Thin films of mononuclear phthalocyanine (FePc, CoPc and F_{16}CuPc) and binuclear phthalocyanine (Co-Fe)Pc were deposited by MBE with a perfect control over growth parameters such as deposition rate, substrate temperature and film thickness on different substrate i.e. (0001) Al_{2}O_{3}, (001) LaAlO_{3}, (100) SrTiO_{3} quartz and ITO. The growth temperature and deposition rate were respectively, 200°C and 2Å/s. Binuclear (Co-Fe)Pc films were found to grown only on (0001) Al_{2}O_{3} substrates at 200°C if deposited using the CoPc/FePc mixture in 1:1 (w/w) ratio. Thin films of CuPcTs were also prepared using drop casting method. In addition all grown films were characterized by various techniques such as, SEM, AFM, GIXRD, UV-Vis, FTIR, Kelvin probe and Raman Spectroscopy. Formation of binuclear (Co-Fe)Pc was confirmed by MALDI mass spectroscopy. The charge transport properties of grown films were investigated by measuring the temperature dependent $J-V$ characteristics as well as resistivity in the temperature range 300-25 K. Also, the suitability of the grown films was examined for their possible application as chemiresistive gas sensors.

In addition $p$-$n$ heterojunction comprising of $p$-type (CoPc) and $n$-type (F_{16}CuPc) as well as $p$-type (CoPc) and $p$-type (FePc) were fabricated using MBE. The charge transport properties of these films were also investigated.
The major conclusions are already presented at the end of each chapter. Here we make a summary of the main results obtained during the thesis work.

1. It has been demonstrated that mononuclear FePc, CoPc and binuclear (Co-Fe)Pc films grow with molecules face-on stacking on (0001) Al$_2$O$_3$ substrate due to the interaction between molecule and of Al terminated surface. AFM and GIXRD studies revealed that (Co-Fe)Pc phthalocyanine films have better structural ordering and hence smooth morphology as compared to the mononuclear films. This is attributed to the additional dipole moment of binuclear (Co-Fe)Pc molecules, which results better face-on stacking as compare to the mononuclear CoPc and FePc films.

2. Due to the better structure ordering the binuclear (Co-Fe)Pc films exhibited $\mu \sim 110$ cm$^2$/Vs, while in case of CoPc and FePc films mobility were found to be 5.3 and 1.1 cm$^2$/Vs.

3. The temperature dependence of resistivity of binuclear (Co-Fe)Pc films exhibited metallic behavior in the temperature range 300K-25K which is the manifestation of the improved ordering also. The $J$-$V$ characteristics of binuclear (Co-Fe)Pc films exhibited trap-free SCLC in the temperature range 300K to 25K. For CoPc and FePc films the temperature dependent resistivity showed that, these films are in the critical regime of metal–insulator transition. The $J$-$V$ characteristics of mononuclear films exhibited SCLC with exponential distribution of traps at low temperature.

4. The temperature dependent $J$-$V$ characteristics of FePc films have also been investigated at very high bias i.e. in the bias range of ± 200 V. In the temperature
range of 300 K–30 K, the charge transport is governed by bulk-limited processes with a bias dependent crossover from ohmic ($J \sim V$) to exponentially distributed shallow trap mediated space-charge-limited conduction ($J \sim V^\alpha$, $\alpha \geq 2$) to space charge limited conduction with field enhanced mobility ($\ln \mu \sim E^{1/2}$). However, at temperatures < 100 K, the charge transport is governed by electrode-limited process, which undergo a bias dependent transition from Schottky ($\ln J \sim V^{1/2}$) to multistep-tunnelling (MUST).

5. In the case of CoPc films grown on (100) SrTiO$_3$ substrate, it has been demonstrated that the molecule stack in edge-on configuration. The temperature dependence of resistivity exhibited semiconductor to like transition at ~110K. XRD measurement revealed that this transition is due to in-plane compressive strains induced by structural phase transition (from cubic-to tetragonal ~ 110K) of SrTiO$_3$ substrate reduce the intermolecular distance.

6. Charge conduction in FePc films under high electrical field has been investigated. A bias dependent transition from ohmic to space-charge limited conduction to space charge limited conduction with field enhanced mobility is observed. At temperatures <100 K, by analyzing the low bias (< 100 V) data, which is governed by Schottky–barrier limited conduction. However at higher bias multistep tunnelling was observed in the FePc films.

7. Structure and morphology of water soluble phthalocyanine (CuPcTs) films prepared by drop casting method were found to be independent of substrate, and have usually amorphous character. We demonstrated that below 280K these films do not transport any current.
8. The gas sensing characteristics of CuPcTs, CoPc, FePc and (Co-Fe)Pc films has been investigated. CuPcTs films exhibited room temperature ppb level Cl\textsubscript{2} gas sensitivity. Selectivity, repeatability, stability and linearity (sensitivity vs concentration) in the range 5 ppb to 2000 ppb are investigated. The chemical adsorption process of Cl\textsubscript{2} on CuPcTs has been analyzed using Elovich equation, which provides an alternative way of qualifying Cl\textsubscript{2} concentration from response rate of sensor. The Cl\textsubscript{2} gas sensing properties of FePc and CoPc films were investigated. The highest sensitivity was obtained at 170°C. It was found that CoPc and FePc films can detect 10 ppb of Cl\textsubscript{2} gas. Due to the high mobility of (Co-Fe)Pc films, they exhibited enhanced response for Cl\textsubscript{2} gas, which is about 16 and 13 times higher than that of FePc and CoPc films. Interestingly, it was found that (Co-Fe)Pc films can detect even 5 ppb of Cl\textsubscript{2} gas.

9. The $p$-$n$ heterojunction comprising of $p$-type CoPc (20nm) and $n$-type F\textsubscript{16}CuPc (20nm) heterojunctions showed ohmic conductance with three order of magnitude higher conductivity as compare to individual CoPc or F\textsubscript{16}CuPc layer. The higher conductivity F\textsubscript{16}CuPc(20nm)/CoPc(20nm) heterojunction is due to the charge carrier accumulation at the interface, which is confirmed by Kelvin probe study. The thickness of charge carrier accumulation layer at the interface was estimated to be ~20 nm. Interestingly these heterojunction films exhibited reverse rectification behavior i.e. conducts current only in reverse bias. On the other hand, CoPc(20nm)/FePc(20nm) ($p$-$p$ type) heterojunction films do not exhibited any charge transfer at the interface. Therefore their electrical properties are identical to the individual layers.
Future Plan

In the present thesis work, we have obtained higher ordered CoPc, FePc as well as binuclear (Co-Fe)Pc films with record mobility $110 \text{ cm}^2/\text{Vs}$. In addition we have fabricated $p$-$n$ heterojunction with high conducting interface. These samples can be used for further investigated some of the possible examples are as follows:

1. Other metal phthalocyanines such as NiPc, CuPc, AgPc and ZnPc can be explored.

2. The magnetic properties of ordered binuclear films, along with the CoPc and FePc films can be investigated. In binuclear films, due to the interaction of two phthalocynine rings one can expect improved magnetic ordering. In addition high mobility binuclear films can be used for fabrication of field effect transistor.

3. The sensing properties of F$_{16}$CuPc/CoPc can be explored.