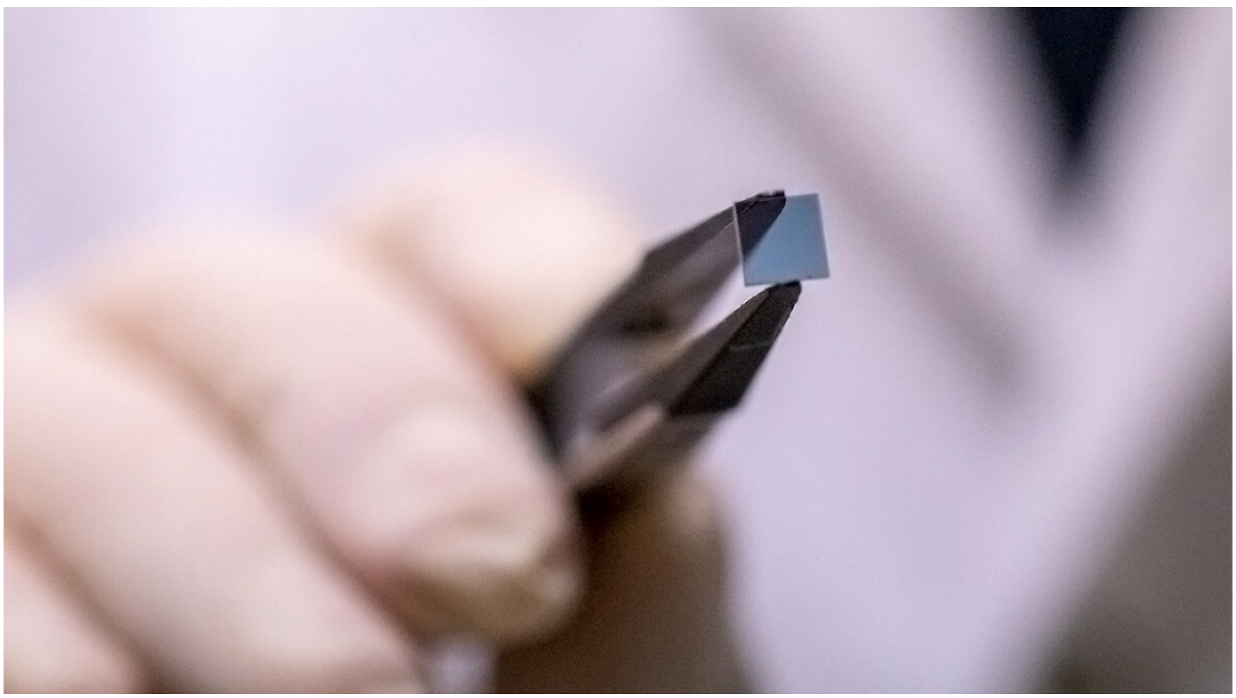
The electrons of some metal oxides, due to their large effective mass when coupled with the ionic lattice of the material, cannot follow the electric field of light and allow it to pass through the material. Transparent and conductive materials are used in smartphone touch screens and solar panels for photovoltaic energy.

Researchers from the Institute of Materials Science of Barcelona (ICMAB-CSIC), propose a new theory to explain the transparency of metal oxides, which are used in the touch screens of smartphones and tablets as well as on the solar cells used in photovoltaic energy. Scientists point out that the effective mass of electrons in these types of materials is large due to the formation of polarons or couplings between the electrons in motion and the ionic lattice of the material, which is distorted around it. These electrons cannot rapidly oscillate following the electric field of light and let it pass rather than reflect it. Until now, the accepted theory to explain this transparency pointed to the interactions between the electrons themselves. The study has been published in the journal *Advanced Science*.

Materials, in general, are transparent to visible light when light photons cannot be absorbed by the material and pass through it without being interrupted by interactions with electrons. The presence of free charges (electrons) is a fundamental characteristic in metals, which are conductors by nature. In these materials, the electrons, under the influence of the electric field of light, are forced to oscillate, and they radiate light at the same frequency as the receive light. This means that metals tend to shine, because they reflect the light that reaches them. In addition, this makes them opaque, since light does not pass through them. In some materials, electrons are heavier, and cannot follow the oscillations caused by the electric field of light as quickly, and cannot reflect it, but let it pass through the material without interacting; the material is then transparent.

Looking for alternatives

Touch screens in smartphones and tablets are made of a transparent and conductive material. Most of them are made of indium tin oxide (ITO), a material that is a semiconductor. This material is also used in solar panels, in LEDs, in LED or OLED liquid crystal displays, and even in the coatings of aircraft windshields. But indium is a very rare metal. In fact, with the high production of touch screens and the expansion of photovoltaic energy, it is estimated that it will be finished before 2050. Hence the importance of finding substitutes. Researchers at ICMAB-CSIC have studied thin films of the metal oxide strontium and vanadium oxide. What they have found is that thin layers of this metallic material, surprisingly, are transparent, something that would have to be related to a large effective mass of its free electrons.



Handling a strontium and vanadium oxide (SrVO3) transparent film only few nanometers thick. Credit: ICMAB-CSIC

"We think that the increase in the effective mass of the electrons is due to their coupling with the crystal lattice. The electrons of strontium and vanadium oxide and, in general, of metal oxides, move in a matrix of ions (positive and negative). This lattice deforms with the moving electron and this distortion moves with it. It would be like an electron dressed in a distortion of the lattice moving through the material. This coupling between the electron and the lattice is called a polaron and it is heavier than the free electron, so the effective mass of the electron is greater, which would explain the transparency of the material to visible light since it cannot follow the oscillations of the electric light field and lets it pass through," explains Josep Fontcuberta, CSIC researcher at ICMAB-CSIC and leader of this study.

This new model breaks with the paradigm established so far in the field of condensed matter physics; Coulomb interactions between electrons were accepted to govern the properties of metal oxides. Instead, this new theory proposes that the interaction between electrons and the ion lattice plays a crucial role.

The study contains a comprehensive and unprecedented analysis of some of the electrical and optical properties that are described by the polaron scenario. "In previous studies it had been seen that there could be a relationship, but it had never been analyzed in depth. Furthermore, apart from checking the theory in strontium and vanadium oxide, it has been analyzed in other metallic oxides and in some doped insulators, and their predictions have been found to be true," explains Fontcuberta.

"This study, among other things, is the result of a very exhaustive characterization of the electrical and optical properties of dozens of thin layers of the material in question. It is also the result of a very careful analysis of the data, which has revealed some discrepancies with scenarios and theories established long ago. The patient and meticulous work of Mathieu Mirjolet, ICMAB predoctoral researcher, has made this possible. I do not know if it has been the most relevant discovery of my career, since I do not know what is still to come, but I can assure you that it is one that best ways to illustrate my genuine pleasure in looking at science and life from another point of view," adds Fontcuberta.

These results come from a collaboration between ICMAB researchers Josep Fontcuberta and Mathieu Mirjolet, from the MULFOX group, with researchers from the University of Santiago de Compostela (Spain), the University of Freiburg (Germany) and the University of Frankfurt (Germany).

More information: Mathieu Mirjolet et al, Electron–Phonon Coupling and Electron–Phonon Scattering in $SrVO_3$, *Advanced Science* (2021). DOI: 10.1002/advs.202004207

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