Chapter – 1

Introduction

1.1 Overview of nanotechnology and nanomaterial

“Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where the properties differ significantly from those at a larger scale” likewise, “Nanotechnologies are the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometre scale”. In the current era of nanoscience, the use of nanotechnology in commercial applications is increasing in many scientific disciplines, including microelectronics, solar cells, catalysts, lithium-ion batteries, supercapacitors, hydrogen storage systems, stain-resistant clothing, cosmetics and medicine for diagnosis, imaging and drug delivery. Nanomaterials, the building blocks for nanotechnology, are engineered materials with one or more components with at least one dimension measuring 100 nm or less. They include nanoparticles, nanofibers and nanotubes, composite materials and nano-structured surfaces. Fig.1.1 shows the classification of nanomaterials related to present work. The main differentiating characteristic of nanomaterials is their size, which falls in the transitional zone between individual atoms or molecules and the corresponding bulk materials [1]. Size reduction can modify the physical and chemical properties of nanomaterials distinctively from their bulk and molecular counterparts. As the particle size decreases to less than 100 nm, the number of particles increases exponentially along with the surface area. This allows a greater proportion of atoms or molecules to be orientated on the surface rather than within the interior of the material, hence allowing adjacent atoms and substances to interact more readily. The surface-to-volume ratio determines the potential number of reactive groups; the intrinsic properties of materials at the nano-sized level are emphasized compared to their larger bulk counterparts. Therefore the unique features of nanomaterials such as high surface to volume ratio, favourable transport properties, altered physical properties, confinement effects resulting from the nanoscale dimension, strength,
conductivity, solubility, durability and reactivity provides greater promises to the fabrication of various nanodevices [2].

**Fig.1.1 Classification of nanomaterials related to present work**

**1.2 Synthesis approach of nanomaterials**

To date various nanomaterials have been prepared by different techniques, including chemical vapour deposition (CVD), electrodeposition, template based, hydrothermal and laser ablation methods [3], giving rise to the possibility of constituting a nanotoolbox for a ‘bottom-up’ approach in nanoscience and nanotechnology. Bottom-up approach refers to the build-up of a material from the bottom: atom-by-atom, molecule-by-molecule, or cluster-by-cluster. In organic chemistry or polymer science, we know polymers are synthesized by connecting individual monomers together. In crystal growth, growth species, such as atoms, ions and molecules, after impinging onto the growth surface, assemble into crystal structure one after another. Bottom-up, or self-assembly, approaches to nanofabrication use chemical or physical forces operating at the nanoscale to assemble basic units into larger structures. Bottom-up approach promises a better
chance to obtain nanostructures with less defects, more homogeneous chemical composition, and better short and long range ordering. This is because the bottom-up approach is driven mainly by the reduction of Gibbs free energy, so that nanostructures and nanomaterials such produced are in a state closer to a thermodynamic equilibrium state. On the contrary, top-down approach most likely introduces internal stress, in addition to surface defects and contaminations. The most common top-down approach to fabrication involves lithographic patterning techniques using short-wavelength optical sources. The challenge for all top-down techniques is that, while they work well at the microscale (at millionths of a metre); it becomes increasingly difficult to apply them at nanoscale dimensions. A second disadvantage is that they involve planar techniques, which means that structures are created by the addition and subtraction of patterned layers (deposition and etching), so arbitrary three-dimensional objects are difficult to construct.

1.3 Nanotechnology in energy storage

Energy storage is accomplished by devices or physical media that store energy to perform useful operation at a later time. It becomes a dominant factor in economic development with the widespread introduction of electricity and refined chemical fuels. Until recently electrical energy has not been converted and stored on a major scale, however new efforts to that effect began in the 21st century. The electrochemical systems for the storage of energy can be classified in three main types: electrochemical capacitors; batteries; fuel cells. The utilization of nanotechnology for the enhancement of electrical energy storage like batteries and super-capacitors turns out to be downright promising. Due to the high cell voltage and the outstanding energy and power density, the lithium-ion technology is regarded as the most promising variant of electrical energy storage. Nanotechnology can improve capacity and safety of lithium ion batteries decisively, as for example through high-performance electrode materials, new ceramic, heat resistant and flexible separators. Supercapacitors, also called electrochemical capacitors, have been considered as one of the most promising candidates for the next generation of energy storage devices due to their higher power densities and longer cycling lives, compared to secondary batteries, and higher energy density than conventional
capacitors. There are two types of supercapacitors: electrical double-layer capacitors with carbon electrodes and pseudocapacitors with metal oxide or conducting polymer electrodes. Transition metal oxides exhibit fast and electrochemically reversible faradic redox reactions to store charge in supercapacitors, resulting in a high capacitance. In the long run, even hydrogen seems to be a promising energy store for environmental-friendly energy supply. Apart from necessary nanostructure adjustments, the efficient storage of hydrogen is regarded as one of the critical factors of success on the way to a possible hydrogen management. Current materials for chemical hydrogen storage do not meet the demands of the automotive industry, which requires a hydrogen-storage capacity of up to ten weight percent.

1.3.1 Lithium ion batteries

The demand for renewable and clean energy has been rapidly increasing because of climate change and environmental degradation [4-5]. As a new alternative energy, the lithium-ion battery has been widely used for portable electronic devices, electric vehicles and other fields, due to its light weight, high energy density, long cycling capability, and lack of memory effect [6-7]. However, despite their outstanding commercial success, these batteries are still open to improvements. Fig.1.2 shows the schematic description of a lithium-ion cell.

![Schematic description of a lithium-ion cell based on electrochemical intercalation processes (discharge)](image)

Fig.1.2 Schematic description of a lithium-ion cell based on electrochemical intercalation processes (discharge)
Li-ion cell has a three layer structure. A positive electrode plate (made with Lithium Cobalt oxide-cathode), a negative electrode plate (made with special carbon-anode) and a separator layer. Inside the battery also exists an electrolyte which is a lithium salt in an organic solvent. The main principle behind the lithium ion battery is redox (oxidation and reduction) reaction that provides power to the battery. Oxidation (removal of electrons) occurs at the anode. Reduction (addition of electrons) occurs to cations at the cathode. Li-ion move from anode to cathode during discharge, and from anode to cathode when charged. Basically, the batteries use a graphite anode, a lithium cobalt oxide (LiCoO$_2$) cathode and an organic lithium ion conducting electrolyte. With the relatively high energy density, long cycle life, and environmental friendliness, lithium ion battery came into commercialization for various portable electronic devices including cellular phones and lap-top computers. A serious drawback is that lithium-ion batteries contain flammable and toxic solvents. Companies have recalled tens of millions of lithium-ion batteries over the years, directly due to this issue or related issues exacerbated by it. Replacing the dangerous solvent with something safer, like water, seems to dramatically reduce long-term battery performance.

However, certain drawbacks, such as safety hazards and rigorous assembly conditions, limit their application in a large scale. An attractive approach to circumvent this problem is to use an aqueous electrolyte for lithium ion batteries. Since these aqueous lithium ion batteries are composed of lithium ion host compounds as electrode materials and weak or alkaline or neutral aqueous solution as electrolytes, they fundamentally resolve the safety problem of the organic electrolyte and avoid the rigorous cell assembly conditions, both of which are the main issues for non-aqueous lithium-ion batteries. In addition, aqueous electrolytes usually have ion conductivity about two orders of magnitude higher than the non-aqueous electrolytes. Therefore, the extraordinary advantages of low toxicity, low cost, high safety, as well as high ion conductivity make the aqueous LIBs promising “green” batteries. Nowadays there has been considerable interest in searching for more attractive electrode materials for aqueous LIBs. It is of great scientific and technological significance to take the step into such fundamental study.
1.3.2 Anode materials

Transition-metal oxides have become in recent years promising candidates for anode materials of LIBs due to their huge specific capacity. Oxide based anode materials for rechargeable lithium batteries were investigated early in 1987 [9]. The principle is that a lithium alloy is used as an anode rather than metallic lithium. These alloys may offer the advantages of a higher melting temperature than metallic lithium, less reactivity with the atmosphere, and less tendency for dendrite growth during cycling. During the discharge, lithium from the alloy reacts with the cathode material and leaves an inactive anode skeleton.

These reactions can be expressed by equation (1.1):

\[ Li_n M_m \leftrightarrow nLi^+ + mM^0 + ne^- \]  

One obvious remark is that in order to enhance the capacity of the anode the ratio \( n/m \) must be as high as possible which means that the alloy must contain as many lithium atoms as possible per metal atom. During the discharge, the lithium is removed from the anode and the alloy is decomposed. At the end of the discharge, only the metal remains. An important feature is that the formation and decomposition of the alloy should occur at low potential versus a metallic lithium reference, i.e., less than 1.5V which enables the lithium battery to work at a reasonable voltage. It should also be highlighted that the alloy does not react with the solvents used in standard liquid electrolytes and that the lithium deposition during cycling is minimum. Aqueous rechargeable lithium batteries (ARLBs) use lithium intercalation compounds as one or two electrodes based on redox reactions and a lithium-containing aqueous solution as the electrolyte.

1.3.3 Cathode materials

Improvements at the cathode side are also critical for the progress of lithium batteries. Indeed, considerable efforts are presently directed to the replacement of the high cost, partially toxic LiCoO\(_2\) with more affordable and sustainable materials. Promising candidates are iron phosphates, such as the phospho olivine LiFePO\(_4\), lithium nickel oxides (LiNiO\(_2\)), vanadium oxides (V\(_2\)O\(_5\)) and other materials. Layered-structured vanadium oxides have versatile redox dependent properties and
have been intensively investigated as one of the most promising cathode materials in rechargeable lithium-ion batteries [14] and it is also cost effective and easily derived from existing mineral deposits like Mn, and due to the accommodation of three stable oxidation states (\(V^{5+}, V^{4+}\) and \(V^{3+}\)) within their close-packed oxygen arrays. Lithium ion can accommodate up to 4 moles (\(Li_xV_2O_5; 0<x<4\)) into the \(V_2O_5\) lattices, producing various structures including some reversible one, resulting in a long battery cycling life. The stability of the capacitance with reversible phase changes corresponds to the intercalation/deintercalation amounts of two equivalent lithium atoms per \(V_2O_5\), \(x = 2\) in the phase \(\gamma-Li_xV_2O_5\) (295 mAh/g). The Lithium insertion into \(V_2O_5\) matrix is shown in equation (1.2)

\[
4Li^+ + 4e^- + V_2O_5 \cdot 0.5H_2O \rightleftharpoons Li_4V_2O_5 \cdot 0.5H_2O \quad \text{............... Eq (1.2)}
\]

Its reversibility is good since it is a highly amorphous host structure and there is no prominent deformation or mechanical breakdown during the lithium insertion/deinsertion processes. Here in we reported a simple way to prepare \(V_2O_5\) nanostructures and it can be explored for the use of lithium-ion battery cathodes.

1.4 Tin dioxide (SnO\(_2\))

Tin dioxide, also known by the systematic name stannic oxide (SnO\(_2\)) is an n-type semiconductor with a wide band gap of 3.65 eV. Stannic oxide possesses the rutile structure, and it is the more abundant form of tin oxide. In addition to the common rutile (tetragonal) structured SnO\(_2\) phase there also exists a slightly more dense orthorhombic high pressure phase. As a mineral, stannic oxide is also called Cassiterite. Fig.1.3 shows the crystal structure of SnO\(_2\), wherein the tin atoms are six co-ordinates and the oxygen atoms are three co-ordinates. The lattice parameters are \(a = b = 4.737\) Å and \(c = 3.185\) Å. The c/a ratio is 0.673. The ionic radii for \(O^{2-}\) and \(Sn^{4+}\) are 1.40 and 0.71 Å, respectively. The metal atoms (cations) are located at positions (0, 0, 0) and (\(\frac{1}{2}, \frac{1}{2}, \frac{1}{2}\)) in the unit cell, and the \(O_2\) atoms (anions) at
\( \pm (u, u, 0) \) and \( \pm (\frac{1}{2}+u, \frac{1}{2}-u, \frac{1}{2}) \), where the internal parameter, \( u \), takes the value 0.307.

**Fig. 1.3 Crystal Structure of SnO\(_2\)**

Each cation has two anions at a distance of \( \sqrt{2}ua \) (2.053 Å) and four anions at \[ 2(\frac{1}{2}-u)^2 + (c/2a)^2 \] \( \frac{1}{2}a \) (2.597 Å). Its electrical conduction results from the existence of point defects (native and foreign atoms) which acts as donors and acceptors. Tin oxide is special in the respect that tin possesses a dual valency, with tin preferably attaining an oxidation state of 2+ or 4+. This dual valency facilitates a variation of the surface oxygen composition. The variation of surface composition is instrumental in explaining and tailoring many of the unique chemical properties of the materials [15].

**1.4.1 Applications of SnO\(_2\) in lithium ion batteries**

As a promising anode material for LIBs, tin-based material has attracted growing attention owing to its extraordinary electrochemical behaviour, such that the initial irreversible capacity induced by Li\(_2\)O formation, and the abrupt capacity fading caused by volume variation could be effectively reduced when in nanoscale form, the high theoretical capacity (780 mAhg\(^{-1}\)) and the higher operating voltage comparing to traditional carbonaceous anode active materials. The SnO\(_2\) nanostructures could provide more reaction sites on the surface and enhance the charge transfer in the electrochemical reactions. Moreover, Sn particles present in the SnO\(_2\) nanostructures also contributes to the Li\(^+\) storage and prevents the capacity loss.
that is induced by the existing metal catalysts. The reaction mechanism of tin-based systems with lithium was well established by Dahn and his group [16-17]. Accordingly, we can explain the discharge curve as the reduction reaction of tin oxide and lithium ion to metallic tin and lithium oxide, and during the charging process, the alloying of metallic Sn and Li takes place, amounting to the actual capacity observed in the subsequent cycles. The reaction mechanism during charge and discharge in the case of SnO₂ can be expressed as,

\[
\text{SnO}_2 + 4\text{Li}^+ + 4e^- \rightarrow 2\text{Li}_2\text{O} + \text{Sn} \quad \text{(First discharge)} \quad \text{Eq (1.3)}
\]

\[
x\text{Li}^+ + xe^- + \text{Sn} \leftrightarrow \text{Li}_x\text{Sn} \quad (0 \leq x \leq 4.4) \quad \text{(Subsequent cycles)......... Eq (1.4)}
\]

After the first cycle, the reversible reaction mechanism shown in Eq. (1.4) is responsible for the observed capacity. Unfortunately, the accommodation of the large amount of lithium is accompanied by severe volume changes in the host metal. These in turn induce mechanical strains which lead the electrode to crack and, eventually disintegrate with its failure in the round of few cycles. An effective way to improve the cycling stability of the electrode is that of modifying their morphology by reducing their particles size to few nanometres or by designing special nanostructures. Indeed, this strategy is expected to have two-fold effects on the performance of the electrodes (i) improvements in cycling stability, since small particles enable to more easily accommodate the mechanical strains (ii) enhancement of power due to the reduction of the lithium ion diffusion length. Up to date, most of functional SnO₂ nanoarchitectures (nanorods, nanowires and nanotubes) have been mainly prepared in the form of powders by solution routes. In addition, the conventional electrode-preparation procedure, in which active materials and electronic conducting agents (often carbon black) are embedded in non-electro active polymer matrix, will limit the kinetic process of the nanomaterial. Currently focus is given to the direct growth of active SnO₂ nanostructures on a current collector, which represent an attractive architecture for Li-ion battery electrode. Present thesis focus
on the electrochemical investigations of nanocrystalline SnO$_2$ thin films in different aqueous electrolyte solutions.

1.4.2 Electrochemical bio sensors

Electrochemical sensors and biosensors have recently found extensive applications in diverse industries. Nowadays, many analytical instruments used in environmental, food, pharmaceutical, or clinical laboratories and also most of the commercial point-of-care devices work using chemical sensors or biosensors, as a whole or a basic part. Glucose biosensors used widely in glucometers and pH electrodes are the important known examples of the electrochemical sensors. Day by day, the numbers of sensors or biosensors coming from the bench of research laboratories to the shelf of the commercial markets are increasing. Due to the high demand of the world market and human interest for having a device to check the concentration of species in different samples, simple and fast, in recent years, a hard competition on design and construct of new sensors and biosensors has occurred among the researchers.

An electrochemical sensor is a device that transforms electrochemical information into an analytically useful signal. An electrochemical sensor usually composed of two basic components, a chemical (molecular) recognition system which is the most important part of a sensor and a physicochemical transducer which is a device that converts the chemical response into a signal that can be detected by modern electrical instrumentations. These two parts form a working (or sensing) electrode. A reference electrode and sometimes a counter electrode are also used in electrical measurements. Biosensors are chemical sensors in which the recognition system utilizes a biochemical mechanism. Transduction of a biological or chemical signal into an electrical signal can be done by amperometry, voltammetry, potentiometry or conductometry. Next generation of sensor or biosensors will require considerable improvements in sensitivity, selectivity, and accuracy to meet the future needs in diversified fields. Today, application of different nanoparticles in construction of sensors and biosensors as a modifier causes to approach to this purpose. The nanoparticles have different effects on response of the sensor or biosensor besides improving their thermal, electrical, and mechanical properties.
Here we have focused on the selective determination of ascorbic acid (AA) at the SnO₂ electrode surface.

1.5 Vanadium pentoxide (V₂O₅)

Vanadium pentoxide V₂O₅ is a semiconductor with a band gap of 2.2 eV and has specific conductivities ranging from 10⁻⁶ S/cm to almost 1 S/cm. Moreover, V₂O₅ is very suitable for device application due to its high temperature coefficient of resistance at room temperature and its relatively low noise properties. This has brought becomes increasing attention to V₂O₅. V₂O₅ possesses the maximal oxidation state among the large family of vanadium oxide compounds and is the most stable member of this series. It is furthermore among the few metal oxides with versatile redox-dependent properties. V₂O₅ crystallizes in two different structures at room temperature. α-V₂O₅ is the prevalent structure. The γ polytype is obtained by deintercalation of Li⁺ ions from γ-LiV₂O₅ bronze. It is metastable in ambient conditions and exhibits a sharp transition to α at 340 °C. The V₂O₅ crystal becomes unstable upon heating in reducing or oxygen-deficient environments and tends to lose oxygen. When liquid V₂O₅ (mp = 680 °C) is quenched rapidly (>10⁶ Ks⁻¹) amorphous V₂O₅ is formed. A rapid crystallization of the amorphous material to α-V₂O₅ is observed at 200 °C.

Fig. 1.4 Crystal Structure of V₂O₅

The α-V₂O₅ phase possesses an orthorhombic structure and is composed of alternating distorted VO₃ square pyramids which create double layers of O-V-O.
These layers are separated by a van der Waals (vdW) gap. Thus, $V_2O_5$ shows strong anisotropic characteristics typical to materials with layered (2-D) structure. The (010) plane (the basal or vdW plane) exhibits a lower surface energy as compared to that of the (100) and (001) planes. Note that, unlike the metal dichalcogenides where the vdW gap occurs along the c axis, the b axis is often used to define the vdW gap for metal oxides with layered structures. Due to the weak interlayer electrostatic binding force, the vdW gap (4.4 Å) provides a large number of intercalation sites. Intercalation of either lithium ions or water results in an expansion of the lattice parameters especially along the b axis (the vdW gap) [18]. Fig.1.4 shows the crystal structure of orthorhombic $V_2O_5$.

1.6 Literature review

We have reviewed work done by other researchers in the field of lithium-ion batteries; it discusses different methods and materials used by researchers in this area. We know how a SnO$_2$ based electrodes functions and all the factors that affect the capacity of a Li-ion battery. The main hindrance against commercial use of SnO$_2$-based anode materials in lithium ion battery is the large volume change and Li$_2$O formation during charging and discharging processes, resulting in the poor cyclability. The main areas of research in improvisation of SnO$_2$ based electrodes has been going on in trying to make them good candidates by using different nanostructures. In this review we will summarize the different literatures of previous researchers.

1.6.1 SnO$_2$ in Lithium ion batteries

Zhao et.al [19] prepared SnO$_2$ electrode for the first time by using a novel facile and low-cost-ink-jet printing technique. Wet ball-milling was employed to stabilize SnO$_2$ nano particles and conducting agent acetylene black (AB) using two kinds of polymeric hyper dispersants CH10B and CH12B, respectively, to prepare the stable colloid as “ink”. The morphology, structure, composition and electrochemical performance of SnO$_2$ thin film electrodes were investigated in detail by scanning electron microscopy (SEM), Transmission electron microscope (TEM), X-ray diffraction (XRD), Energy dispersive X-ray (EDX) spectroscopy, cyclic...
voltammograms (CV) and galvanostatic charge–discharge measurements. SEM images show uniform distribution of as-printed SnO$_2$ thin film electrodes. High initial discharge capacity of 812.7 mAhg$^{-1}$ was observed at a constant discharge current density of 33μA/cm$^2$ at first cycle and the capacity degrades to 350 mAhg$^{-1}$ after multiple cycles.

Liang et.al [20] synthesized SnO$_2$ nano-single crystals using tin (IV) chloride as precursor by the modified hydrothermal method. Controllable morphology and size of SnO$_2$ could be obtained by adjusting the concentration of the hydrochloric acid. The SnO$_2$ nanoparticles as anode materials in lithium-ion batteries exhibit high lithium storage capacities. The reversible capacities are more than 630 mAhg$^{-1}$, where the electrode exhibited a substantial capacity fading from 400 to 300 mAhg$^{-1}$ in 30 cycles.

Hu et.al [21] synthesized porous micro-tubes by the thermal decomposition of SnC$_2$O$_4$ precursor. The morphology of SnC$_2$O$_4$ could be preserved after the controlled heat treatment and a lot of mesopores left due to the release of gases. The mesoporous nature with a range of 3–50 nm was characterized by Brunauer-Emmett-Teller (BET) method. SEM images showed that the obtained SnO$_2$ samples were rhombic tube-like with swallow-tailed nozzles. When the porous SnO$_2$ micro-tubes were used as anode materials for lithium-ion battery, they exhibited high lithium storage capacity and coulomb efficiency of 530 mAhg$^{-1}$ after 20 cycles.

Wang et.al [22] prepared B$_2$O$_3$-doped SnO$_2$ thin film by a novel experimental procedure combining the electrodeposition and the hydrothermal treatment, and its structure and electrochemical properties were investigated by SEM, TEM, XRD, and EDX and galvanostatic charge–discharge tests. It was found that the as-prepared modified SnO$_2$ film shows a porous network structure with large specific surface area and high crystallinity. The results of electrochemical tests showed that the modified SnO$_2$ electrode presents the largest reversible capacity of 676 mAhg$^{-1}$ at the fourth cycle, close to the theoretical capacity of SnO$_2$ (790 mAhg$^{-1}$); and it still delivers a initial reversible Li$^+$ storage capacity of 524 mAhg$^{-1}$ and the capacity fades to 200 mAhg$^{-1}$ after 20 cycles.
Yu et al. [23] prepared three-dimensional (3D) porous amorphous SnO$_2$ thin films on Ni foam substrates by electrostatic spray deposition (ESD) technique as anodes for Li-ion batteries. These films display good capacity retention of 94.8% after 100 cycles at 0.5 C and rate capability of 362 mAh$^{-1}$ at 10 C. The improved performance originates from the fact that the 3D porous structure offers a “buffer zone” to accommodate the large volume change during cycling, and the foam-like substrate maximizes the contact area between electrode and electrolyte.

Ho et al. [24] obtained three structures of Sn, Sn$_6$O$_4$(OH)$_4$, and SnO$_2$ could be obtained in the 1 mM SnCl$_2$ aqueous solution for various aeration periods in air. In order to obtain the pure SnO$_2$ coatings as the anode of thin-film lithium ion battery, the aeration should proceed for 10 days to oxidize tin valence from stannous to stannic in SnCl$_2$ aqueous solution. The coating films were further annealed and characterized by XRD, SEM, Fourier transform infrared (FTIR) spectroscopy, Thermo gravimetric analysis (TGA), Raman spectroscopy, and cyclic voltammetry. The SnO$_2$ film containing H$_2$O in the pristine state could be dehydrated at 300 °C for 2 h, or at 250 °C for 12 h. The crystallinity and surface coarsening of the coating films were promoted with increasing annealing temperature. The dehydrated SnO$_2$ film used as the anode of a lithium battery showed a reversible capacity as high as 500 mAh$^{-1}$ after 10 cycles at a discharging rate of 0.2 C, which could result from the nano-sized microstructure of coating film.

Pena et al. [25] prepared thin films of tin dioxide and antimony doped tin dioxide thin films using a sol-gel technique. Films are homogeneous in composition and morphology and show a remarkable decrease in grain size and resistivity with doped antimony. Films were tested as potential anodes in lithium-ion batteries. The best electrochemical performance was obtained from the Li/SnO$_2$ (doped with 5% Sb) which provides more than 250 mAh$^{-1}$ during 75 cycles, mean while the Li/SnO$_2$ cells capacity fades after a few cycles.

Wang et al. [26] synthesized thin SnO$_2$ nanosheets successfully through a facile one-pot hydrothermal method. The as-prepared products possess a surprisingly high BET surface area and pore volume and exhibit a superior lithium storage capacity and cycle performance as an anode in lithium-ion batteries. In comparison,
the charge capacity of SnO$_2$/graphene remains $\sim$593 mAh$^{-1}$ after 20 cycles which is slightly higher than our results of 559 mAh$^{-1}$.

*Hua et.al [27]* investigated the influence of nanostructure on the electrochemical properties of Li-ion battery. Tin-oxide nanotubes were prepared by combining sol-gel method with polycarbonate template. Scanning electron microscopy and X-ray diffractometry were used to characterize the obtained material. The electrochemical measurements were conducted on the nanostructured tin-oxides as electrode of Li-ion batteries. The nanotubes exhibited initial discharge capacity of 760 mAh$^{-1}$ and the capacity drastically degrades to 320 mAh$^{-1}$ at the 30$^{th}$ cycle. The diameter of the tube controls the cycling performance of the nanotubes.

*Park et.al [28]* fabricated self-catalysis-grown SnO$_2$ nanowires by a thermal evaporation process. The ball-milled evaporation source served to increase production and decrease the synthesis temperature. The Sn particles in the evaporation source played the role of the catalyst, allowing vapor-liquid-solid (VLS) growth of the SnO$_2$ nanowires. The 1D nanowire structure could provide more reaction sites on the surface and enhance the charge transfer in the electrochemical reactions. Moreover, Sn particles at the tips of nanowires also contributed to the Li$^+$ storage and prevented the capacity loss that is induced by the existing metal catalysts. Nanowires exhibit improved cyclic performance and a higher reversible specific capacity of over 300 mAhg$^{-1}$ up to the 50$^{th}$ cycle.

*Zhang et.al [29]* developed a programmed method to load mono dispersed SnO$_2$ nanoparticles onto single layer graphene sheets. The specific charge capacity of the composite was 720 mAh$^{-1}$ in the first cycle and 440 mAh$^{-1}$ after 50 cycles, which is nearly the same as previously reported by Hua et.al. The SnO$_2$-G composite consisting of 60 wt% SnO$_2$ nanocrystals exhibits nearly as high initial reversible capacity of 786 mAh$^{-1}$ as commercial SnO$_2$. More importantly, the cycling performance has been drastically improved.

*Wang et.al [30]* synthesized SnO$_2$ nanotube arrays on titanium substrate by prefabricated ZnO nanowire array as sacrificial templates. The as-synthesized SnO$_2$
nanotube arrays were applied as anode materials of Li-ion battery, which exhibit high capacity and improved cycling performance. The good contact and adhesion with the current collector, as well as good strain accommodation of SnO$_2$ nanotube arrays on titanium substrates, may be responsible for the good performance. Moreover, such strategy can be extended to synthesize other metal oxide nanotube arrays on metallic substrate.

*Paek et.al [31]* fabricated SnO$_2$/graphene nanoporous electrodes with three-dimensionally delaminated flexible structured electrode. According to the TEM analysis, the graphene nanosheets are homogeneously distributed between the loosely packed SnO$_2$ nanoparticles in such a way that the nanoporous structure with a large amount of voids spaces could be prepared. The obtained SnO$_2$/GNS exhibits a reversible capacity of 810 mAh$^{-1}$; furthermore, its cycling performance is drastically enhanced in comparison with that of the bare SnO$_2$ nanoparticle. After 30 cycles, the charge capacity of SnO$_2$/GNS still remained 570 mAh$^{-1}$, that is, about 70% retention of the reversible capacity, while the specific capacity of the bare SnO$_2$ nanoparticle on the first charge was 550 mA$^{-1}$, dropping rapidly to 60 mA$^{-1}$ only after 15 cycles. The dimensional confinement of tin oxide nanoparticles by the surrounding GNS limits the volume expansion upon lithium insertion, and the developed pores between SnO$_2$ and GNS could be used as buffered spaces during charge/discharge, resulting in the superior cyclic performances.

*Wu et.al [32]* has successfully synthesized various SnO$_2$ hierarchical structures assembled from nanosheets by a facile hydrothermal method. These 3D hierarchical structures provide several advantages for lithium storage, including a short diffusion length for lithium ions determined by the small thickness of nanosheets, better interconnection between building blocks, and high porosity for efficient transport of lithium ions. As a result, these SnO$_2$ hierarchical structures can retain a high reversible capacity of 516 mAh$^{-1}$ at a current density of 400 mA$^{-1}$ after 50 cycles.

*Jin et.al [33]* have presented the successful formation of a nanocomposite electrode, fabricated by using a simple hydrothermal process to attach synthesized SnO$_2$ nanoparticles to MWCNTs with surfaces functionalized by acid treatment. The
carboxylate anions on the MWCNT surfaces served as the linkers for the electrostatic interaction between the MWCNTs and the SnO₂ nanoparticles with diameters of ≈3 nm. Pure SnO₂ nanoparticles showed a poor electrochemical performance because of their high aggregation and the resulting interparticle resistance. However, SnO₂ nanoparticles were uniformly anchored on the surfaces of the MWCNTs without any appreciable aggregation in the MWCNT/SnO₂ nanocomposites, allowing the favourable utilization of the high surface area by the nanoparticles and in the Li⁺ electrochemical reactions. Therefore, the MWCNT/SnO₂ nanocomposites could deliver reversible high capacities of ≈420 mAh⁻¹ even after 100 cycles, which are much higher than those of graphite-based anodes.

X.Chen et.al [34] reported pure SnO₂ films were deposited on copper substrates by one-step cathodic electrodeposition without any pre-treatment of the electrolyte or post-treatment of the deposit. It was found that the concentration of HNO₃ in the electrolyte, ageing of the electrolyte, the electrodeposition temperature, and the electrodeposition voltage are critical to obtain SnO₂ films and avoid co-deposition of Sn. By carefully controlling those processing parameters, pure SnO₂ films composed of fine particles with good adherence to the Cu substrate have been successfully prepared.

A.Y.El-Etre et.al [35] prepared nanocrystalline SnO₂ thin films by cathodic electrodeposition anodic oxidation and its structure was characterized by X-ray diffraction, SEM, UV–visible absorption and nitrogen adsorption–desorption by BET method. The obtained film has a surface area of 137.9 m²/g with grain sized of 24 nm. Thus the prepared SnO₂ thin film can be applied as an electrode in dye-sensitized solar cell. The SnO₂ electrode was successfully sensitized by erythrosine dye and photoelectrochemical measurements indicate that the cell present short-circuit photocurrent (Jₑₒ) of 760 μA/cm², fill factor (FF = 0.4), photovoltage (Vₑₒ = 0.21 V) and overall conversion efficiency (η) of 0.06% under direct sun light illumination. The relatively low fill factor and photovoltage are attributed to the reduction of triiodide by conduction band electrons and intrinsic properties of SnO₂.

S.T.Chang et.al [36] obtained nanocrystalline and two-layered SnO₂ coatings by electrodeposition at 85°C in nitric acid solution. The coating was composed of an
upper porous layer and an underlying dense layer, about 400 nm and 12 mm, respectively in thickness for the coating deposited at 0.6V vs. Ag/AgCl for 10 min. The porous structure of the upper layer possessed a large surface area of 34.3 m$^2$/g, while the underlying high-density layer promoted the adhesion between the substrate and the porous layer. Both the upper and the underlying layers were constructed by nanocrystalline grains, and the sizes of the grains were 5 and 10 nm, respectively. The present study also showed that a very small amount of metallic Sn co-existed in the coating with a concentration of less than 3 mol%. Results from X-ray diffraction, deposition weight gains, X-ray photoelectron spectrum, scanning electron microscopy and transmission electron microscopy were described and correlated with the deposition reactions and characteristics of the coatings. In summary, although as a low-temperature process, the electrodeposition is of great potential to prepare nanocrystalline coatings with a high porosity and a good adhesion simultaneously.

S.T Chang et al. [37] prepared Sn/SnO$_2$ nanocomposite and nanocrystalline SnO$_2$ coating from nitrate solution by chronoamperometry and pulse technique, respectively. For the chronoamperometric technique, the percentage of Sn, ranging from 12.3 to 49.1 mol%, can be controlled by the applied voltage (−0.2 to −0.6 V). The co-deposited metallic Sn can be oxidized into nanocrystalline SnO$_2$ at −0.1 V versus Ag/AgCl by using a pulse technique composed of alternatively a higher voltage stage (−0.2 to −0.6 V) and a low voltage stage (−0.1 V), and then a pure nanocrystalline SnO$_2$ coating can thus be synthesized. The grain size of SnO$_2$, ranging from 28.9 to 16.6 nm, could also be controlled by the applied voltage. The phase compositions and morphologies of the coatings were characterized by XRD and SEM observation, respectively, and the percentage of Sn was determined by X-ray photoelectron spectroscopy (XPS) analysis.

W.Sun et al. [38] prepared nanocomposites of graphene (GR) and SnO$_2$ nanosheets which were used to modify an N-hexylpyridinium hexafluorophosphate based carbon ionic liquid electrode. The presence of GR–SnO$_2$ nanocomposite on the electrode surface exhibited synergistic effects to improve the electrochemical performance of the modified electrode. Electrochemical behaviors of dopamine (DA)
on the electrode were evaluated by cyclic voltammetry and differential pulse voltammetry. The results indicated that the GR–SnO$_2$ nanocomposite modified electrode displayed high electrocatalytic activity to the oxidation of DA with the increase of the redox peak currents and the decrease of the peak-to-peak separation. Under the selected conditions the oxidation peak current was proportional to the DA concentration in the range from 0.5 to 500.0 μmol/L with a detection limit of 0.13 μmol/L (S/N = 3). The modified electrode showed excellent selectivity and sensitivity even in the presence of high concentration of uric acid. The proposed method was applied to determine DA content in real samples with satisfactory results.

A.Yang et.al [39] synthesized graphene nanosheet/SnO$_2$ nanoparticle hybrid nanocomposites (GN/SnO$_2$) by using graphene oxide nanosheets (GONs) functionalized with sodium dodecyl sulfonate and SnCl$_2$ as the starting materials by one pot synthesis method. The morphology and structure of the synthesized SDS-GN/SnO$_2$ nanocomposites were characterized by Raman spectroscopy, transmission electron microscopy (TEM) and X-ray diffraction analysis. It was found that SnO$_2$ nanoparticles were homogeneously distributed on the graphene nanosheets. The electrochemical behaviour of dopamine (DA) at the SDS-GN/SnO$_2$ nanoparticle modified electrode was studied by cyclic voltammetry (CV) and differential pulse voltammetry (DPV). The results showed that the modified electrode exhibited excellent electrocatalytic activity towards the electrochemical oxidation of DA. The separation of the oxidation peak potentials for ascorbic acid (AA)-DA, uric acid (UA)-DA and UA-AA obtained by DPV is about 132 mV, 128 mV and 260 mV, respectively, which allows selective and sensitive detection of DA in the presence of AA and UA. The anodic peak currents were linear with the concentration of DA in the range from 1.0 x10$^{-7}$ to 1.0 x 10$^{-5}$ M with a coefficient of 0.9980. The detection limit was 80 nM (S/N=3). The proposed method could be applied for the determination of DA in real human urine samples.

D.Sun et.al [40] prepared novel SnO$_2$ nanoparticles/multi-walled carbon nanotubes/carbon paste electrode (nano SnO$_2$/MWCNTs/CPE) for simultaneous detection of dopamine (DA), uric acid (UA), and ascorbic acid (AA) via cyclic
voltammetry (CV) and differential pulse voltammetry (DPV). The novel nano SnO$_2$/MWCNTs/CPE electrode showed high electrochemical catalytic behaviour for DA, UA, and AA. The three compounds could be completely separated on the electrode in CV and DPV at optimal conditions. DPV provided larger peak potential separations and higher response sensitivities of DA, UA, and AA compared to CV. In DPV, there are linear relationships between the peak currents and the concentrations in the ranges of 0.3–50 mM for DA, 3–200 mM for UA, and 0.1–5 mM for AA, with the detection limits (S/N=3) of 0.03, 1, and 50 mM for DA, UA, and AA, respectively. The proposed method was applied for the simultaneous detection of DA, UA, and AA in human urine samples, with recoveries of 91.0%, 97.4%, and 103.0% for DA, UA, and AA, respectively. The relative standard derivations (RSDs, n =5) were 2.8–4.4%.

1.6.2. V$_2$O$_5$ in Lithium ion batteries

Benmoussa et.al [41] prepared vanadium pentoxide thin films by the sol–gel route by dissolving V$_2$O$_5$ powder (99.5% purity) in H$_2$O$_2$ solution. The solution is spin-coated on glass substrates for optical (UV–VIS–NIR) and XRD analysis, and on ITO coated glass substrates for electrochromic measurements. The samples are then annealed at 150°C for 1 hour. The resulting films have a yellow-orange colour, typical of polycrystalline V$_2$O$_5$. XRD measurements have shown that after annealing in air at 400°C the structure of the films has a c-axis preferred orientation, the (0 0 1)-type planes lying parallel to the substrate. SEM analysis revealed a smooth surface. The films optical and physical constants (n, a, Eg, the thickness d and the mean thickness inhomogeneity σ) are calculated using a simple and accurate method based on the transmission spectrum alone. The films electrochromism is studied using CV and chronoamperometry in propylene carbonate solution containing 1 mol/l LiClO$_4$. The films show reversible multichromism (yellow–green–blue) upon Li$^+$ ion insertion/extraction.

Akbarzadeh et.al [42] deposited thin films of vanadia–titania with good adhesion to the various substrates such as glass slides, glass helix and silica raschig rings by simple sol–gel dip coating process using vanadium and titanium peroxide gel. The optimum concentration of vanadia in titania for obtaining good uniform
A viscous gel was found to be 0.5–4 wt% beyond which the vanadia particles disturb the gel network, resulting in the formation of a gelatinous precipitate. The films of vanadia–titania as well as the dried powder of the bulk gel were characterized by different characterization techniques. Vanadia doped TiO$_2$ thin films were also found to be very active for photocatalytic degradation of formaldehyde from aqueous solution in sunlight.

Guerra et al. [43] investigated the effect of pore structure on the behaviour of lithium intercalation into an electrode containing porous V$_2$O$_5$ film and compared with the electrode containing a non-porous V$_2$O$_5$ film. XRD patterns indicate a lamellar structure for both materials. Nitrogen adsorption isotherms, t-plot method, and SEM show that the route employed for the preparation of mesoporous V$_2$O$_5$ was successful. The electrochemical performance of these matrices as lithium intercalation cathode materials was evaluated. The porous material reaches stability after several cycles more easily compared with the V$_2$O$_5$ xerogel. Lithium intercalation into the porous V$_2$O$_5$ film electrode is crucially influenced by pore surface and film surface irregularity, in contrast with the non-porous surface of the V$_2$O$_5$ xerogel.

Ivanova et al. [44] prepared TiO$_2$–V$_2$O$_5$ colloidal solution with a stability of more than 2 years. Xerogels, dried at 80°C and treated at 300 and 560 °C, were investigated by Fourier transform infrared spectroscopy (FTIR). Powder XRD measurements showed that the sample treated at 300°C is amorphous, and crystallization began after 450°C. Vanadium-doped titanium dioxide thin films were prepared by using sol–gel dipping technique. Highly transparent TiO$_2$–V$_2$O$_5$ coatings were formed on quartz substrates. The optical properties of the sol–gel mixed thin films were characterized as a function of the annealing temperatures from 200 to 650°C.

Ding et al. [45] synthesized orthorhombic V$_2$O$_5$ single-crystalline nanobelts by hydrothermally treating V$_2$O$_5$·xH$_2$O precipitate derived from aqueous solution of V$_2$O$_5$ and H$_2$O$_2$. The synthetic method is facile, fast, environmental friendly, and easy to scale up. The V$_2$O$_5$ single-crystalline nanobelts are 30–80 nm in width, 30–40 nm in thickness, and lengths up to several tens of micrometers. The
V$_2$O$_5$·xH$_2$O precursor is crucial for the formation of orthorhombic V$_2$O$_5$ single-crystalline nanobelts. The influences of synthetic parameters, such as reaction time and reaction temperature, on the crystal structures and morphologies of the resulting products have been investigated. Time-dependent experiments show that V$_2$O$_5$·xH$_2$O are dehydrated gradually and converted into orthorhombic V$_2$O$_5$ single-crystalline nanobelts. High reaction temperature also favours the formation of orthorhombic V$_2$O$_5$ nanobelts.

*Kim et.al [46]* treated electrodeposited V$_2$O$_5$ thin films by electron beam irradiation with various electron beam doses. Crystallinity, surface morphology, and oxidation state were significantly changed by electron beam irradiation and were found to be strongly dependent on irradiation time. Temperature increase and ozone generation may play important roles in the modification of the surface morphology, crystallinity, and oxidation state of Vanadium oxide. The enhanced electrochemical properties can be attributed to high surface area and facilitated charge transfer resulting from electron beam irradiation.

*Lee et.al [47]* deposited mesoporous vanadium oxide (V$_2$O$_5$) thin films electrochemically onto indium tin oxide coated glass substrates from an aqueous solution of vanadyl sulphate using CTAB (hexadecyltrimethylammonium-bromide) as a templating agent. For comparison, a control sample was electrodeposited without CTAB templating. Transmission electron microscopy and small angle X-ray diffraction indicated the presence of mesoporosity with a well-ordered lamellar phase in the electrodeposited films. The crystallinity of the V$_2$O$_5$ thin films was confirmed by X-ray diffraction. Cyclic voltammetry and chronoamperometry were used to measure electrochemical properties of synthesized films. The mesoporous films prepared with CTAB templating had a much higher capacity and lithium-ion diffusion rate than the non-porous electrode prepared without CTAB templating.

*Park et.al [48]* prepared vanadium pentoxide/polyaniline (V$_2$O$_5$/PANi) composite films by a two-step electrochemical method and evaluated their application in lithium batteries. As a first step the PANi film was potentiodynamically grown in an acid solution containing aniline monomer, and secondly vanadium oxide was oxidatively deposited on the polyaniline film in a
temperature controlled VOSO$_4$ solution. The increased current efficiency obtained with the larger anodic current in the high temperature solutions results in high contents of V$_2$O$_5$ in the composites, even if the oxidative dissolution of PANi also occurs. The large value of the diffusion coefficient estimated from the cyclic voltammograms for the composite film provides evidence for the synergistic effect of the conducting polymer and the inorganic composite. The cell exhibited excellent cycle stability with a high charge storage capacity. The large increase in the specific capacity for the composite film prepared in this work demonstrates that the conducting polymer in the composite acts as a binding and conducting element by contributing its electroactivity. The V$_2$O$_5$/PANi composite film cathodes show a large specific capacity (270 mAh g$^{-1}$) and improved cyclability with an extremely small amount of capacity fading (3.4%) during repeated charge/discharge cycles.

Takahashi et.al [49] grown single-crystal vanadium pentoxide (V$_2$O$_5$) nanorod arrays from VOSO$_4$ aqueous solution by electrochemical deposition using polycarbonate membrane. Uniformly sized vanadium oxide nanorods with a length of about 10μm with diameters ranging from 100 to 200 nm were grown over a large area with near unidirectional alignment. Nanorods have single crystalline structures oriented along [010], and the growth of single-crystal vanadium pentoxide nanorods was attributed to an evolution selection growth mechanism. Nanorod array electrodes have approximately 5 times higher applicable current density than sol-gel-derived film, and in a given current density, a nanorod array electrode can intercalate up to 5 times higher concentration of Li$^+$. 

Wang et.al [50] synthesized nanotube arrays of amorphous V$_2$O$_5$ via template-based electrodeposition, and its electrochemical properties were investigated for Li-ion intercalation applications. The nanotubes have a length of 10 μm, outer diameter of 200 nm and inner diameter of 100 nm. Electrochemical analyses demonstrate that the V$_2$O$_5$ nanotube array delivers a high initial capacity of 300 mAh g$^{-1}$, about twice that of the electrochemically prepared V$_2$O$_5$ film. Although the V$_2$O$_5$ nanotube array shows a more drastic degradation than the film under electrochemical redox cycles, the nanotube array shows a more drastic degradation than the film under electrochemical redox cycles, the nanotube array reaches a
stabilized capacity of 160 mAhg⁻¹, which remains about 1.3 times the stabilized capacity of the film.

*M.Castriota et.al [51]* deposited thermal-induced structural modifications of thin film of vanadium pentoxide xerogels deposited on indium tin oxide (ITO)-coated glasses. Vanadium pentoxide xerogel has been prepared by using the sol–gel proton exchange resin route without any resin pre-treatment. To monitor the effect of the “resin efficiency” on the gelation process, the solution coming out from the resin has been collected in a sequence of different containers (vials), separately investigated by Raman spectroscopy. After the spin coating deposition, the thin films of vanadium pentoxide gel have been subjected to different annealing treatments. The highest thermal treatment (600°C) induces a complete transformation of the gel phase into an anhydrous polycrystalline phase of a sodium containing vanadate, different from the usual V₂O₅ crystal. It is due to the diffusion of foreign ions (mainly sodium) coming from the substrate into the vanadium oxide layer.

*X.Wu et.al [52]* Vanadium oxide films with different thicknesses were deposited on quartz substrates at room temperature by thermal evaporation technique. For investigating the effect of thermal cycling on the properties of the films, the as-deposited films were heated from the room temperature up to 300 °C and then cooled down to the room temperature. The structure and the surface morphology of the samples were studied by XRD, Raman spectra and atomic force microscopy. The transmittances of the samples were measured by spectrophotometer. Electrical resistance during thermal cycling was recorded by dual probe method. The experimental results show that the amorphous as-deposited film changes to crystalline structure after thermal cycling. The crystalline film consists of V₂O₅ and a little of VO₂. A reversible semiconductor–metal phase transition, with decrease of electrical resistance in a factor of 10³, is observed at temperature about 230°C during the heating process. An obvious thermal hysteresis in electrical resistance is observed during the thermal cycling. After thermal cycling, the transmittance of the film decreases, but the refractive index and extinction coefficient increase, which are the results of structural change from amorphous to crystalline phase.
E.M. Guerra et.al [53] investigated the effect of pore structure on the behaviour of lithium intercalation into an electrode containing porous V₂O₅ film and compared with the electrode containing a non-porous V₂O₅ film. X-ray diffraction patterns indicate a lamellar structure for both materials. Nitrogen adsorption isotherms, t-plot method, and SEM show that the route employed for the preparation of mesoporous V₂O₅ was successful. The electrochemical performance of these matrices as lithium intercalation cathode materials was evaluated. The porous material reaches stability after several cycles more easily compared with the V₂O₅ xerogel. Lithium intercalation into the porous V₂O₅ film electrode is crucially influenced by pore surface and film surface irregularity, in contrast with the non-porous surface of the V₂O₅ xerogel.

X.Wei et.al [54] synthesized a series of cathode materials for lithium-ion batteries with the formula (MoO₃)₁₋ₓ(V₂O₅)ₓ (x = 0.00, 0.01, 0.02, 0.03, 0.04) were synthesized by high-temperature solid-state method. The effects of V₂O₅ on the structural, morphology and electrochemical properties of the cathode materials were investigated through XRD, SEM, charge–discharge test, CV and electrochemical impedance spectroscopy (EIS) experiments. The results show that cathode materials exhibit better electrochemical performance after V₂O₅ doping. (MoO₃)₀.₉₈(V₂O₅)₀.₀₂ shows the highest first discharge capacity of 280.6 mAhg⁻¹ and the best cycling reversibility.

X.Jiang et.al [55] prepared homogeneous and transparent V₂O₅–TiO₂ composite nanometer thin films were prepared on glass substrates by sol–gel processing and dip-coating technique. The films as well as the dried powder of bulk gel were characterized by different techniques like XRD, high-resolution scanning electron microscopy (HRSEM), atomic force microscope (AFM) and thermogravimetry–differential thermal analysis (TG–DTA). The hydrophilicity of the films was determined by measuring the water contact angles on the films. The results showed that the dopant of V₂O₅ on TiO₂ thin films could produce a visible-light response to the films, and the introduction of V₂O₅ could suppress the structural phase transition and crystal growth of TiO₂ crystal. Finally, the relationship between crystalline size and hydrophilicity under sunlight was investigated in this article.
1.7 Scope of the present work

Several reports have been available on the preparation of SnO$_2$ nanostructures through physical and chemical methods and applied it as an anode material for lithium ion batteries consists of non aqueous electrolyte solutions. Theoretically, a tin oxide anode can give a maximum charge-storage capacity of 781 mAh g$^{-1}$, which is about twice the theoretical capacity of carbon anode. However only few reports are available on the use of SnO$_2$ electrodes as anode material in aqueous lithium-ion batteries. Hence we have analysed electrochemical performance of electrodeposited SnO$_2$ thin films in different aqueous electrolyte solutions.

In this present work, we have prepared different nanostructures of SnO$_2$ on anodized copper substrates through electrodeposition method. Its structural, compositional and morphological analysis is carried out by XRD, FTIR, Raman and FESEM analysis and we have investigated its electrochemical properties through cyclic voltammetry and chronoamperometry analysis. There have been more limitations experienced in preparing electrode materials for lithium ion batteries through conventional slurry preparation method. However, there has been few research conducted on coating active materials directly on current collector substrates. Therefore, we have reported the results on electrodeposition of active SnO$_2$ materials directly on current collector substrates at different optimized conditions in the present work. The SnO$_2$ electrode can be applied as anode for aqueous lithium ion batteries. Ascorbic acid (AA) is an electroactive compound that can be easily oxidized on the electrode, so the electroanalysis of AA based on electro-oxidation has been proposed. One of the objectives of the present study is to determine the Ascorbic acid (AA) at high concentration. The results show that nanostructured SnO$_2$ thin films were more selective towards the oxidation of AA.

The vanadium pentoxide xerogel (V$_2$O$_5$,nH$_2$O) matrix has been widely studied as host material over the last years. Several of its properties, such as being an important cathodic material for secondary lithium batteries, have been attracting the attention of researchers. We have also reported results on sol-gel dip coated V$_2$O$_5$ nanostructures and its electrochemical performances.
1.8 Organization of the thesis

This thesis is divided into eight chapters,

**Chapter-I**, provides outline about nanotechnology and nanomaterials and its synthesis approach. Essential of aqueous Lithium ion batteries, improvements needed in anode and cathode, crystal structure of SnO$_2$ and V$_2$O$_5$ and its application in lithium ion batteries is also discussed. A detailed literature survey is furnished along with the scope of the work.

**Chapter-II**, deals about experimental and characterization methods applied to prepare nanostructured SnO$_2$ and V$_2$O$_5$ thin films and also the instrumental techniques used for characterizing the synthesized material.

**Chapter-III**, describes the anodization process and influence of deposition voltage on the morphology of nanostructured SnO$_2$ thin films. FE-SEM, FTIR, Raman, XRD, EDX, and UV-Visible analysis results of SnO$_2$ thin films are interpreted and discussed. In addition electrochemical performance of the SnO$_2$ electrode is investigated in detail by cyclic voltammetry and chronoamperometry analysis.

**Chapter-IV**, explains the influence of bath temperature on morphology of nanostructured SnO$_2$ thin films. Also the electrochemical performance of each SnO$_2$ nanostructures in different aqueous electrolytes LiOH.H$_2$O, Li$_2$CO$_3$, Li$_2$SO$_4$, LiNO$_3$ and Na$_2$SO$_4$ are discussed well.

**Chapter-V**, explains the influence of supporting electrolyte on morphology of nanostructured SnO$_2$ thin films. Also the electrochemical performance of each SnO$_2$ nanostructures in different aqueous electrolytes LiOH.H$_2$O, Li$_2$CO$_3$, Li$_2$SO$_4$, LiNO$_3$ and Na$_2$SO$_4$ are conversed well.

**Chapter-VI**, gives out the selective determination of ascorbic acid (AA) at the surface of nanostructured SnO$_2$ thin films. Proposed reaction mechanism of SnO$_2$ with AA is discussed and the electrochemical detection of AA is analysed by cyclic voltammetry (CV) and differential pulse voltammetry (DPV) techniques.
Chapter-VII, deals with sol-gel dip coating, characterization and electrochemical properties of nanostructured V$_2$O$_5$ thin films. The overall summary and conclusion has been presented in Chapter-VIII.
1.9 References


