



# CHAPTER 5





## Chapter

# Conclusions

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Photocatalytic dissociation of water utilizing solar radiation is a promising technology for hydrogen production which is considered a future source of energy carrier. CdS is an active photocatalyst for the reaction as it has a narrow band gap and also the conduction band edge is suitable placed with respect to the reduction potential of water. However, for high activity the recombination rate of electrons and holes should be contained. Making composite of CdS with metals or other semiconductors are established techniques to reduce charge recombination rate. Composite of CdS with GO/rGO are particularly promising because it may affect charge separation as well as owing to high electron conductivity of GO/rGO, transfer of electron to the solid-liquid interface

becomes fast and hence the activity. However, the activity is reported to be highly dependent on the microstructure in particular the nature of the interface between CdS and GO/rGO. Microstructure in turn depends on the details of preparation variables.

In present work GO/rGO supported catalysts were prepared by various techniques, characterization and studied for activity, deactivation & reactivation and effect of ultrasound. Based on results and discussion presented in previous chapter the following conclusions are drawn.

CdS supported on rGO photocatalyst prepared by impregnation of rGO into an ammoniacal solution of CdSO<sub>4</sub> followed by drying and high temperature reaction with H<sub>2</sub>S gas has superior activity to that of a photocatalyst of same composition prepared by commonly reported hydrothermal technique. CdS supported on GO and prepared by the gas-solid reaction (as used for rGO-CdS) was also found to have low activity.

The FTIR analysis showed existence of C–S bond in photocatalyst prepared by gas-solid reaction. Shifting in stretching vibration of Cd–S in catalyst–3 was observed due to chemical interaction between CdS and rGO/GO resulting in change in the bond strength of Cd–S. The PL spectroscopy revealed that a better charge separation took place in photocatalyst prepared by the gas-solid reaction. The diffuse reflectance spectroscopy showed a continuous absorption in the range of visible light due to a greater surface electric charge on the CdS due to the presence of GO/rGO. Narrowing of bandgap has been also observed due to the interfacial interaction of CdS with GO/rGO.

The XRD results did not indicate any defect structure and it also showed that activity may not be directly correlated with crystallite size. The TEM showed that particles in catalysts were not agglomerated. The XRD results which was supported by

electron diffraction results, showed existence of only hexagonal phase of CdS in catalyst prepared by the gas-solid reaction. However less active cubic phase of CdS was also observed in the catalyst prepared by hydrothermal technique.

The XPS analysis revealed doping of sulphur in GO/rGO in catalyst prepared by gas-solid reaction. The analysis of S 2p peaks of XPS further revealed that a chemical interaction has established between CdS and GO/rGO in all the catalysts but such an interaction was highest in catalyst prepared by adopting gas-solid reaction. Activity of GO/rGO supported CdS photocatalysts depended on the formation of a heterojunction by a chemical interaction between S of CdS and C of GO/rGO at the interface of the CdS and support GO/rGO.

Impregnation of rGO and followed by a gas–solid reaction causes a stronger chemical interaction at the interface. Such an interaction prohibited charge recombination by efficiently transferring the photogenerated electrons from the conduction band of CdS to the support of rGO. Chemical interaction is due to electronic transition between  $\pi^*$  orbital of C and  $n$  orbital of S in CdS.

The EIS study confirmed that rGO supported catalysts have high electron conductivity compared to GO supported catalyst. Thus, high conductivity of rGO compared to that of GO further facilitated transfer of electrons to the solid–liquid interface. Therefore, the restriction of charge recombination and a greater mobility of electron imparted superior activity to the rGO supported CdS catalyst prepared by impregnation followed by the gas-solid reaction.

Further study was performed to evaluate the intensifying effect of ultrasound on photocatalytic hydrogen production. Applying the force balance and drawing the

analogy with boiling phenomena, it is concluded that the mechanical energy of ultrasound helped in bubble detachment from the catalyst surface and thus enhanced the rate of mass transfer of hydrogen from the surface of the catalyst to bulk. It resulted in enhancement of the hydrogen transfer rate as well as larger fraction of catalyst-surface was made available for adsorption of reactants and surface reaction. Both the effects resulted in a higher hydrogen production rate when photocatalysis was addicted by ultrasound.

Kinetic studies revealed that the product hydrogen deactivated the catalyst. The deactivation was found to be completely reversible. The reaction was kinetically controlled by desorption of product hydrogen. As the concentration of hydrogen in the photocatalytic system increased, the rate of desorption and consequently the rate of overall process i.e., the rate of hydrogen production became slow.

The solar-hydrogen technologies are still in its infancy. At present the cost of production of solar-hydrogen is about 10 times more than hydrogen produced by steam reforming of natural gas. The major cost of solar-hydrogen will be due to area-related cost, i.e., the photoreactors. This cost can go down substantially with better design of active photocatalysts.

The detailed cost analysis was not carried out in the present study. The present study work has focused on development of active photocatalysts. Catalysts reported in the present work showed superior activity in laboratory. However, to bring down the cost and to become commercially viable, catalyst need to be developed which is responsive to a wider range of wave length. Also designing of reactor which provides for multiple reflections, shall be required.