List of Figures

Fig. 1.1  Schematic diagram of optical gas sensor
Fig. 1.2  Schematic diagram of surface acoustic wave gas sensor
Fig. 1.3  Schematic diagram of amperometric gas sensor
Fig. 1.4  Metal oxide gas sensor
Fig. 1.5  (a) Crystal structure of SnO$_2$, (b) Crystal structure of anatase, rutile and brookite TiO$_2$
Fig. 1.6  Photograph of medicinal mushroom G. lucidum
Fig. 1.7  Chemical structures of ganoderic acids
Fig. 1.8  Schematic illustration of the XRD, $\theta$ - $2\theta$ Scan
Fig. 1.9  Schematic diagram of an X-ray diffraction beam showing the incident and scattered X-rays, from a pair of atoms in different planes
Fig. 1.10  A photo image of FE-SEM JEOL 6300 FEG microscope
Fig. 1.11  Schematic diagram of a scanning electron microscopy
Fig. 1.12  Schematic diagram of emission of X-ray
Fig. 1.13  Electronic transitions process during light absorption
Fig. 1.14  Schematic diagram of UV-Vis spectroscopy and output nature
Fig. 1.15  Schematic diagram of transmission electron microscopy.
Fig. 1.16  Photograph of HRTEM-300kV at SAIF IIT Bombay
Fig. 1.17  Photoelectron emission in X-ray photoelectron spectroscopy
Fig. 1.18  Types of isotherms on the basis of porosity

Fig. 2.1  Growth mechanism of SnO$_2$
Fig. 2.2  Growth mechanism of TiO$_2$
Fig. 2.3  Photographs of as-prepared SnO$_2$ and TiO$_2$ films by using Doctor’s Blade method
Fig. 2.4  Photographs of as-prepared Ag, Au and Pd sensitized SnO$_2$ and TiO$_2$ films
Fig. 2.5  Photograph for home-built computer interfaced static gas sensing characterization system
Fig. 3.1  (a) XRD patterns of SnO$_2$ films: S1, S2, S3, S4 and S5, (b) XRD pattern of SnO$_2$ films showing right shift in the (110) and (101) Millar planes. (c) Deconvoluted XRD pattern of film S3, (110) and (101) planes
Fig. 3.2.  (a) Effect of uniform and non-uniform strains on diffraction peak position and width, (b) W-H Plot.
Fig. 3.3.  Variation of (a) crystallite size and texture coefficient (b) crystallite size and strain (c) dislocation density and strain with molar concentration and (d) diffraction angle with molar concentration
Fig. 3.4.  XRD pattern of Ag, Au and Pd sensitized S3 film
Fig. 3.5.  FESEM images of SnO$_2$ thin films of different molar concentration of SnCl$_4$ precursor (S1) 0.1M, (S2) 0.2 M, (S3) 0.3 M, (S4) 0.4 M, (S5) 0.5 M and (S3’’) high magnification image of S3.
Fig. 3.6.  FESEM image of; (a) Ag-SnO$_2$, (b)Au-SnO$_2$ and (d)Pd-SnO$_2$sensitized films.
Fig. 3.7  (a) TEM image of pure SnO$_2$, (b) HRTEM images of pure SnO$_2$ with SAED pattern (inset figure), (c) TEM image of Au-SnO$_2$ and (d) HRTEM image of Au-SnO$_2$.
Fig. 3.8  (A) EDAX spectra analysis of SnO$_2$ thin films at different molar concentrations of Sn-precursor; (S1) 0.1M, (S2) 0.2 M, (S3) 0.3 M, (S4) 0.4 M and (S5) 0.5 M. (B) EDAX spectra of sensitized films (a) Ag-SnO$_2$, (b) Au-SnO$_2$ and (d) Pd-SnO$_2$
Fig. 3.9. (a) UV-Visible spectra of SnO$_2$ thin films of different molar concentration of Sn-precursor (S1) 0.1M, (S2) 0.2 M, (S3) 0.3 M, (S4) 0.4 M and (S5) 0.5 M. (b) The Tauc’s plot of SnO$_2$ thin films of different molar concentration of Sn-precursor (S1) 0.1M, (S2) 0.2 M, (S3) 0.3 M, (S4) 0.4 M and (S5) 0.5 M.

Fig. 3.10 (a) UV-Visible spectra, and (b) the Tauc’s plots of Ag, Au and Pd sensitized SnO$_2$ films.

Fig. 3.11 (a) XPS spectra of SnO$_2$ and Au-SnO$_2$ films and high resolution XPS spectra of (b) O1S(c) Sn 3d and (d) Au 4f.

Fig. 3.12 Nitrogen adsorption/desorption isotherms of (a) pure SnO$_2$ and (c) Au-SnO$_2$, and BET pore size distribution of (b) pure SnO$_2$ and (d) Au-SnO$_2$.

Fig. 3.13 Selectivity study of S1-S5 films towards different gases.

Fig. 3.14 Plots of; (a) transient response with time towards 100 ppm ethanol at 300 °C, and (b) temperature dependent responses of S1-S5 films to 100 ppm ethanol.

Fig. 3.15 Plots of (a) response of S1-S5 films as a function of different ethanol concentration at 300 °C and (b) Response of film S3 as a function of time towards different C$_2$H$_5$OH concentration at 300 °C.

Fig. 3.16 Plots of: (a) response of pure SnO$_2$ (S3) film as a function of time upon 100 ppm exposure of C$_2$H$_5$OH at 300°C, (b) change in SnO2 film resistance upon 100 ppm exposure of C$_2$H$_5$OH at 300°C, and (e) response vs recovery at different concentrations of C$_2$H$_5$OH.

Fig. 3.17 Plots of (a) reproducibility and (b) stability study of SnO$_2$ film towards 100 ppm C$_2$H$_5$OH at 300°C.

Fig. 3.18 (a) Selectivity study and (b) temperature dependent response of Ag, Au and Pd-SnO$_2$.

Fig. 3.19 Plots of response of Ag, Au and Pd-SnO$_2$ films as a function of different C$_2$H$_5$OH concentrations (inset figures depict response of Ag, Au and Pd-SnO$_2$ films as a function of time towards different C$_2$H$_5$OH concentrations.)

Fig. 3.20 Plots of response as a function of time of (a) Ag-SnO$_2$, (b) Au-SnO$_2$ and (c) Pd-SnO$_2$ films to 100 ppm C$_2$H$_5$OH, plots of change in film resistance upon 100 ppm exposure of C$_2$H$_5$OH as a function of time of (d) Ag-SnO$_2$, (e) Au-SnO$_2$ and (f) Pd-SnO$_2$ films and plots of response vs. recovery time as a function of different concentration of C$_2$H$_5$OH of (g) Ag-SnO$_2$, (h) Au SnO$_2$ and (i) Pd-SnO$_2$.

Fig. 3.21 (a), (b) and (c) Repeatability study of Ag, Au and Pd-SnO$_2$ respectively, (d) Stability study of Ag, Au and Pd-SnO$_2$ film operating at 100 ppm concentration.

Fig. 3.22 (a) Proposed gas sensing mechanism of SnO$_2$ film (a) in air atmosphere and (b) in C$_2$H$_5$OH atmosphere.

Fig. 3.23 (a) Charge transport mechanism, barrier potential and space charges between two particles in presence of air and ethanol environment, (b) Dynamic response and change in resistance upon exposure of C$_2$H$_5$OH gas.

Fig. 3.24 Energy band diagrams of metal and n-type semiconductor contacts (a) before equilibrium, (b) after equilibrium (Evac - vacuum energy; Ec - energy of conduction band; Ev - energy of valence; $\phi_m$ - metal work function; $\phi_s$ - semiconductor work function; $\chi_s$ - electron affinity of the semiconductor) and (c) Electronic sensitization mechanism and (d) spillover mechanism.
Fig. 4.1. (a) XRD patterns of TiO$_2$ thin films obtained at different precursor TTIP molar concentrations; (T1) 0.1 M, (T2) 0.15 M, (T3) 0.2 M and (T4) 0.25 M, and (b) Deconvoluted XRD pattern of sample T1, (101) plane.

Fig. 4.2. Variation of (a) crystallite size and texture coefficient with molar concentration and (b) dislocation density, $\delta$ and strain, $\varepsilon$ with molar concentration of Ti precursor.

Fig. 4.3. XRD pattern of pure and Ag, Au and Pd sensitized TiO$_2$ film.

Fig. 4.4. FESEM images of TiO$_2$ films of different molar concentration of TTIP precursor (T1) 0.1 M, (T2) 0.15 M, (T3) 0.2 M and (T4) 0.25 M.

Fig. 4.5. FESEM images of (a) Ag-TiO$_2$, (b) Au-TiO$_2$ and (d) Pd-TiO$_2$.

Fig. 4.6. (a) TEM, and (b) HRTEM images of pure TiO$_2$ with SAED pattern (inset figure), and (c) TEM and (b) HRTEM images of Pd-TiO$_2$.

Fig. 4.7. (A) EDAX spectra of TiO$_2$ films of different molar concentration of Ti precursor (T1) 0.1 M, (T2) 0.15 M, (T3) 0.2 M, and (T4) 0.25 M. (B) EDAX spectra of sensitized films (a) Ag-TiO$_2$, (b) Au-TiO$_2$ and (d) Pd-TiO$_2$.

Fig. 4.8. (a) UV-visible spectra and (b) the Tauc’s plot of TiO$_2$ films obtained at different molar concentrations of Ti-precursor (T1) 0.1 M, (T2) 0.15 M, (T3) 0.2 M, and (T4) 0.25 M.

Fig. 4.9. (a) UV-Visible spectra and (b) the Tauc’s plot of Ag, Au and Pd sensitized TiO$_2$ films.

Fig. 4.10. (a) XPS survey spectra of TiO$_2$ and Pd sensitized SnO$_2$ films and High resolution XPS spectra of (b) O 1S (c) Ti 2p and (d) Pd 3d.

Fig. 4.11. Nitrogen adsorption/desorption isotherms of (a) pure TiO$_2$ and (c) Pd-TiO$_2$, and BET pore size distribution of (b) pure TiO$_2$ and (d) Pd-TiO$_2$.

Fig. 4.12. Selectivity study of T1-T5 films towards different gases.

Fig. 4.13. Plots of (a) transient response with time and (b) temperature dependant response of T1-T4 films towards 100 ppm Cl$_2$.

Fig. 4.14. Plots of (a) response of T1-T5 films as a function of different Cl$_2$ concentration at 250 °C and (b) Response of film T1 as a function of time towards different Cl$_2$ concentration at 250°C.

Fig. 4.15. Plots of (a) response, (b) change in TiO$_2$ film resistance upon 100 ppm exposure of Cl$_2$ gas at 250 °C and (c) response vs recovery of T1 at different concentration of Cl$_2$ gas.

Fig. 4.16. Plots of (a) reproducibility and (b) stability study of TiO$_2$ film towards 100 ppm Cl$_2$ at 250 °C.

Fig. 4.17. (a) Selectivity study and (b) temperature dependent response of Ag, Au and Pd-TiO$_2$.

Fig. 4.18. Plots of response of Ag, Au and Pd-TiO$_2$ films as a function of different Cl$_2$ gas concentrations (inset figures depict response of Ag, Au and Pd-TiO$_2$ films as a function of time towards different Cl$_2$ gas concentrations.)

Fig. 4.19. Plots of response as a function of time of: (a) Ag-TiO$_2$, (b) Au-TiO$_2$ and (c) Pd-TiO$_2$ film sensors to 100 ppm Cl$_2$ gas, (d-f) plots of change in film resistance upon 100 ppm exposure of Cl$_2$ gas as a function of time of Ag-TiO$_2$, Au-TiO$_2$ and Pd-TiO$_2$ films and (g-i) plots of response time vs recovery time as a function of different concentration of Cl$_2$ gas of Ag-TiO$_2$, Au-TiO$_2$ and Pd-TiO$_2$ films.

Fig. 4.20. Repeatability study of (a) Ag-TiO$_2$, (b) Au-TiO$_2$ and (c) Pd-TiO$_2$ respectively, (d) Stability study of Ag, Au and Pd-TiO$_2$ film operating at 100 ppm concentration of Cl$_2$. 
Fig. 4.21  (a) Proposed gas sensing mechanism of TiO$_2$ film (a) in air atmosphere and (b) in Cl$_2$ gas atmosphere

Fig. 4.22  (a) Charge transport mechanism, barrier potential and space charges between two particles in presence of air and Cl$_2$ gas environment, (b) Dynamic response and change in resistance upon exposure of Cl$_2$ gas.