List of figures

Chapter 1

Figure 1.1: Classification of nanoparticles based on dimensions

Figure 1.2: Schematic of different configurations of bimetallic nanoparticles

Figure 1.3: Chemical structures of Biopolymers

Figure 1.4: Chemical structure of DNA

Figure 1.5: Chemical structures of Amino polycarboxylic acids (APCAs)

Figure 1.6: Application of Nanoparticle in various fields

Figure 1.7: Representative diagram of Nanocatalysis (a bridge gap between homogenous and heterogenous catalysis) and magnetically separable nanocatalyst

Figure 1.8: Diagram for Suzuki coupling and magnetically separable catalyst

Figure 1.9: Electromagnetic and chemical SERS enhancement

Figure 1.10: p-Nitrophenol reduction in water

Chapter 2

Figure 2.1: (A) UV-Vis spectra of Ag@Ch, (B) Overlay IR spectra of Chitosan and Ag@Ch

Figure 2.2: (A) TG TG-DTA curves of Chitosan and (B) TG-DTA curves of Ag@Ch

Figure 2.3: (A) SEM image of Synthesized dry Ag@Ch sample (beads), (B) SEM images silver nanoparticles homogenously decorated on the surface of chitosan beads

Figure 2.4: (A)TEM image of Ag@Ch, (B, C) HRTEM image of Ag@Ch, (D) SAED pattern of Ag@Ch

Figure 2.5: PXRD spectra of Ag@Ch

Figure 2.6:(A) Survey spectrum of Ag@Ch, (B) C 1s XPS Spectra of Ag@Ch, (C) N 1s XPS Spectra of Ag@Ch, (D) O 1s XPS Spectra of Ag@Ch, (E) Ag 3d XPS Spectra of Ag@Ch

Figure 2.7: Optimization of analyte amount

Figure 2.8: Optimization of Substrate amount

Figure 2.9 UV-Vis spectra of 1-30 ppm Methylene blue dye

Figure 2.10 SERS measurements of (A) methylene blue, (B) Cryctal violet and (C) p-Nitrophenol with chitosan supported silver nanostructure using method 1

Figure 2.11: SERS measurements of (A) methylene blue, (B) Cryctal violet and (C) p-Nitrophenol by using method 2

Figure 2.12: SERS measurement of liquid samples using method 3

Figure 2.13: SERS measurements with Chitosan using method 1

Figure 2.14: (A) Computational SERS data of p-NP, (B) Computational SERS data of MB, (C) Computational SERS data of CV

Figure 2.15: (A) Computational SERS data of p-NP, (B) Computational SERS data of MB, (C) Computational SERS data of CV with 4Ag@Ch under solvent effect

Figure 2.16: (A) p-Nitrophenol reduction catalysed by Ag@Ch, (C) Kinetic study of p-Nitrophenol reduction catalysed by Ag@Ch, (C) Recyclability study of the Ag@Ch

Figure 2.17: Catalytic reduction of p-Nitrophenol monitored by Raman spectroscopy

Chapter 3

Figure 3.1 Overlay IR spectra of Chitosan, IO-Chitosan, Pd@IO-Chitosan, Ni@IO-Chitosan, Pd@Ni@IO-Chitosan

Figure 3.2: (A) SEM image of IO-Chitosan, (B) EDX of IO-Chitosan, (C) TEM image of Io-Chitosan, (D) SEM image of Pd@IO-Chitosan, (E) EDX of Pd@IO-Chitosan, (F) TEM image of Pd@IO-Chitosan, (G) SEM image of Ni@IO-Chitosan, (H) EDX of Ni@IO-Chitosan, (I) TEM image of Ni@IO-Chitosan, (J) SEM image of Pd@Ni@IO-Chitosan, (K) EDX of Pd@Ni@IO-Chitosan, (L) TEM image of Pd@Ni@IO-Chitosan

Figure 3.3: (A) SAED image of IO-chitosan, (B) HRTEM image of Pd@IO-chitosan, (C)SAED image of Pd@IO-chitosan, (B) HRTEM image of Ni@IO-chitosan, (C)SAED image

of Ni@IO-chitosan, (B) HRTEM image of Pd@Ni@IO-chitosan, (C) SAED image of Pd@Ni@IO-chitosan

Figure 3.5: (A) XRD pattern of IO-Chitosan, (B) XRD pattern of Pd@IO-Chitosan, (C) (B) XRD pattern of Ni@IO-Chitosan, (D) (B) XRD pattern of Pd@Ni@IO-Chitosan

Figure 3.6: (A-D) C, N, O, Fe XPS spectra of IO-Chitosan and (E-I) C, N, O, Fe, Pd XPS spectra of Pd@IO-Chitosan

Figure 3.7: C, N, O, Fe, Ni XPS spectra of Ni@IO-Chitosan

Figure 3.8: C, N, O, Fe, Ni, Pd XPS spectra of Pd@Ni@IO-Chitosan

Figure 3.9: (A) Fe K edge XANES spectra of Pd@IO-Chitosan, (B) Fe K edge XANES spectra of Pd@Ni@IO-Chitosan, (C) Ni K edge XANES spectra of Pd@Ni@IO-Chitosan

Figure 3.10: (A) TG-DTA curve of IO-Chitosan, (B) TG-DTA curve of Pd@IO-Chitosan, (C) TG-DTA curve of Ni@IO-Chitosan, (D) TG-DTA curve of Pd@Ni@IO-Chitosan

Figure 3.11: Overlay VSM spectra of IO-Chitosan, Pd@ IO-Chitosan, Ni@ IO-Chitosan and Pd@Ni@IO-Chitosan

Figure 3.12: (A) p-Nitrophenol reduction catalysed by Pd@IO-Chitosan, (B) Kinetic study of p-NP reaction catalysed by Pd@IO-Chitosan, (C) p-Nitrophenol reduction catalysed by Pd@Ni@IO-Chitosan, (D) Kinetic study of p-NP reaction catalysed by Pd@Ni@IO-Chitosan, (E) p-Nitrophenol reduction catalysed by IO-Chitosan, (F) p-Nitrophenol reduction catalysed by Ni@IO-Chitosan

Figure 3.13: Optimization of Suzuki coupling reaction catalyzed by Pd@IO-Chitosan and Pd@Ni@IO-Chitosan, (A)Optimizations of Solvent, (B) Optimizations of base, (C) Optimizations of base amount, and (D) Optimizations of time for reaction between Iodobenzene and Phenyboronic acid in aqueous medium. **Reaction condition:** Iodobenzene (1.59 mmol), Phenylboronic acid (1.59 mmol), catalyst dose:1 mg, solvent (10 ml water), Base-K_2CO_3 (1 equi.), TLC (n-hexane), GC-MS (HPLC grade chloroform)

Figure 3.14: SEM Images of recycled catalyst (Pd@IO-Chitosan)

Figure 3.15: SEM Images of recycled catalyst (Pd@Ni@IO-Chitosan)

Figure 3.16: (A) VSM spectra of recycled catalyst (Pd@IO-Chitosan), (B) VSM spectra of recycled catalyst (Pd@Ni@IO-Chitosan)

Figure 3.17: (A) TG-DTA Curve of recycled catalyst (Pd@IO-Chitosan), (B) TG-DTA Curve of recycled catalyst (Pd@Ni@IO-Chitosan)

Figure 3.18: (A&B) Fe and Pd XPS spectra of recycled catalyst after 10^{th} cycle, (C&D) Survey spectrum of fresh and recycled catalyst.

Figure 3.19:(A) XPS survey spectrum of Fresh catalyst (B) XPS survey spectrum of Recycled catalyst (C) Fe2p XPS spectra of Recycled catalyst (D) Ni2p XPS spectra of Recycled catalyst (E) Pd3d XPS spectra of Recycled catalyst

Chapter 4

Figure 4.1: Optimization of Adsorption of Palladium from ELP solution

Figure 4.2: UV-vis spectra of GCC, Pd@GCC and Pd@GCC-r

Figure 4.3: FTIR spectra of GCC and Pd@GCC

Figure 4.4: (A) SEM image of GCC, (B) SEM image of Pd@GCC, (C) EDX of Pd@GCC,

Figure 4.5: (A) TEM image of Pd@GCC, (B) HRTEM image of Pd@GCC, (C) SAED pattern of Pd@GCC

Figure 4.6: XRD pattern of Chitosan, GCC and Pd@GCC

Figure 4.7: (A) XPS survey spectra of Pd@GCC, (B) Pd XPS spectra of Pd@GCC

Figure 4.8: (A) Thermogram of GCC, (B) Thermogram of Pd@GCC, (C) Pd K edge XANES spectra of Pd@GCC

Figure 4.9: Overlay IR spectra of Recycled Pd@GCC catalyst

Figure 4.10: Reduction of p-NP catalyzed by Pd@GCC

Figure 4.11: Degradation of Dyes (Malachite green, Methylene blue, Crystal violet, Rhodamine 6g) catalyzed by Pd@GCC

Chapter 5

Figure 5.1: IR spectra of (A) DTPA, (B) IO-DTPA, (C) Pd@IO-DTPA, (D) Ni@IO-DTPA, (E) Pd@Ni@IO-DTPA.

Figure 5.2: (A) SEM image of IO-DTPA, (B) EDS of IO-DTPA, (C) TEM image of IO-DTPA, (D) SEM image of Pd@IO-DTPA, (E) EDS of Pd@IO-DTPA, (F) TEM image of Pd@IO-DTPA, (G) SEM image of Ni@IO-DTPA, (H) EDS of Ni@IO-DTPA, (I) TEM image of

Ni@IO-DTPA, (J) SEM image of Pd@Ni@IO-DTPA, (K) EDS of Pd@Ni@IO-DTPA, (L) TEM image of Pd@Ni@IO-DTPA.

Figure 5.3: (A) SAED image of IO-DTPA, (B) HRTEM image of Pd@IO-DTPA, (C) SAED image of Pd@IO-DTPA, (D) HRTEM image of Ni@IO-DTPA, (E) SAED image of Ni@IO-DTPA, (F) HRTEM image of Pd@Ni@IO-DTPA, (G) SAED image of Pd@Ni@IO-DTPA

Figure 5.4: (A) STEM image of Pd@$NiFe_2O_4$-DTPA (B-F) HAADF mapping of Pd@Ni@IO-DTPA

Figure 5.5: (A) XRD spectra of IO-DTPA, (B) XRD spectra of Pd@IO-DTPA, (C) XRD spectra of Ni@IO-DTPA and (D)XRD spectra of Pd@Ni@IO-DTPA

Figure 5.6: C, N, O, Fe XPS spectra of IO-DTPA

Figure 5.7: C, N, O, Fe and Pd XPS spectra of Pd@IO-DTPA

Figure 5.8: C, N, O, Fe and Pd XPS spectra of Ni@IO-DTPA

Figure 5.9: C, N, O, Fe, Ni and Pd XPS spectra of Pd@Ni@IO-DTPA

Figure 5.10: (A) Fe k edge spectra of Pd@IO-DTPA, (B) Fe k edge spectra of Pd@Ni@IO-DTPA, and (C) Ni k edge spectra of Pd@Ni@IO-DTPA

Figure 5.11: (A) TG-DTA graph of IO-DTPA (B) TG-DTA graph of Pd@IO-DTPA and (C) Overlay VSM spectra of IO-DTPA and Pd@IO-DTPA

Figure 5.12: Overlay VSM spectra of IO-DTPA, Pd@IO-DTPA, Ni@IO-DTPA and Pd@Ni@IO-DTPA

Figure 5.13: (A, B) p-Nitrophenol reduction catalysed by Pd@IO-DTPA & Pd@Ni@IO-DTPA monitored by UV-Vis spectroscopy, (C) Reaction with IO-DTPA, (D) Reaction with Ni@IO-DTPA and (E, F) kinetic plot of ln(At/A0) vs time. **Reaction conditions:** 50 ml 25 ppm p-NP, 10 mg $NaBH_4$, 1 mg catalyst

Figure 5.14: (A)Optimizations of Solvent, (B) Optimizations of base, (C) Optimizations of base amount, and (D) Optimizations of time for reaction between Iodobenzene and Phenyboronic acid in aqueous medium. **Reaction condition:** Iodobenzene (1.59 mmol), Phenylboronic acid (1.59 mmol), catalyst dose:1 mg, solvent (10 ml water), Base- K_2CO_3 (1 equi.), TLC (n-hexane), GC-MS (HPLC grade chloroform)

Figure 5.15: SEM images of Recycled catalyst (Pd@IO-DTPA)

Figure 5.16: (A) Recyclability of the catalyst, (B) overlay Fe K-edge XANES spectra of fresh and recycled catalyst, (C) Overlay VSM spectra of Fresh and recycle catalyst (After 6th cycle), (D) TG-DTA data of recycled catalyst (After 6th cycle), (E) Pd leaching study by ICP-MS

Figure 5.17: Fe, Pd XPS Spectra of Recycled catalyst, survey spectrum of fresh and recycled catalyst (after 6^{th} cycle)

Figure 5.18: (A-C) SEM images of Recycled catalyst, (D) TGA of recycled catalyst, (E) VSM spectra of fresh and recycled catalyst (F) Pd leaching study by ICP-MS

Figure 5.19:(A-C) C, N, O XPS spectra of recycles catalyst. (D) Fe XPS spectra of Recycled catalyst, (E) Ni XPS spectra of Recycled catalyst, (F) Pd XPS spectra of Recycled catalyst (G) XPS Survey spectrum of Fresh catalyst (H) XPS Survey spectrum of Recycled catalyst

Chapter 6

Figure 6.1 Overlay IR spectra of IO-DTPA, IO-DTPA-DNA and Pd@IO-DTPA-DNA

Figure 6.2: (A) SEM image of IO-DTPA-DNA, (B)EDS data of IO-DTPA-DNA, (C) TEM image of IO-DTPA-DNA, (D) HRTEM image of IO-DTPA-DNA, (E) SEM image of Pd@IO-DTPA-DNA, (F)EDS data of Pd@IO-DTPA-DNA, (G) TEM image of Pd@IO-DTPA-DNA, (H) HRTEM image of Pd@IO-DTPA-DNA

Figure 6.3: C, N, O, Fe XPS spectra of IO-DTPA-DNA

Figure 6.4: C, N, O, Fe, Pd XPS spectra of Pd@IO-DTPA-DNA

Figure 6.5: (A) overlay XRD spectra of IO-DTPA-DNAand Pd@IO-DTPA-DNA, (B) Fe K edge XANES of Pd@IO-DTPA-DNA, (C) Pd K edge XANES spectra of Pd@IO-DTPA-DNA

Figure 6.6: (A)Thermogram of IO-DTPA-DNA, (B) Thermogram of Pd@IO-DTPA-DNA, (C) VSM spectra of IO-DTPA-DNA and Pd@IO-DTPA-DNA

Figure 6.7: (A) Time study of p-NP reduction catalysed by Pd@IO-DTPA-DNA, (B) Kinetics of p-NP reduction catalysed by Pd@IO-DTPA-DNA, (C) p-NP reduction catalysed by IO-DTPA-DNA

Figure 6.8: Optimization of reaction condition for Suzuki coupling reaction; **Reaction condition**: Iodobenzene (1.59 mmol), Phenylboronic acid (1.59 mmol); Base-K_2CO_3, Water (solvent) 10ml, Catalyst (1 mg), TLC(n-Hexane), GC-MS (HPLC grade chloroform), Yields were obtained by GC-MS analysis.

Figure 6.9: (A) SEM image of fresh catalyst, (B) SEM images of Recycled catalyst, (C) VSM spectra of fresh and recycled catalyst, (D) TGA thermogram of Recycled catalyst, (E) IR spectra of fresh and recycled catalyst

Figure 6.10: (A) Fe XPS of recycled catalyst, (B) Pd XPS of recycled catalyst, (C) XPS Survey spectrum fresh catalyst, (D) XPS Survey spectrum of recycled catalyst

Chapter 7

Figure 7.1 Comparison study of Suzuki coupling reaction catalysed by synthesized catalytic systems

Figure 7.2: Plausible mechanism from Suzuki coupling reaction catalysed by monometallic Pd nanosystem

Figure 7.3: Comparison Study of p-Nitrophenol reduction catalysed by Synthesized catalyst, Reaction conditions: for Pd@IO-Chitosan, Pd@Ni@IO-Chitosan, Pd@IO-DTPA, Pd@Ni@IO-DTPA: 25 ppm 50 ml p-NP, $NaBH_4$: 7-12 mg, Time: 8-12 min; For Ag@Ch: 10 ppm 10 ml p-NP; $NaBH_4$: 2 mg, Time: 15 min; For Pd@GCC: 10 ppm 10 ml p-NP; $NaBH_4$: 4mg, Time: 25 min

Figure 7.4: Plausible mechanism from p-Nitrophenol reduction reaction

Figure 7.5: Probable mechanism p-NP reduction reaction catalysed by Pd@Ni@IO-DTPA