Many countries are already reforming their fossil fuel economies to implement alternative and sustainable solutions, considering the imminent fossil fuel shortages and their harmful effects on nature. A hydrogen-based economy is one of the main candidates for a clean energy source, given hydrogen's positive impact on the environment and its great potential as an abundant energy carrier with high energy density and efficiency. Photocatalytic water splitting is one of the simplest and most efficient methods for hydrogen production.

The efficiency of converting solar energy to hydrogen largely depends on the properties of photoelectrodes, particularly the photoanode, where the oxygen evolution reaction (OER) occurs. The more energy the photoanode absorbs, the more intense the chemical reactions at its surface. Various semiconductor materials, such as ZnO, TiO_2, WO_3, CdS, and ZnS, have shown high potential as photoanode materials. TiO_2 and ZnO are widely used due to their chemical stability, nontoxicity, low cost, and high photosensitivity in the UV region. However, their main drawback is the inability to utilize visible light because of their high bandgap values (over 3 eV). This limitation affects photocatalytic efficiency since visible light represents 50% of the solar radiation spectrum. Notably, ZnO-based and TiO_2-based heterojunctions have shown improved photoactivity compared to ZnO and TiO_2 alone.

Several approaches have been explored to fabricate highly efficient photoelectrodes, including interface engineering and morphology design. One essential approach to optimize the light absorption of photocatalysts is doping. Nitrogen doping suppresses the recombination rate of photogenerated electrons and holes, enhancing photocatalytic activity by increasing visible light absorption without reducing UV light absorption, thus improving the overall efficiency of TiO_2/ZnO heterojunctions. Another method to boost photoanodes' photoelectrochemical (PEC) performance is the fabrication of heterostructures with noble metals. Transition metals such as Ag, Pt, Pd, and Au improve photocatalytic activity due to their localized surface plasmon resonance (LSPR) effect. The LSPR effect enhances light absorption efficiency by coupling the energy of incident light to plasmonic nanostructures under resonant excitation conditions. Furthermore, the strong resonance absorption peak is highly tunable across the visible and near-infrared spectra. Titanium nitride (TiN), a plasmonic material, can be a cost-effective and sustainable substitute for these expensive metals due to its high metallic conductivity, electron mobility, low resistivity, excellent mechanical properties, and similar LSPR effect.

The primary aim of this project is to develop and explore multilayered nanocomposites based on metal oxide heterostructures modified by defects (ZnO/TiO_2, N-doped ZnO/TiO_2, ZnO/N-doped TiO_2) and metal oxide/metal nitride heterostructures (TiN/TiO_2, TiN/ZnO). These structures will be produced using the atomic layer deposition (ALD) technique, which is expected to enhance PEC water splitting significantly. To gain a fundamental understanding of these new nanocomposites, it is necessary to conduct detailed characterizations of their chemical, electro-optical, photoelectrochemical properties, and hydrogen production and determine their interrelations.