Correlated Metals as electrodes in UV-C LEDs

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Abstract. This paper illustrates an overview of the high potential of correlated metals as transparent electrodes in UV-C LEDs. These materials are strontium-based oxides and exhibit noticeable properties of electrical conductivity and transparence below 300 nm. Their exploitation depends on growth capability on non-lattice matched substrates.

Keywords: Correlated Metals, UV-C LEDs, Transparent Conductive Oxides (TCOs), AlGaN-based LEDs.

1 Introduction

In the market of UV-C LEDs, in particular, the development of transparent conductive electrodes is fundamental. Traditional electrode materials often struggle to strike the delicate balance between these conflicting requirements. It is worth noting that several possible solutions developed to fabricate UV-C LED electrodes currently appear as non-practicable or difficult to implement. The absorption of ITO or other conventional transparent conductive oxides (TCOs) is as high as 60-70% in the UV-C wavelength range. Other possible solutions such as AlGaN-based tunnel junctions are difficult to achieve due to the high rate of Al demanded and the consequent problems of growth. Fabricating tunnel junctions as electrodes in AlGaN-based LEDs presents significant challenges primarily due to the unique material properties and operational requirements of these devices. The main challenges are: material mismatch, band alignment, process complexity, reliability and stability, device integration. Also, tunnel junctions based on simple GaN could be a feasible option but like in the ITO films, the low transmission rate in the UV-C region can dramatically reduce the external efficiency of the LEDs.

Correlated metals, characterized by their complex electronic structures and strong electron-electron interactions, present an intriguing avenue for engineers and scientists seeking to push the boundaries of traditional semiconductor technology. Unlike conventional conductors, where electrical conductivity is primarily governed by the behavior of free electrons, correlated metals exhibit emergent phenomena arising from the intricate interplay of charge, spin, and orbital degrees of freedom.

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One of the most compelling attributes of correlated metals lies in their ability to transmit UV light while simultaneously facilitating the flow of electrical current, a feat that has proven elusive for many materials.

2 Challenges to use correlated metals as electrodes in AlGaN-based LEDs

The most promising correlated metals that could be used as electrodes in UV-C LEDs have a perovskite cubic structure; they are strontium compounds such as $SrVO_3$, $SrMoO_3$, $SrNbO_3$. High ultraviolet–visible transmittances as high as 80% are achieved thanks to the fact that *p*-4*d* transition (or *p*-3*d* for $SrVO_3$) occurring at higher photon energy than in other conventional conductive oxides. Extremely low resistivity as low as 100 μΩ cm at room temperature have been obtained due to the high number of electrons in the outermost *d* orbitals. Moreover, correlated metals exhibit a huge robustness to oxygen vacancies different from that of conventional TCOs; this is attributed to the lack of formation of defect states near the Fermi level [1].

The deposition of such materials can occur without using the same epitaxial technique to grow the LED structure. This means that correlated metal films can be deposited by using simpler and economical methods such as sputtering, and pulsed lased deposition (PLD). However, in order to fully exploit the unique properties of transparence and conductivity it is necessary that they are epitaxially grown on appropriate substrates. In other words, differently from conventional TCOs, the growth temperatures must be definitely higher and a high lattice-matching between film and substrate is required. These two issues conflict with the structure of AlGaN-based LEDs since too high temperatures could play a negative role in the activation of the *p*-type, and there is no possibility of lattice-matching between the cubic perovskite and the wurtzite nitride structures.

These matters probably are the main impediment of a more intense development of such materials as electrodes of UV-C LEDs. Another drawback, directly linked with the perovskite structure is the high cost of the substrates that match with the lattice of the correlated metal films. Pricey wafers as $GdScO_3$ (110), $(La_{0.3}Sr_{0.7})(Al_{0.65}Ta_{0.35})O_3$ (LSAT) (001), $SrTiO_3$ (001), $KTaO_3$ (001), $LaAlO_3$ (LAO) are necessary to assure an epitaxial growth of the layers. Successful UV-C LEDs capable of commercial exploitation of the correlated metals must first solve all of these problems. The use of an appropriate buffer layer on the wurtzite nitride LED structure seems to be the more practicable solution. A buffer layer of $SrTiO_3$ deposited at relatively low temperature on the top of the LED structure could foster the growth of a subsequent thicker correlated metal layer such as $SrMoO_3$ or $SrMoO_3$, given the low mismatch of just 1.69% [2].

A summarizing chart of different correlated metals, where the transmissivity at 270 nm is put in relationship with the resistivity of a 10-nm film, is displayed in Fig. 1.

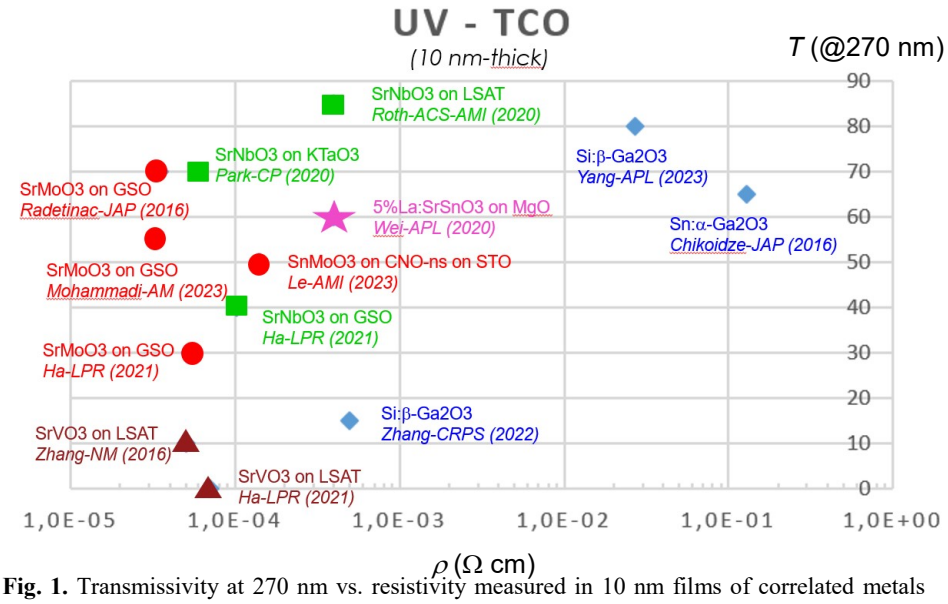

Fig. 1. Transmissivity at 270 nm vs. resistivity measured in 10 nm films of correlated metals reported in scientific literature.

The chart shows another candidate as TCO in the UV-C region: the doped Ga_2O_3. However, its electrical characteristics appear to be poor compared to those of correlated metals.

In conclusion, in the absence of further improvements in AlGaN-based tunnel junctions, future trends for light extraction from UV-C LEDs could be the adoption of correlated metals electrode, instead of doped oxides given the high absorption of the latter when heavily doped.

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