

## List of figures

---

Figure no.	Figure caption	Page no.
Figure 1.1	World energy consumption	5
Figure 1.2	Energy consumption in India	6
Figure 1.3	Flow diagram of steam reforming of hydrocarbon	13
Figure 1.4	Flow diagram of partial oxidation process	14
Figure 1.5	Flow diagram of oxidative steam reforming	15
Figure 1.6	Schematic representation of electrolysis of water	17
Figure 1.7	Schematic representation of high temperature steam electrolysis	19
Figure 1.8	Schematic representation of a photovoltaic cell plus electrolyzer system	21
Figure 1.9	Schematic representation of a photoelectrochemical system	22
Figure 1.10	Flow diagram of the bio-photolysis process	23
Figure 1.11	Schematic representation of a photocatalysis process for H <sub>2</sub> production	24
Figure 2.1	(a) The semiconductor-electrolyte interface before (LHS) and after (RHS) equilibration (i.e. contact of the two phases) shown for an <i>n</i> -type semiconductor. (b) as in (a) but for a <i>p</i> -type semiconductor	31
Figure 2.2	Band bending for (a) an <i>n</i> -type semiconductor, and (b) a <i>p</i> -type semiconductor in equilibrium with an electrolyte	32
Figure 2.3	Fundamental principle of semiconductor-based photocatalysis(Example: Photocatalytic water splitting for hydrogen production)	33
Figure 2.4	Fundamental steps of photocatalytic water splitting for hydrogen production	34
Figure 2.5	Solar energy distribution	37
Figure 2.6	New valence band formation by doping of non-metal ions	39
Figure 2.7	Donor level (A) and acceptor level (B) formed by metal ion doping	40
Figure 2.8	Metal/semiconductor Schottky junction with energy level equilibration. (Left), processes of charge transfer in charge separation between host photocatalyst and cocatalyst (Pt) (Right). $E_F$ -Fermi energy, $E_v$ -valence band position, $E_c$ - conduction band position, $\Phi_m$ - work function of metal, $\Phi_s$ – semiconductor band gap, $\epsilon$ = Difference between Fermi level and conduction band position of semiconductor, $\Phi_b = \Phi_m - \Phi_s$ , $\Phi_{bi}$ = barrier potential created due to Schottky junction.	43

Figure 2.9	Schematic of the Schottky barrier	44
Figure 2.10	Schematic diagram showing the energy band structure and electron– hole pair separation in the $p$ – $n$ heterojunction.	45
Figure 2.11	Schematic diagram showing the energy band structure and electron– hole pair separation in the non- $p$ – $n$ heterojunction	46
Figure 2.12	Processes of charge transfer (charge separation) between host photocatalyst and another semiconductor in mixed semiconductor combination system.	47
Figure 2.13	Reduction potential of graphene	49
Figure 2.14	Typical energy band and structure of graphene	51
Figure 2.15	(a) Energy band and structure of graphene; Shifting from Dirac point - Energy band structure of b) $n$ -type and c) $p$ -type graphene by suitable heteroatom doping.	52
Figure 2.16	Schematic diagram of the synthesis of the graphite oxide, GO, rGO	53
Figure 2.17	Energy scheme for photocatalytic water splitting	66
Figure 2.18	Diagram of ultrasound range	74
Figure 2.19	Growth and collapse of cavitation bubbles in aqueous solution under ultrasonic irradiation	76
Figure 3.1	Schematic diagram of experimental set-up for photocatalytic reaction	93
Figure 3.2	Experimental set-up (a) reactor, (b) magnetic stirrer, (c) $N_2$ - gas cylinder, (d) light source, (e) gas collector	94
Figure 3.3	Summary of the experimental procedure for producing XPS depth profiles.	100
Figure 3.4	Basic components of Nyquist plot of electrochemical impedance spectroscopy	102
Figure 3.5	Schematic diagram of reaction set-up for photocatalysis with ultrasound	104
Figure 4.1	FTIR comparison of graphite (A), graphite oxide (B), reduced graphite oxide (C).	114
Figure 4.2	FTIR comparison of graphite (A), graphite oxide (B), reduced graphite oxide (C).	115
Figure 4.3	XRD pattern of sample graphite (A), GO (B), rGO (C).	118
Figure 4.4	XRD pattern of catalysts catalyst–1 (A), catalyst–2 (B), catalyst–3 (C) and catalyst–4 (D)	119
Figure 4.5	TEM images of catalyst–2 (I), catalyst–3 (II), and catalyst–4 (III).	125
Figure 4.6	Selected area diffraction pattern for catalyst–2 (A), catalyst–3 (B), and catalyst–4 (C).	126

Figure 4.7	Photoluminescence spectra of various catalysts.	127
Figure 4.8	Diffuse reflectance spectra of catalysts.	130
Figure 4.9	Bandgap of CdS in catalysts.	132
Figure 4.10	Schematic illustration for rGO-CdS photocatalysts (the magnified illustration is the transfer charge carriers between CdS and GO/rGO).	133
Figure 4.11	The C 1s XPS spectra of GO (A), rGO (B), catalyst-2 (C), catalyst-3 (D), catalyst-4 (E) including the multiple sub-peaks decomposed by Lorentzian Gaussian fitting.	135
Figure 4.12	The Cd 3d XPS spectra of catalyst-1 (A), catalyst-2 (B), catalyst-3 (C), catalyst-4 (D).	137
Figure 4.13	Depth profile for catalyst-2, Cd 3d after etching at various time intervals (a <sub>0</sub> - without etching, a <sub>10</sub> - etched for 10 s, a <sub>30</sub> - etched for 30 s).	139
Figure 4.14	Depth Profile for catalyst-3, Cd 3d after etching at various time intervals (a <sub>0</sub> - without etching, a <sub>10</sub> - etched for 10 s, a <sub>30</sub> - etched for 30 s).	140
Figure 4.15	Depth Profile for catalyst-4, Cd 3d after etching at various time intervals (a <sub>0</sub> - without etching, a <sub>10</sub> - etched for 10 s, a <sub>30</sub> - etched for 30 s).	141
Figure 4.16	$\Delta E$ vs. etching time for Cd 3d $\Delta E$ = Difference between binding energy of respective catalyst for Cd 3d <sub>5/2</sub> and binding energy of catalyst-1 for Cd 3d <sub>5/2</sub> after etching at various time interval.	142
Figure 4.17	The S 2p XPS spectra of various catalysts (A): catalyst-1, (B): catalyst-2, (C): catalyst-3, (D): catalyst-4.	143
Figure 4.18	Depth profile for catalyst-2 S 2p after etching at various time intervals (a <sub>0</sub> - without etching, a <sub>10</sub> - etched for 10 s, a <sub>30</sub> - etched for 30 s).	147
Figure 4.19	Depth profile for catalyst-3 S 2p after etching at various time intervals (a <sub>0</sub> - without etching, a <sub>10</sub> - etched for 10 s, a <sub>30</sub> - etched for 30 s).	148
Figure 4.20	Depth profile for catalyst-4 S 2p after etching at various time intervals (a <sub>0</sub> - without etching, a <sub>10</sub> - etched for 10 s, a <sub>30</sub> - etched for 30 s).	149
Figure 4.21	$\Delta E$ vs. etching time for S 2p $\Delta E$ = Difference between binding energy of respective catalyst for Cd 3d <sub>5/2</sub> and binding energy of catalyst-1 for Cd 3d <sub>5/2</sub> after etching at various time interval.	150
Figure 4.22	Temperature program oxidation peaks of samples A- rGO, B- catalyst-1.	151
Figure 4.23	Temperature program oxidation peaks of catalysts A- catalyst-2, B-catalyst-3, and C-catalyst-4.	152

Figure 4.24 Nyquist plots recorded for various catalysts in electrolyte having sulphide and sulphite at room temperature.	154
Figure 4.25 Hydrogen evolved vs time with ultrasound (Input power 35 W).	156
Figure 4.26 Hydrogen evolved (in 2 h) vs ultrasonication power applied in photocatalytic reaction with solar radiation.	158
Figure 4.27 Forces on single bubble on solid surface	160
Figure 4.28 Schematic representation of hydrogen bubbles on catalyst surface without ultrasound	161
Figure 4.29 Effect of surfactant - hydrogen evolved by photocatalysis A: without ultrasound B: with ultrasound.	163
Figure 4.30 Schematic representation of hydrogen bubbles on catalyst surface with ultrasound.	163
Figure 4.31 Hydrogen evolved vs time without ultrasound.	165
Figure 4.32 Hydrogen production rate without ultrasound.	165
Figure 4.33 Hydrogen production rate A: without ultrasound, B: with ultrasound (Input power 35 W).	167
Figure 4.34 Hydrogen evolved (without ultrasound) A: electrolyte was purged with N <sub>2</sub> for 1 h, B: electrolyte was purged with H <sub>2</sub> for 2 h.	167