Green Hydrogen Economy with Nano-photonics: Technology Outlook for the Energy Transition

Anupma Thakur

CSIR-Central Scientific Instruments Organisation, Chandigarh-160030, India,

Academy of Scientific and Innovative Research, (AcSIR), Ghaziabad- 201002, India

Photosynthesis is one of the key tools to utilize solar energy by converting or storing it in the form of chemical energy for a library of day-to-day uses. The future potential and commercial viability of photosynthesis have stimulated worldwide researchers to design an efficient and stable artificial light-harvesting system to mimic the process using various heterostructured materials. Moreover, the emerging deficit in the demand and supply of fossil fuel reframed the critical need of its alternative energy source from renewable energy, where solar to hydrogen production is one of the main research interests in today's energy sector. Plentiful material combinations have been reported in-search of the ideal photoelectrodes (photoanode/photocathode), with limited success due to their poor efficiency and aqueous stability. This research is focused on the energy economy policies of countries to become the leaders of renewable energy to fulfil energy demands. We have successfully employed 'nanophotonics' developed efficient and stable photoanodes (TiO2 nanofibers, GaN carbon quantum dots, plasmonic nanomaterials) and photocathodes (2D Materials, transition-metal based nanostructures, and chalcopyrites) which act as 'artificial leaf' to harvest solar energy and convert it into chemical fuel i.e. hydrogen. We have achieved a maximum efficiency of 4.8% with the stability of >10 hrs of these developed photoelectrodes. Further, the trending practice of flexible electronics is a strategic-aiding aspect for the speedy-propagation of miniaturized & flexible devices. Motivated by this, we herein demonstrate polypyrrole polymer decorated laboratory filter paper (PFP) as photoanodes (PAs) which mimics the 'natural leaf' for artificial solar light harvesting and photoelectrochemical (PEC) water splitting. The straddling band position with water redox and the measured band gap of PFP-PAs is ~1.88 eV, which makes them effective for remarkable solar light-assisted water splitting reactions. The in-situ polymerized polypyrrole polymer coated onto filter paper (i.e. for the fabrication PFP-PAs), has spherical morphology and average particle size of the order ~15 nm as portrayed by HR-TEM. The results manifest excellent photoanodic PEC activity of these PFP-PAs, yielding a photocurrent density of ~9.5 mA/cm2 (at 1.23 V vs. RHE) under 1-sun irradiation. The incident photon-to-current efficiency (IPCE) and applied bias photon-to-current efficiency (ABPE) is measured to be 43.19% and ~1%, respectively. Moreover, the robustness of these flexible PFP-PAs is also visualized by testing their stability for more than ~160 minutes in alkaline conditions. The PFP-PAs are further decorated with Cu2ZnSnS4 chalcopyrite nano-worms which yields a photocurrent density of 18 mA/cm2 at 1.23 V vs RHE and 3% ABPE, in the three-electrode benchtop device for hydrogen production. The current study provides a proof-of-concept for the realization of cost-effective, flexible, and efficient nanoengineered paper-based artificial photocatalysts (like a natural leaf) for solar-driven water splitting with remarkable performance. The present study also opens up the avenue for the exploration of flexible photoelectrodes for PEC water splitting employing 'nano-photonics' which could redefine the use of papers for 'green hydrogen' production in fulfilling the future energy demand as an alternative clean fuel.

anupmathakur92@gmail.com