Background and present study

1.1 Introduction

Thin film science was possibly started as early as in 1852 when Grove [1] formed metal films by sputtering method. Since then, it has grown to be a full grown academic discipline today with lots of application in industry as well as in household appliances. It is also used in many active and passive elements like storage of solar energy, piezo-electric device, catalytic material, sensor elements, reflecting and anti-reflecting coatings [2] etc. Thin films are preferred over their bulk counterpart due to reliability, performance, compactness, lower cost and mostly they show some special characteristics, due to low dimensionality which is absent in bulk. Properties of thin films depends not only on their structures but also depends on the growth process, the substrate on which it is grown and the thickness of the film [3,4]. A solid material extended up to infinity in two direction (x, y) and limited in other direction (z) is known as thin films. The thickness of thin films can be from few Angstroms to many micrometers depending on the nature of studies. Depending on the thickness, thin films can be divided into three categories- (1) ultrathin, (2) thin and (3) thick films. Films having thickness between few Å to 100 Å are ultrathin films whereas, 100-1000 Å thick films are of second category. Typically, thick films have thickness greater than 1000 Å or so. Though a precise definition of ultrathin film is not easy, but generally the film thickness is below some characteristic length scale
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of the material, such as the mean-free path of electrons, the spin diffusion length, the electron-hole mean recombination length, the magnetic domain wall widths etc. so that new phenomenon starts to occur. In this thesis, mostly ultrathin films, grown in ultra high vacuum (UHV) are discussed with a chapter covering thin films grown in ambient condition. In recent times, metallic, intermetallic and oxide materials are studied by growing as a thin films which is eventually incorporated for application purpose.

On the other hand, research on two-dimensional (2-D) materials is on the rise in the last decade [5–7] after the discovery of graphene [8]. Materials with sizeable band gap and high mobility has huge applications in electronics and optoelectronic devices [9,10]. 2-D materials can be of different type such as, (1) transition-metal dichalcogenides (TMDs) (such as MoS$_2$, MoSe$_2$, WS$_2$, WSe$_2$, ZrS$_2$,ReS$_2$), (2) hexagonal BN (h-BN), (3) X-ene (graphene, silicene, germanene and stanene), (4) black phosphorus (b-P, i.e., phosphorene), (5) group IIIA chalcogenides (such as GaS, GaSe) and (6) group IVA dichalcogenides (such as SnS$_2$). Out of these, stanene is the newest entry into the list [11]. Stanene is single, hexagonal layered material of tin similar to graphene. The experimental realization of stanene on Bi$_2$Te$_3$(111) surfaces was reported recently [12]. Since then research has been going on forming stanene on different substrate and tuning it for application purposes. This thesis also include study on the growth of tin metal on different substrates keeping in mind the stanene study, particularly after the theoretical report that stanene may be formed on Au(111) [13]. Tuning the band gap is of great importance to engineer the performance of 2D-material based devices. Alloying among different material is one of the process which is important for tuning the electronic structure as well as the lattice parameters [14]. Metallic thin films, on the other hand, may form surface alloy with the substrate even in those cases where no bulk alloy formation is possible. These thin films form new structures which is not only interesting from a fundamental point of view but also has wider applications too [15].

1.2 Alloying and tin metals

Alloying, perhaps is the oldest discoveries of the mankind with bronze being discovered some 3000 years ago. In modern times, alloys help the mankind in technological
advancement in science. Alloying allows to create materials with new properties, starting from increased hardness of steel to tuning electronic properties to enhance the Rashba effect in surface alloys [15]. Alloys, mainly the noble metal alloys are also extensively used in catalysis [15, 16]. Bulk alloys have been studied more extensively compared to the surface alloys [14] due to the difficulties in producing high quality surface alloys. However, with the advancement in ultrahigh vacuum (UHV) and thin film technology, growth of good quality surface alloys are possible. The detailed structures of these surface alloys is probed with surface sensitive structural techniques such as Low Energy Electron Diffraction (LEED), Scanning Tunnelling Microscopy (STM) while their detailed electronic structures are studied using X-ray Photoelectron Spectroscopy (XPS), Angle Resolved Photoemission Spectroscopy (ARPES). Tin (Sn) and its alloys have been at people’s service since 3000 BC when bronze (alloy of tin and copper) was produced in large scale.

Industrial applications of tin and its alloys have been on the rise in the last few decades making it one of the largest used alloy material. Sn is rarely used in pure form because of it’s softness. Rather, it is used mostly as an alloy or a compound. According to a report by international tin research institute (ITRI) [17], use of tin increased form 166,500 tonnes in 1950s to 314,500 tonnes in 2000s becoming almost double. Though currently tin is mostly used in soldering and tin plating, but use in chemical industry/research is increasing [17]. The non-toxic nature, superior corrosion resistance and attractive appearance have made Sn a very popular material for plating and surface finish. Over 90% of world production of tinplate is used to manufacture containers (tin cans) for packaging of food products and soft drinks, motor oil, disinfectants, detergents and polishes. Steel coated with Sn-Pb alloy, known as Terneplate, is used in roofing and weather sealing material due to it’s strength, corrosion resistance and good thermal resistance. Sn alloys are also used in the automotive industry where good resistance to wear and corrosion is required in disc brake pistons, hydraulic breaking mechanisms, piston rings etc. On the other hand, Sn chemicals covers almost half the total chemical usage in different industries. Tin finds applications in air purification systems, next generation solar cells, binary oxide catalysts, production of bio-diesels and hydrogen, to name a few [18].

There are only a few reports of the study of epitaxial tin films in the literature due to the fact that tin forms alloys with most metallic substrates. Epitaxial Sn
films were grown on Si(111) [19–21], CdTe(111) [22], (001) and (111) surface of InSb [23–25] as inter-diffusion is very less for these systems. Sn forms in two phases, a semiconducting phase with diamond structure below 286.2 K known as $\alpha$-phase and a metallic $\beta$-phase with a tetragonal structure which exists above this temperature. Mainly, $\alpha$-Sn was grown on silicon substrate which finally transform towards $\beta$-Sn islands [21]. Sn films grown on InSb(111) was reported to have $\alpha$-Sn phase whose stability depends on the thickness of the films [26]. On the other hand Sn is reported to form alloy with noble metal surfaces viz., platinum, copper and gold on both (001) and (111) surfaces. In most of the cases for growth on these metal surfaces, Sn incorporates in to the substrate forming alloy structure rather than forming an overlayer structure due to the high solubility of Sn in these substrates. Generally, a true 2-D alloy phase is formed for one-third monolayer of Sn in Cu(111) [27–29], Au(111) [30], Ni(111) [28,31], Pt(111) [28,32], Ag(111) [33], Rh(111) [34] forming a $(\sqrt{3} \times \sqrt{3})R30^\circ$ surface structure and one-quarter monolayer of Sn in Cu(001) [27,29,35], Au(001) [30], Ni(001) [36,37] etc. forming $p(2 \times 2)$ or $c(2 \times 2)$ structure. This is the reason that epitaxial films of Sn was only reported on InSb or CdTe and no epitaxial or even thin films of pure metallic Sn phase is reported on noble metals. However, It is also reported that for systems like Sn on Cu(111) [38] there is no alloy formed as for Sn on Au(111) no alloy formation was observed at low temperatures [30]. For Sn on silver, it is poorly studied and only 1/3 ML case is studied on Ag(111) [33]. It is still unexplored the growth mode for higher coverage whether non-alloying can be observed. So, is the aim of this thesis to explore the studies on Ag(001) and Ag(111) for higher coverages. This is the motivation to study these systems for my thesis.

Experimental study of deposition of Sn is well reported on different (111) surfaces where $(\sqrt{3} \times \sqrt{3})R30^\circ$ type of surface alloy has been observed. In most of the cases, it was only reported for sub-monolayer to monolayer thick films as the said pattern can be seen for one third monolayer where Sn atoms replace every third substrate atom from the substrate surface. The alloy surface is rumpled in most of the cases due to the atomic size mismatch. Buckling of even 0.5 Åwas reported for Sn growth in Ni(111) [28] which was attributed to the larger size of Sn atoms compared to Ni atoms. Similar buckling was also observed for Sn growth on Ni(001) [39]. This alloy surface is shown to be formed at RT and is stable up to 1000 K. Study of the alloy structure is also motivated by the fact that Rashba-type spin split bands are observed
for Bi, Sb, Pb [40–42] on Ag(111). The splitting is found to increase with increasing atomic number. So the motivation to grow Sn on Ag(111) was to see whether any spin-split bands could be detected for this system. An earlier study did attempt this and could not observe any spin-split bands even though this study was limited only to 1/3 ML coverage of Sn on Ag(111) [33]. Though Auger electron spectroscopy (AES) and XPS measurements were reported for some of the alloy systems named earlier but detailed electronic structure, mainly valence band structure for these system is less characterised.

Experimental study of deposition of Sn on (001) face of the noble metal is less studied compared to growth on (111) face. Though Sn deposition is studied on different substrates like Au(001), Ni(001) but it is Cu(001) which dominates the growth study for Sn. In case of Sn growth on Au(001), it was suggested that a 2D surface alloy with surface composition close to AuSn forms during initial stages of growth [30]. When Sn is deposited on to Ni(001), an ordered stable c\((2\times2)\) 2D Sn-Ni surface alloy is formed even at a growth temperature of 250 K for a coverage of 0.5 ML [36]. Even for higher coverages, this surface alloy is found to be stable when the surface is annealed to higher temperatures (600-900 K). The Sn atoms are found to be buckled above the Ni plane by about 0.44 Å by Li\(^+\) scattering studies [36]. In case of Sn growth on Cu(001), the structural evolution in the submonolayer region was first undertaken by Argile and Rhead [27] and identified four distinct phases, namely \(p(2\times2)\) (for 0.2 ML), \(p(2\times6)\) (for 0.33 ML), \((3\sqrt{2} \times \sqrt{2})R45^\circ\) (for 0.5 ML), \(c(4\times4)\) (for 0.65 ML). Subsequently, atomic and electronic structure of each of these phases were studied in detail [43–47]. So from structural point of view, growth of Sn on face centred cubic (fcc) (001) substrate is more complex than (111) face where only a single phase is reported.

There have been numerous attempts to find the analogs of ‘graphene’ for other elements in this group. Monolayer (ML) of hexagonally arranged tin atoms, called ‘stanene’ is the latest addition in that list after silicene and germanene. It was predicted that stanene is a topological insulator and may display dissipationless currents at its edges near room temperature [11]. Soon after that attempts were made to grow stanene experimentally. Though topological behavior of Sn based thin films were established experimentally on InSb(001) surfaces [25,48], the first observation hexagonal tin monolayer was reported very recently by Zhu et al. [12] on
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Bi$_2$Te$_3$(111) surfaces [12]. Recently, it was also predicted theoretically that stanene can be realized on top of Au(111) surfaces [13]. Hence, it is important to study the detailed growth mechanism of Sn on noble metal surfaces.

Sn growth on (001) and (111) faces of fcc substrates gives rise to alloy formation where Sn atoms incorporates into the surface of the substrate. The scenario changes when Sn is grown on Mo(110). It is reported that layer-by-layer growth occurs for the first two layers of Sn on Mo(110) after which a 3D island growth proceeds [49,50]. Alloy for this systems can only be seen at temperatures higher than 800 K. In contrast to noble metals the problem of intermixing is greatly reduced in case of refractory metals like Mo(110). So, tungsten, another most used refractory metal with a body-centered cubic (bcc) structure, is an interesting case for studying the growth of Sn without any alloying with the substrate. Surprisingly, there is no study available for the growth of Sn on W(110) which in the literature which motivated us to look into this case also. The high melting point and absence of intermixing with the overlayer makes it an interesting case to study. Moreover, tungsten has a large spin-orbit coupling compared to the Mo(110) case, which may be used to modify the electronic properties of the overlayers and may yield large Rashba-type spin split bands.

As mentioned before, there have been some studies of Sn growth on noble metal surfaces, especially on Au and Cu. However surprisingly, there is almost no report available on the growth of Sn on widely used substrate material as silver. There is a single report of 1/3 ML Sn growth on Ag(111) while no report is available on the Sn growth on Ag(001). This was the main motivation for me to explore the detailed growth process and mechanism of Sn on Ag(001) and Ag(111) at room temperature as well as at elevated temperatures. Similarly, another system studied is the Sn growth on W(110), where there is no reported growth is available in the literature. Thus, one of the main emphasis of this thesis is to perform growth of metallic Sn on these substrates from sub-monolayer to thick coverages and to study the underlying growth mechanisms and their electronic structures after the suitable growth optimization processes using suitable surface sensitive electron spectroscopic techniques such as LEED, XPS and ARPES.
1.3 Oxide Surfaces

Almost all metal surfaces are covered by a native oxide layer due to the oxidation of the metal with ambient oxygen. It is this oxide layer that governs the surface characteristics of the metal than the metal itself for most of the common application. For example, surface reactivity, surface diffusion, lubrication property of a metal is largely influenced by the oxide layer present on that metal. This is the reason that oxide surfaces need to be studied in detail for understanding their surface properties. However, oxide surfaces are less explored than the metal and semiconducting surfaces [51,52] even though oxides cover almost all aspect of material science and physics. Oxides play an important role in material science such as from superconductors to insulators, from covalent to highly ionic and having applications in different fields like paint pigment, non-linear optics, microelectronics, data storage, sensors and catalysis [53] etc. Issues related to oxide surfaces, like their surface reactivity of oxide surface, electronic properties, mechanical properties are still unexplored for many oxides. This lack of scientific studies of oxide surfaces are mainly due to the difficulties in preparing oxide surfaces and also due to the insulating nature of most of the oxide surfaces. The first difficulty was overcome to a large extent by using thin film growth techniques by which a wider range of the oxide surfaces can be grown. The issue of non-conducting surfaces can be overcome by choosing an appropriate metal substrate where the ultrathin film of the oxides can be deposited and can be studied using surface sensitive electron spectroscopic methods. In this thesis two oxide surfaces namely, tin oxide and nickel oxide will be studied.

1.3.1 Tin oxide

Tin oxide is an interesting candidate for study. Tin forms two oxides, stannous oxide (SnO) and stannic oxide (SnO$_2$), as Sn can have dual valency of 2$^+$ or 4$^+$. This dual valency is responsible for the variation of surface oxygen composition. This type of variable valency is well known to occur for other oxides as well like iron oxide [54], vanadium oxide [55] etc. This variation of surface composition however is general for oxides and may be user to tune the surface composition to achieve different chemical properties. Still, the surface properties of tin oxide is relatively unexplored
in comparison to similar oxide systems such as TiO$_2$ \cite{56}, NiO \cite{57,58}, CoO \cite{59,60}, iron oxides \cite{54} etc. This is mainly due to the non-availability of large single crystals of both stannic and stannous oxides. Though single crystals of SnO$_2$ were prepared in the past but they were very small in size and only recently there is a report of large SnO$_2$ bulk single crystal growth using physical vapor transport \cite{61}. Once this initial problem was fixed with the help of technological advancement mainly using thin film technique tin oxide films were made. Even though polycrystalline thin films of tin oxides were prepared using thin film deposition methods, however, it was not easy to differentiate between the stannic and stannous oxides as there is very small shift in the binding energies of the XPS core levels.

Stannous oxide is much less explored than stannic oxide. In fact there are only very few reports available for epitaxial SnO films. Krasevec \textit{et al.} \cite{62} reported first epitaxial growth of SnO film on sodium chloride while another report of epitaxial SnO film on sapphire was reported by Pan \textit{et al.} \cite{63}. However, in both these cases the epitaxial nature was not studied by LEED or reflection high-energy electron diffraction (RHEED). But there are almost no reports of epitaxial SnO in recent times though there are some theoretical studies have been done on SnO \cite{64-67}. However, oxidation of Sn-noble metal alloy surface gave rise to SnO as one of the phases \cite{68-70}. Other phases of tin oxide were also reported for these alloy systems. In the literature, many authors have used SnO$_x$ to represent the tin oxides as the exact ratio between different phases are not often known or to represent the non-stoichiometric nature of tin oxides. This notation will also be used in this thesis. In case of Sn/Pt(111) surface alloy \cite{69}, oxidation by NO$_2$ gas gave rise to SnO$_{1.5}$ at 900 K which is an intermediate state between SnO and SnO$_2$. Seko \textit{et al.} \cite{71} predicted the existence of SnO$_{2-x}$ intermediate tin oxide phase theoretically by using cluster expansion technique combined with first principles calculations. Batzill \textit{et al.} \cite{68} also did not observe any pure SnO$_2$ phase while oxidising Sn/Pt(111) alloy surface. However, they observed two tin oxide phases, one being the SnO pseudomolecules at preferential sites and other an incommensurate tin oxide overlayer. They also noticed LEED pattern corresponding to regular stress relief pattern which transforms into ordered array of tin oxide islands. It was also reported that even small variation in the amount of tin and oxygen or different alloying condition at the interface of the substrate and tin leads to different kind of tin oxide formation which is stoichiometrically
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different. However, at elevated temperatures epitaxial tin oxide formed following
Stranski-Krastanov (SK) growth mode was confirmed as SnO$_2$ [72]. However, there
are very few studies of co-evaporation (or reactive deposition) of tin in oxygen
atmosphere which is a more general process for the growth of metallic oxides. Tin
oxide has been grown by reactive deposition method in this thesis and compared it
to the tin oxide growth by oxidising the alloy surface. Here, we have performed the
tin oxide growth on Ag(001) and Ag(111) substrate surfaces at room temperature
as well as at elevated temperatures from sub-monolayer to thick film coverages and
have studied their surface structure and electronic structure using LEED, XPS and
ARPES spectroscopic methods.

1.3.2 Nickel oxide

Transition metal oxides constitute probably one of the most interesting classes of solids,
exhibiting a variety of structures and properties. The nature of metal oxygen bonding
can vary from nearly ionic to highly covalent. The unusual properties of transition
metal oxides are clearly due to the unique nature of the outer d-electrons. The late 3$d$
transition metal monoxides (MnO, FeO, CoO, NiO) are particularly important thanks
to their appealing properties such as relatively high Neel temperature, chemical and
mechanical stability, low lattice mismatch with respect to the corresponding magnetic
metals and their alloys, and their large electronic gap. Out of these monoxides, NiO
is the most studied system as its optical properties, electronic structure and magnetic
structure have drawn a lot of scientific studies even though it has relatively simpler
rocksalt (NaCl) structure. Nanoparticle and single crystal of NiO was already studied
in our group with special emphasis on antiferromagnetism shown by NiO [57, 73–75].
This work was further extended to the studies of epitaxial NiO thin films by another
group member [76–79]. The growth process of nanoparticles and ultrathin films
in UHV, their magnetic structure as well as electronic structures were studied in
details. All the previous studies performed in our group previously with NiO films
were prepared by reactive deposition of nickel in oxygen environment in a UHV
chamber. After studying the NiO thin film system, as a next step, we wanted explore
the application of these films for resistive random access memory (RRAM) device
structures on silicon wafers in order to be integrated with the silicon technology.
NiO thin films have been prepared by different methods namely, evaporation in UHV [79], sputtering [80], electrodeposition [81], thermal decomposition [82] and sol-gel technique [83]. Out of all these, the sol-gel method were found to be the most suitable for simple and cost-effective production of NiO films on silicon substrate for the RRAM application.

The resistive switching phenomenon in oxides was first reported in the 1960s [84]. This phenomenon in binary transition metal oxides (TMO) has received considerable attention because of the potential application in non-volatile memory devices that combine rapid read and write speeds, high storage density and non-volatility [85]. Since Samsung demonstrated NiO memory array integrated with the 0.18 µm silicon CMOS technology in 2004 [86], research activities have been focused on binary oxides. NiO is suitable candidate for this due to its simple constituents, clear switching characteristics and a high on/off ratio. Generally speaking, there are two types of resistive switching memory. One type is based on the conductive filaments (CF) of oxygen vacancies (V<sup>•◦</sup>) and the other type is CF of metal atoms. In this thesis we will keep our discussion limited only to oxygen vacancy driven resistive switching. Let us first introduce some basic concepts of oxide RRAM. The switching from high resistance state (HRS) to low resistance state (LRS) is called the “SET” process. Conversely, the switching event from LRS to HRS is called the “RESET” process. Usually for fresh samples in its initial resistance state, a voltage larger than the set voltage is needed to trigger on the resistive switching behaviors for the subsequent cycles. This is called the “FORMING” process. The switching modes of the oxide RRAM can be broadly classified into two switching modes: unipolar and bipolar. Unipolar switching means the switching direction depends on the amplitude of the applied voltage but not on the polarity of the applied voltage. Thus SET/RESET can occur at the same polarity. If the unipolar switching can symmetrically occur at both positive and negative voltages, it is also referred as a non-polar switching mode. Bipolar switching means the switching direction depends on the polarity of the applied voltage. Thus, SET can only occur at one polarity and RESET can only occur at the reverse polarity.

Although switching behaviour of NiO was known from 1960s [87], there are several questions still remain unanswered. Since then, it is being extensively studied and used in RRAM devices [88–90]. There are still controversies regarding the
position of the resistive switching (RS) occurring in the NiO film with some reports claiming it at the anode interface [91] while some others reported at the cathode interface [92]. NiO always exhibit an excess of oxygen or in other word Ni deficiency. As a result of which it is not easy to prepare stoichiometric NiO. Extra oxygen cannot be placed inside the NaCl structure of NiO. Thus, Ni vacancies are created making it a p-type semiconductor [93]. Due to the presence of metal vacancies instead of oxygen vacancies in NiO, the switching mechanism of the n-type oxides like TiO$_2$ is not applicable in this case. In addition, if oxygen ions are lost due to the redox reaction at the anode interface, Ni interstitial may also be formed and these can participate in the filament formation process. NiO has no stable suboxide phase, and it is likely that the filament is made of a metallic Ni chain. On the other hand, silicon is the most popular substrate in microelectronics and microelectromechanical system. Recently, Choi et al. [94] reported that for NiO/SiO$_2$ system the operation voltage depends on the thickness of the SiO$_2$ layer and it increases with increasing thickness. Resistive switching observed in this case is due to the filaments formed in the SiO$_2$ layer. So the switching voltage is tunable and can be optimized by controlling the thickness of the SiO$_2$ layer. Chou et al. [95] showed that the electrical conductivity of the NiO films grown by metallo-organic chemical vapor deposition on SiO$_2$ is due to presence of a metal-like electron density from the Ni clusters formed by partial reduction of NiO. So it is important to study the thickness effect of the SiO$_2$ layer in the NiO/Si assembly as any silicon substrate has a native oxide layer and that oxide layer has an important role to play for the NiO switching behaviour. Keeping this in mind, the detailed thickness and interface effect is taken up in this thesis whereas current-voltage ($I$–$V$) characteristics is also studied using a Ag/NiO/ITO assembly.

1.4 Overview of the thesis

This thesis is divided into seven chapters including this chapter on background study. A chapter-wise summary of the thesis with the important findings are given below:

**Chapter 2** presents a general introduction to various experimental techniques used for the investigation of the metallic/oxide thin films and surfaces studied in this thesis. The different techniques used to clean the surface and the *in situ* structural characterization of the surface using LEED have been discussed. The basics of
photoemission, ARPES, theory behind the ARPES technique, different modes of ARPES data collection are also summarized. Since the above mentioned techniques are very surface sensitive due to the short inelastic mean free path of the electrons, all the experiments were performed in UHV. X-ray scattering technique, which is used to study the nickel oxide thin films has been discussed in details. The instrument developments performed at the laboratory and at the beamline during my Ph. D. tenure are also summarised in this chapter with initial experiments.

Chapter 3 has been devoted to the detailed growth of Sn metal on Ag(001). The growth of Sn on Ag(001), both at room temperature (RT) and at high temperature (HT) are discussed in details with the help of LEED and XPS results. The surface structural evolution in both the cases are discussed from the LEED data. The electronic structure of the the grown sample is also discussed. The formation of Sn-Ag alloy as well as Sn layer are also reported in this chapter. Finally a comparative discussion is presented for RT and HT growth mode.

Chapter 4 deals with the growth of Sn on Ag(111) substrate. The growth mode for both RT and HT are discussed in detail. The surface structure of the Sn/Ag(111) is discussed with the help of LEED and XPS data whereas, the electronic structure evolution is discussed with the help of ARPES data. Specially, the surface and electronic structure for thick films beyond 1/3 ML coverage is reported for the first time in this system.

Chapter 5 summarizes the results on Sn metal films grown on W(110) at RT as well as at HT which is comparatively higher temperature than the growth temperature of Sn on silver. This chapter contains detailed discussion on the growth mode of Sn on W(110) with the main focus to check the pseudomorphic growth. Evolution of the electronic structure, mainly the W(110) Dirac state is discussed with the help of ARPES data.

Chapter 6 gives a review on growth of tin oxide ultrathin films on different silver single crystal substrates, Ag(001) and Ag(111). The oxide growth and the evolution of surface structure are discussed in detail. The temperature dependent growth mode is also covered in this chapter. A comparative study of the growth by two different modes namely reactive deposition of tin in oxygen environment and oxidation of the Sn-Ag alloy surface is presented.
Chapter 7 covers the preparation of nickel oxide thin films by cost-effective wet chemical route. The structure of NiO thin film grown on silicon substrate studied using x-ray scattering method is discussed in addition to the x-ray photoelectron spectroscopy and atomic force microscopy data. The current - voltage (I-V) study, keeping in mind the application of NiO films for the resistive random access memory (RRAM) device application is presented in details.