**Name of the candidate :** **Sunny Khan**

**Name of the Supervisor :** **Prof. Mohammad Zulfequar**

**Name of the Co-Supervisor :** **Prof. Mushahid Husain**

**Name of the Co-Supervisor :** **Prof. Harsh**

**Department :** **Physics**

**Tittle : Synthesis of Graphene using Chemical Vapour Deposition Method and its Characterisation**

---

## Abstract

A one atom thick planar sheet of $sp^2$ hybridised carbon atoms arranged in a hexagonal fashion makes the wonder material of the 21$^{st}$ century. This wonder material forms the elementary building block of graphite and termed as the graphene. Ever since its discovery in 2004, it has attracted the attention of numerous researchers. The present thesis has been organised into six chapters, the description of each chapter has been provided as under:

The ***chapter 1*** comprises of two sub sections. The section 1a, lays down the foundation of the thesis. In this chapter, research problem has been described with proper introduction of the topic i.e., nanotechnology in general and graphene in particular. It has set the aim of the thesis along with a glimpse of the techniques to be made use of, for the achievement of the stated aim. The second section namely, section 1b, provides an elaborate literature review pertaining to graphene.

The ***chapter 2,*** is an extension of section 1b, which specifically discusses the techniques employed during the course of research to achieve the research objectives i.e., growth of graphene, its characterisation and finally the applications. The graphene has been synthesised by three major techniques which include Low Pressure Chemical Vapor Deposition (LPCVD) method, Plasma Enhanced Chemical Vapor Deposition (PECVD) method and Hummers method. All the three have been amply explained along with the advantages and disadvantages. The sample characterisation has been done by Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Raman Spectroscopy. The optical studies have been performed using UV–visible spectroscopy. DC conductivity, Field Emission study have also been done for electrical and field emission studies.

***Chapter 3***, has been focused mainly on the LPCVD technique based graphene synthesis and further characterisations along with electrical and optical studies. The major work covered in this chapter can be enlisted as under:

- Synthesis of graphene over Cu coated Si and quartz substrates using LPCVD and its electrical and sensing studies
- Synthesis of graphene over Cu coated quartz substrates at varying temperatures using LPCVD method and their comparison by opto-electronic studies
- Synthesis of graphene over Cu foil
- Synthesis of graphene over Ni (Nickle) coated Si substrate

The above stated targets have been successfully achieved in the chapter. Single to few layered graphene films have been obtained using LPCVD method. The Cu has been found to be a better catalyst or substrate for synthesis of graphene as against Ni both as the catalyst film as well as foil. The substrate based studies also point towards quartz being a better substrate as compared to Si. This fact has been established by comparing several parameters like high free charge carrier concentration ~ $10^{17}$ $cm^{-3}$ in case of quartz substrate and having three orders of magnitude higher dc conductivity as compared to graphene grown over Si substrate. The same has been found to be a very good sensing material ( $H_2$ sensing) having a sensing response of 7.5%. The growth temperature based study of as grown graphene also suggests that the best quality graphene film has been obtained at 800°C over Cu coated quartz substrate having optical band gap of 3.98 ev and a very impressive transmittance of 97.2%.

The ***chapter 4***, is based on PECVD based graphene growth. The single to few layered graphene has been grown using PECVD with a fair degree of success and the same has been studied for field emission properties. The good quality, high purity, better controlled graphene growth has been observed through PECVD techniques that too at temperature as low as 600°C. The field emission studies also prove that graphene can be a very good field emitter. As current density of 2.4 $mA/cm^2$ and a field enhancement factor of 705 has been obtained for the as grown graphene samples.

The ***chapter 5*** deals with synthesis of graphene through chemical route which is often termed as r-GO (reduced graphene oxide). The Modified Hummers method has been used for the purpose. Furthermore, the as grown r-GO has been made nanocomposite with Ag nanoparticles termed as decoration of graphene. This type of decoration has aided to improved properties of reduced graphene oxide as far as electrical conductivity and activation energy is concerned. The optical studies using UV visible spectroscopy reaffirmed high optical transmittance of graphene based materials. Transmittance was found to be 90% for r-GO-Ag-NP an improvement of 20% point over r-GO (pristine). An improvement in the charge carrier concentration and reduction in optical band gap and decrement of Urbach's energy, on attachment of Ag nanoparticles to r-GO has been observed.

The ***chapter 6*** concludes the thesis in the light of earlier stated aims and objectives. It summarises the major achievements of the research work and also indicates towards future scope of the present work done.