

Utilizing environmentally-friendly copper-based chalcogenide colloidal quantum dot films for more spectrally adapted efficient greenhouses for improved crop yield

Stefan C. Ghany, Richard A. Taylor

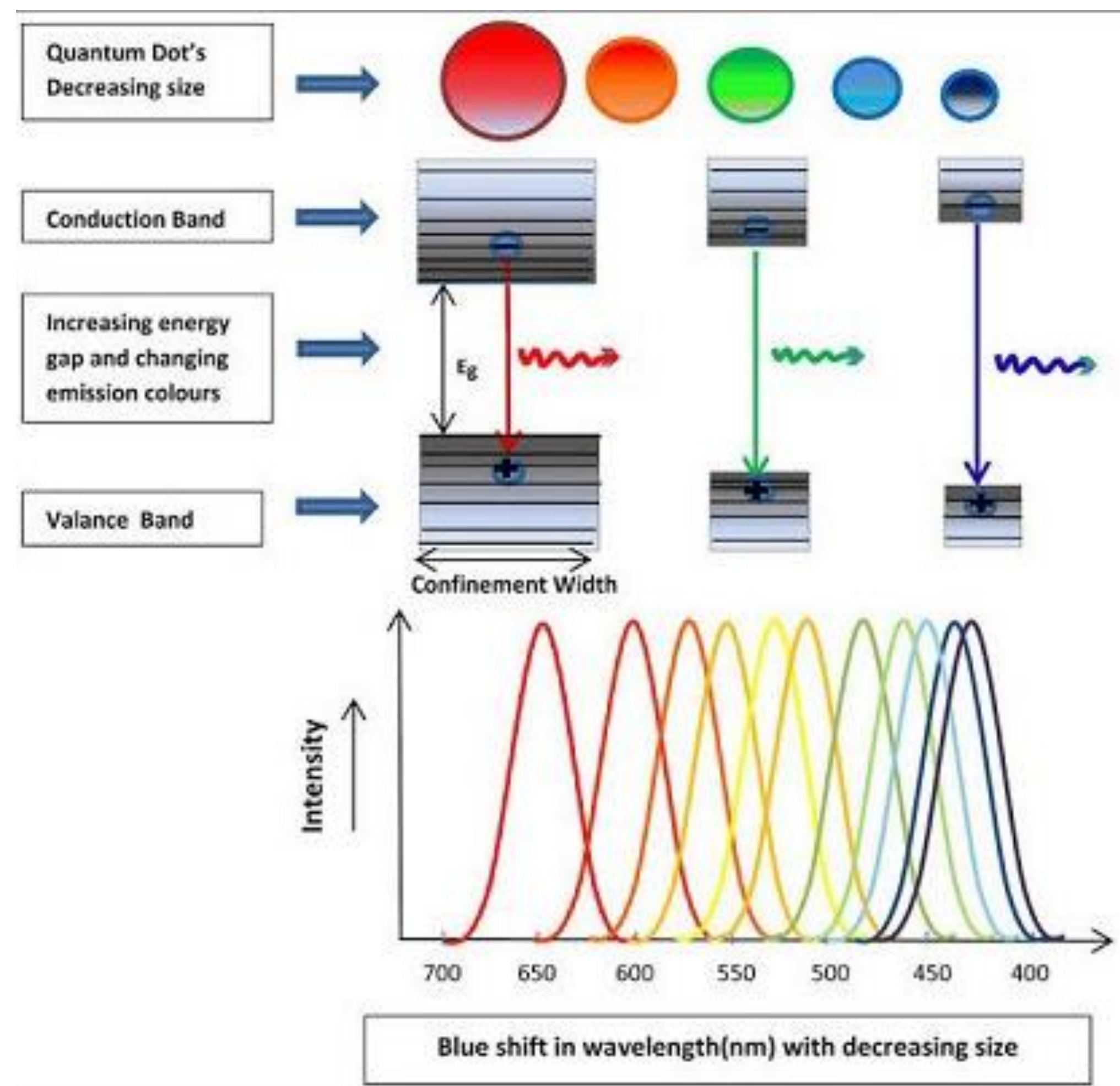
The University of the West Indies, St. Augustine Campus, Trinidad and Tobago, W.I.

ABSTRACT

This project seeks to fabricate, through a facile colloidal synthesis method, environmentally-friendly ternary copper-based chalcogenide quantum dots (QDs) which are able to spectrally adapt the incoming Electromagnetic Radiation (EMR) Spectrum by down-converting high energy radiation into lower-energy radiation. These QDs will be incorporated into polymers to develop a nanocomposite film for the application of greenhouse (GH) coverings in hot-climate countries. The GH will seek to reduce direct light transmittance, increase light diffusivity, and reduce overheating, thereby creating more optimally suited conditions for crop production. Surface mounted solar cells will be incorporated into these films to aid in electricity generation schemes and putting a GH on the path to self-sustenance.

INTRODUCTION

- QDs are semiconductor nanoparticles (2 – 10 nm) generally composed of two or more elements that have extremely high quantum efficiencies of light emission.¹
- Band Gap (E_g) of a material, which is a region bet. the highest valence band (VB) and lowest conduction band (CB) where no energy levels can exist, determines the minimum energy required to create an exciton.
- The E_g , inversely related to QD size, can be tuned, thus changing the energy gap between the band edges. Consequently the absorption and emission properties can be tuned by varying QD size which is very attractive for applications involving spectral adaptation e.g., solar cells, solar windows, etc.



Source: <http://www.medium.com/>

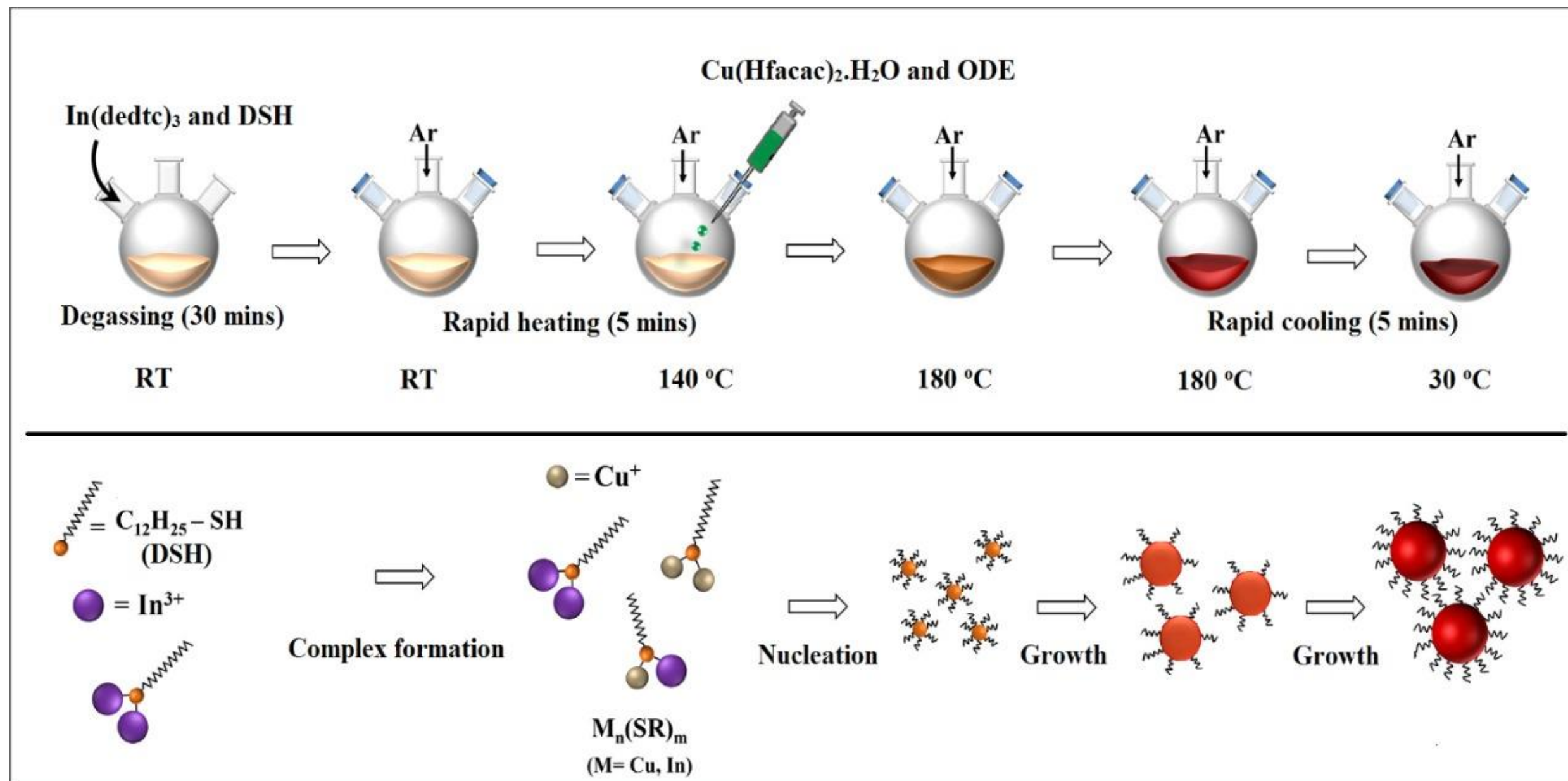
- Films required for spectral adaptation in GH.
 - Thin (mm thick) sheets of QD-embedded polymer used as covering material. QD concentration is varied to determine the flux of visible light transmitted (VLT), while absorbing a portion of the EMR spectrum (VLA), reflecting (VLR), and then subsequently emitting (isotropically).

- The QD in films down-convert high energy radiation into lower energy radiation, becoming more suitable for plants. This is mainly required for some crops in harsh hot-climate conditions.
- Photovoltaic (PV) cells are electrical devices that convert light directly into electricity. The QD PL contacts the surface of the PV, surface mounted beneath the QD film, thus supplying the PV's electrons to become excited and to flow into external circuits used to power appliances in GH.

METHODOLOGY

STAGE 1: Fabricate and Characterise QDs

A facile colloidal synthesis approach will be used to fabricate Cu-based chalcogenide QDs (CXS_2/ZnS ; X = Sn, W, Mo, In, Sb) to establish size, morphology, composition, shell thickness, and functionality to tune their optical properties.



- The structural and optical properties of the as-synthesised QDs will be evaluated for their ability to down-convert light energy, using techniques of Transmission Electron Microscopy (TEM), X-Ray Diffraction (XRD), Raman spectroscopy, Elemental Analysis (EDS), Optical spectroscopy, and Atomic Force Microscopy (AFM).

STAGE 2: Fabricate Nanocomposite Films

- Incorporate QDs in laboratory-scale nanocomposite films of various thicknesses and evaluate their optical and physical properties
- QDs dispersed in chloroform will be carefully cleaned and filtered before adding into proposed monomers of lauryl methacrylate, and ethylene glycol dimethacrylate.
- QDs, chloroform, UV-initiator, and monomers will be mixed and stirred overnight to form a homogenous slurry before being centrifuged to remove any bubbles for high quality films.
- The nanocomposite will be poured into moulds of varying thicknesses, and cured under UV light for a specified period before removal.
- The efficacy of the films will be determined using techniques of Powder X-Ray Diffraction (P-XRD), SEM-energy dispersive X-Ray spectroscopy (SEM-EDX), X-Ray photoelectron spectroscopy (XPS), Absorption and Photoluminescence spectroscopy.

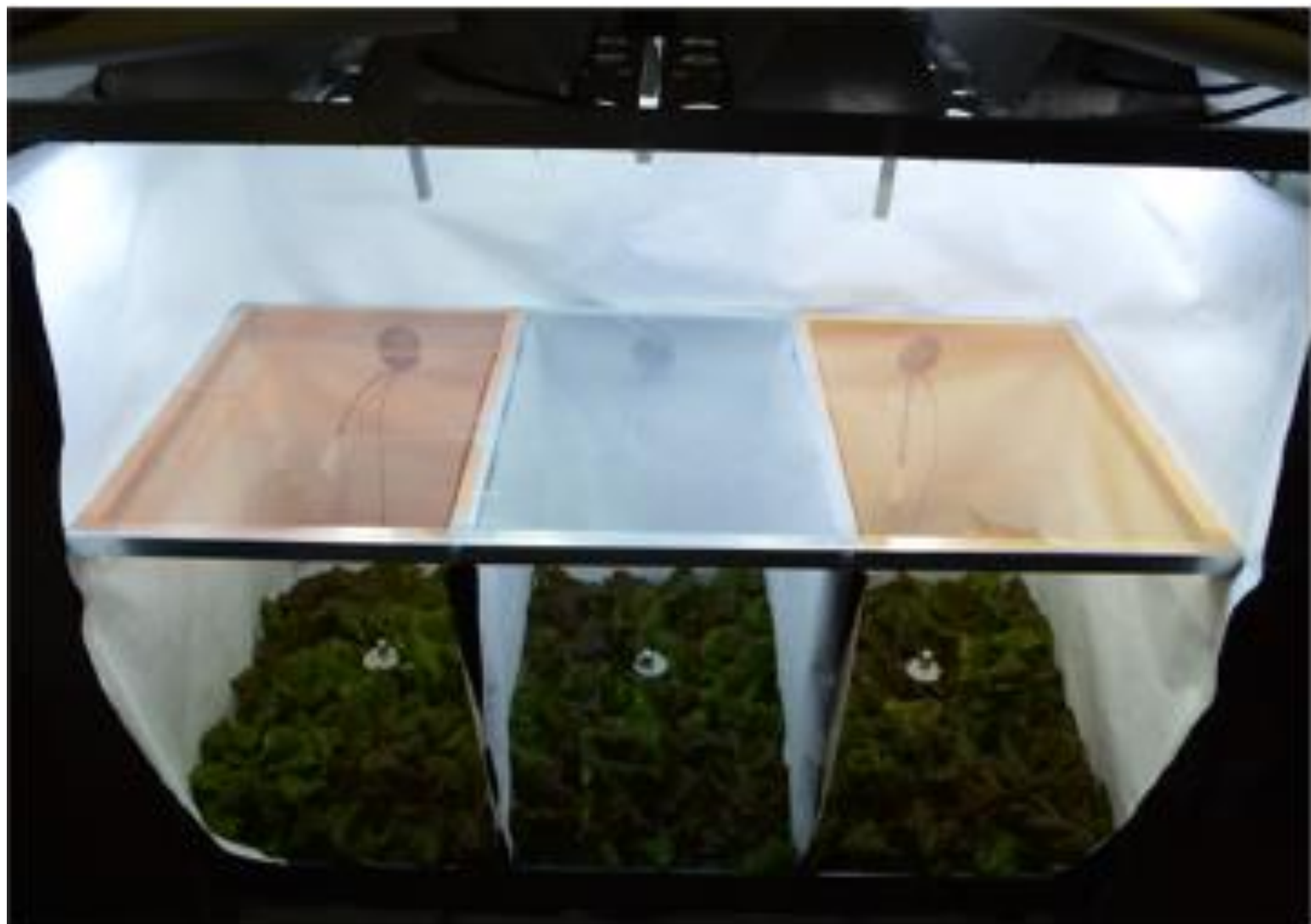
Factors which inhibit PL include the emission of photons within escape cones from textured surfaces on the film³, absorption by the type of matrix used to embed the QDs, haze from polymer impurities, re-absorption due to small Stokes-shift and spectral overlap, high chromophore aggregation and concentration, high UV-initiator concentrations, chemical attack by radicals during the polymerisation process⁴ etc.

STAGE 3: Nanocomposite Films with Solar Cells

- Fabricate and evaluate the most effective film with mounted solar cells and determine their electrical properties
- The size, arrangement, and number of the solar cells per unit area would be determined to negate severe light obscurity.
- The solar cells will be mounted using optically clear adhesive to prevent the film's spectrally adapted light from becoming waveguided away from the PV cell's surface.
- The efficacy of the solar cell and its arrangement on the film will be determined by its Internal/External Quantum Efficiencies, Power Conversion Efficiency, Optical Efficiency, PL Intensity Lifetime, PL Intensity and wavelength with increasing distance from solar cell, Photo- and Thermal-stability, and current density etc.

STAGE 4: Efficacy of Films

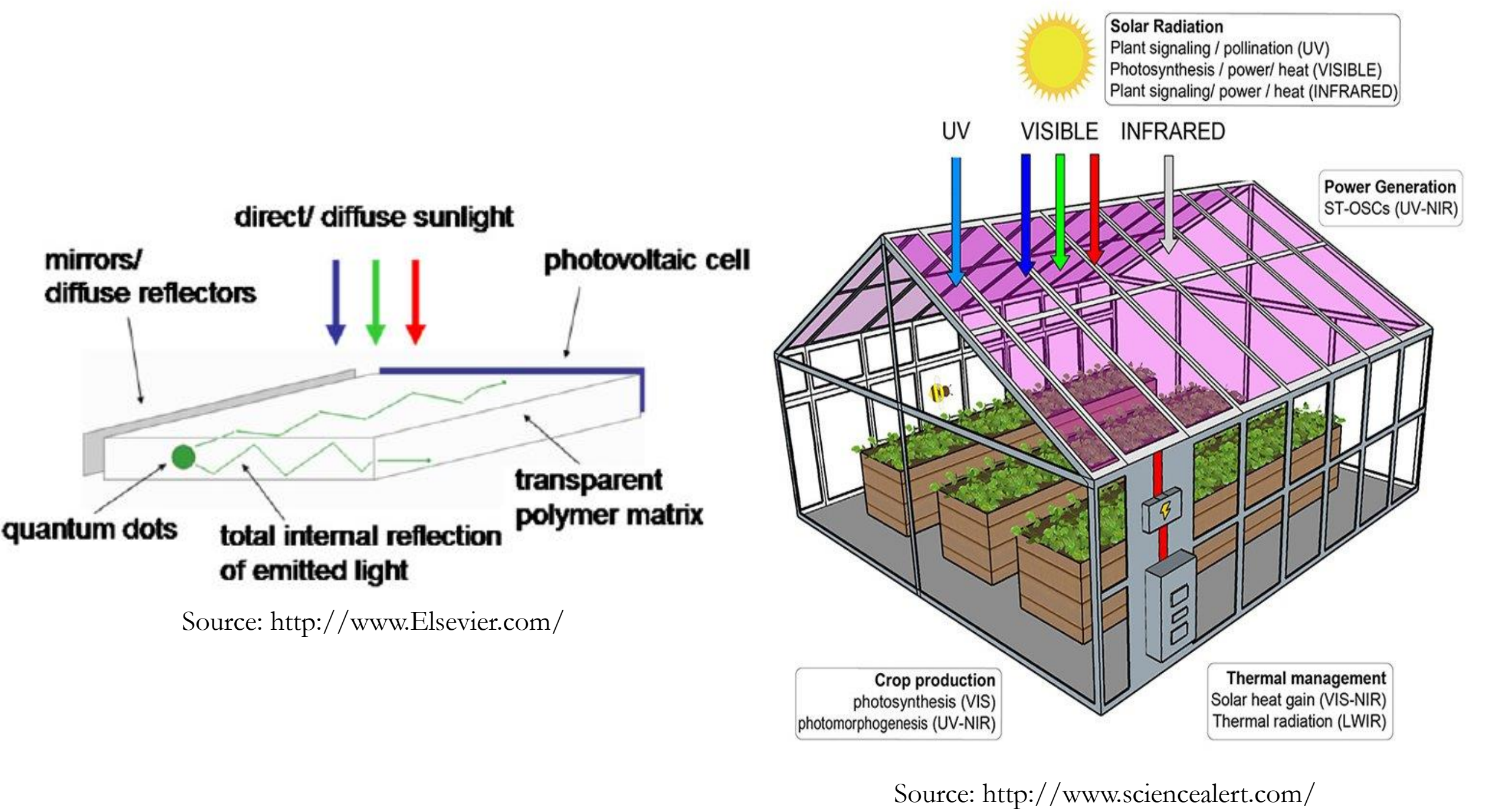
- The QD films will be subjected to controlled simulated environmental conditions⁵ which mimic that of hot-climate conditions and also determine the projected lifetime of the film.



Source: <http://nature.com/>

STAGE 5: Miniature Lab-scale GH

- Build a miniature Lab-scale GH and assess and evaluate the crops grown using the nanocomposite films.
- The crops will be evaluated to determine their fresh mass, dry mass, total leaf area, bioaccumulated nutrients, antioxidants, damage by UV radiation, pest resistance etc. under controlled parameters of carbon dioxide concentration, pH and nutrient concentrations, and obtaining readings for temperature, and electricity generation.



Source: <http://www.sciencealert.com/>

CONTRIBUTION TO UN SDGs



Source: <http://www.un.org/>

REFERENCES

- Raja, P. M. V. et al., 2021, *Using UV-Vis for the detection and characterization of silicon quantum dots*, <https://chem.libretexts.org/@go/page/55921>
- Wu, K. et al., 2021, *Nature*, <https://doi.org/10.1038/s41566-017-0070-7>
- Corrado, C. et al., 2013, *Elsevier*, <http://dx.doi.org/10.1016/j.solmat.2012.12.030>
- Bomm, J. et al., 2011, *Elsevier*, <https://doi.org/10.1016/j.solmat.2011.02.027>
- Parrish II, C. et al., 2021, *Nature*, <https://doi.org/10.1038/s42003-020-01646-1>

ACKNOWLEDGEMENTS

This work was made possible by:

- The University of the West Indies, School of Graduate Studies and Research
- The UWI's Chemistry Department of the Faculty of Science and Technology
- The Taylor Research Group
- The Royal Society of Chemistry
- Commonwealth Chemistry



Stefan C. Ghany

stefan.ghany@my.uwi.edu