Semiconductor heterostructures based on abundant elements for photovoltaics: from material to device

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The development of metal-oxide materials based on Earth-abundant elements such as Zn, Mg, Al, and Cu is crucial for advancing next-generation optoelectronic devices, particularly thin-film solar cells. This work focuses on the synthesis and optimization of ternary and quaternary alloys using cost-effective and environmentally sustainable techniques, including Ultrasonic Spray Pyrolysis (USP) and Spin Coating, with water-based precursor solutions and glass substrates. The primary objective is to optimize and adjust the optical, structural, morphological, and electrical properties of these metal-oxide alloys for their application as transparent conducting layers, window layers, buffer layers, and absorbers in "all-oxide" solar cell heterostructures. This study investigates Zinc Oxide (ZnO) and Zinc Magnesium Oxide (ZnMgO) thin films prepared by ultrasonic spray pyrolysis, which exhibit high transparency (>90%), a polycrystalline wurtzite structure with strong <002> preferred orientation, and tunable electrical resistivity ranging from 10^{-2} to 10 $\Omega \cdot$ cm. ZnMgO thin films, with magnesium compositions varying from 0 % to 4 %, demonstrate adjustable bandgap energies between 3.28 eV and 3.34 eV, making them suitable for buffer and window layers. Additionally, Copper(I) Oxide (Cu_2O) thin films were synthesized using spin coating technique with precise phase control, exhibiting a direct bandgap of approximately 2 eV, p-type conductivity, carrier mobility of 17–30 $cm^2 V^{-1} s^{-1}$, and carrier concentrations of 8×10^{13} - 10^{15} cm^{-3}. These properties position Cu_2O as an efficient absorber material for all-oxide solar cells. The results underscore the potential of ZnMgO and Cu_2O thin films, prepared via eco-friendly and scalable methods, for sustainable optoelectronic applications such as solar cells, gas sensors, and beyond. By using these materials in complete heterostructures, this work advances the manufacture of all-oxide solar cells with low environmental impact, paving the way for the next generation of sustainable, energy-efficient optoelectronic devices.