**Study of Electrical and Optical Behavior of Metal and Metal Oxide Nanostructures**

**Parul Yadava**

*aPhysics deptt, Maitreyi College, Chankayapuri, University of Delhi*

*\*Tel.:01124673815; Mob. No.: (+91)-9654687857*

*\*E-mail: pyadav@maitreyi.du.ac.in*

**Mansi Dhingra**

*aPhysics deptt, Maitreyi College, Chankayapuri, University of Delhi*

*\*Tel.:01124673815; Mob. No.: (+91)-8178607040*

*\*E-mail: mdhingra@maitreyi.du.ac.in*

**ABSTRACT**

Preparation of ZnO and copper nanoparticles was done using sol-gel technique. Sol-gel technique helped us to get solutions which was further drop coated on glass substrates. The film so obtained was characterized using X-ray diffraction (XRD), UV-Vis spectrophotometer and electrical conductivities were measured using two probe method.

The results obtained from spectroscopy measurements was analysed to obtain band gap of ZnO. Copper, on the other hand showed surface plasmon resonance. Also, the electrical conductivities were measured using digital multimeter. It was seen that copper film showed a conducting nature whereas ZnO film was non conducting at room temperature.

**KEYWORDS-** Sol-gel, BandGap, Copper, ZnO, Nanoparticle

1. **INTRODUCTION**

Electrical and optical properties of metal and semiconductors have long been studied. But when we take any material to nanoscale it shows a new range of properties which can be understood by various characterization techniques. Metal which is supposed to be highly conducting in macroscopic dimension when reduced to microscopic dimension shows an altogether different property. Similar is the case with semiconductor nanofilms [1-3]. It is believed that on approaching nanoscale lengths the continuous structure of energy bands get converted to discrete energy levels.

It is important to understand the basic differences between metal and metal oxide nanoparticles. The following table gives some of the basic differences:

| **Aspect** | **Metal Nanoparticles** | **Metal Oxide Nanoparticles** |
| --- | --- | --- |
| Definition | Consist of pure metal atoms | Consist of metal atoms bonded to oxygen atoms |
| Chemical Composition | Elemental metal | Metal + Oxygen |
| Properties | Metallic properties | Combination of metallic and oxide properties |
| Reactivity | Generally more reactive | Often less reactive due to oxide layer |
| Stability | Prone to oxidation and corrosion | More stable due to oxide layer |
| Color | Typically have metallic luster (shows SPR) | Often have distinct colors (Absorbs energy corresponding to band-gap) |
| Electrical Conductivity | High electrical conductivity | May have reduced conductivity |
| Applications | Catalysis, electronics, etc. | Catalysis, sensors, ceramics, etc. |

Metals such as copper, aluminum and titanium meet this criterion and exhibit Plasmon resonances in UV-visible-near infrared regions.

Copper has been increasingly used as a replacement of aluminium in integrated circuits and printed circuit boards because of its superior electrical conductivity. Heat sinks and heat exchangers prefer copper as compared to aluminium, as a result of superior heat dissipation capacity of copper. It is now well known that the interaction of light with free electrons in metal nanoparticles such as copper, aluminium and titanium in addition to noble metal such as gold and silver can give rise to collective oscillations commonly known as surface plasmons. The phenomenon of SPR was not known until Faraday proposed that metal of reduced size is capable of strong interaction with light. This became the first notable scientific study of the optical properties of metal nanoparticles in colloidal solutions in 1850s [4]. The next significant contribution in the study of optical properties of metal nanoparticles was made by Gustav Mie in 1908 who published a seminal work [5] on extinction properties of metal sphere.

ZnO, on the other hand, is an extremely promising candidate for several device applications due to its highly stable structure at room temperature. It is a wide band gap semiconductor with band gap approximately 3.3 eV is being used for various practical applications like photovoltaic devices, gas sensors etc [6-8]. Being a member II-VI family of semiconductors it is well known to be n-type in nature [9].

Metal which have its conduction band and valence band overlapping in macroscopic length scales tend to show an energy bandgap (difference between conduction and valence band energies) at nanometer scale. Also reflected in its optical properties where it absorbs that particular light from the electromagnetic spectrum which give rise to collective oscillations commonly known as surface plasmons.

On the other hand the semiconductors which are believed to have a band gap at macroscopic scales are expected to show an increase in the values of energy band gap at microscopic scales.

In this chapter, we have synthesized Copper nanoparticles (metal) solution reduction process and ZnO nanoparticles (semiconductor) using sol gel technique. In order to compare the optical properties of the two, measurements were carried out using UV-Vis spectrophotometer whereas the electrical measurements were carried out using Digital multimeter.

1. **EXPERIMENTAL DETAILS**
2. Synthesis of Metal Oxide and Metal nanopowders

Synthesis of nanostructures of uniform shape and size is extremely important in accordance with the extensive development of nanotechnology for their potential applications. A large number of synthesis methods are used to achieve this goal. The wet chemical route for the synthesis of nanostructures has been done and optical as well as electrical studies are carried out under this project.

Tosynthesize the ZnO nanoparticle, we have chosenbottom up approach as we started our synthesis from molecular level using the chemical reactions .Firstly, known weights ofzincacetate were mixed inethanol according to their molar ratios .To prepare ZnO nanoparticles, approximate amounts (for 0.3M solution, 6.5814 g was added in 100 ml of ethanol) of zinc acetate were mixed in ethanol according to the formula:

 Zn(CH3COO)2 + 2 CH3CH2OH 2 Zn(OH)2 + CH3CH2CH2COO (at 3000 C) ZnO + H2O +

 CH3CH2CH2COO

To synthesize copper nanopartcles, entire reagent used in this Cu synthesis was of analytical grade and used without further purification. Nanoparticles were synthesized through a solution reduction process using sodium borohydride as a reducing agent. First the copper ammonia complex solution prepared by adding 1 g copper metal in 10 ml of (27%) ammonia solution forms the blue copper ammonia complex by consuming all the copper metal. To this blue solution of copper ammonia complex added dilute HCl (5%) under stirring until solution becomes neutral. After this, 100 ml of 0.25 M NaBH4 solution having 4 g starch as a stabilizing agent was added slowly dropwise in half hour at room temperature, the color of solution changed to dark brown which confirmed the formation of Cu nanomaterial. The prepared nanomaterial is then separated out by centrifuge at 4000 rpm.

**FIGURE 1: Schematic of preparation ZnO nanoparticles**

**FIGURE 2: Schematic of preparation copper nanoparticles**

1. **RESULT AND DISCUSSION**
2. **STRUCTURAL STUDIES**

 The structural characterizations of prepared nanopowders were carried out by X-ray diffraction (XRD). The XRD patterns were recorded at room temperature by using Philips XPERT-PRO diffractometer system (2 theta range was taken from 40 º to 80 º) using Cu Kα radiation having a wavelength of 1.5406 Å.

 Figure 1 shows the XRD patterns of different copper nanopowder. The XRD patterns were indexed using standard database (JCPDS). For prepared sample, lattice parameters were calculated for FACE CENTERED CUBIC structure for copper and HEXAGONAL structure for ZnO. The average crystallite size of the copper nanoparticles was estimated using the Scherrer formula which is given as:



where *Dhkl* is the particle size perpendicular to the normal line of (h k l) plane, *k* is a constant (0.9), *βhkl* is the full width at half maximum (FWHM) of the (h k l) diffraction peak, *Ɵhkl* is the Bragg angle of (h k l) peak and *λ* is the wavelength of X-ray. It shows that the average crystallite sizes are around 7 nm and lattice parameter was found to be 2.77 Ǻ for copper nanoparticles.

For ZnO, average crystallite size was found to be approx 50 nm and lattice parameters a= 3.41Ǻ and c= 5.28 Ǻ.



**FIGURE 3: XRD pattern of copper nanoparticles**



**FIGURE 4: XRD pattern of ZnO nanoparticles**

1. **OPTICAL STUDY**

Absorbance spectra were recorded at room temperature for the wavelength range 300-800 nm for prepared samples. We recorded the absorbance spectra of the samples of ZnO and copper nanoparticles by UV- visible spectroscopy and plotted them in the graph as shown in figure 5 . Absorbance peak of ZnO is found to be 369nm. .So from the above data we can see that the ZnO nanoparticles absorb UV radiation as the energy band gap (3.3eV) of ZnO corresponds to UV wavelength region. [since E (in eV)=1234/wavelength(in nm) = {1234/369} eV = 3.34 eV~3.3eV]. For copper (Cu) nanoparticles, absorbance peak is centered at 542 nm which lies in visible region so this peak is due to surface Plasmon resonance ( resonance of electron oscillation with light)



**Figure 5: Absorption spectra of ZnO and Cu nanoparticles**

1. **ELECTRICAL STUDY**

**DIRECT CURRENT (DC) CONDUCTIVITY MEASUREMENT:**

There are two methods to measure electrical conductivity: Two probe measurement, and four probe measurement. As the names suggest, in the two probe measurement, the sample is simultaneously contacted in two places and conductivity is measured, whereas in the four probe measurement, the sample is simultaneously contacted at four places to measure its conductivity

In DC conductivity measurement process, in principle current from a DC source should flow through the sample and the potential difference that develops across the sample must be measured. Using Ohm’s law the resistance of the sample can be determined, and then using the dimensions of the sample, the conductivity of the sample can be determined.

In Figure 6, a schematic is shown of the two probe measurement technique to obtain conductivity of the sample. The copper and ZnO nanoparticles were coated on non-conducting substrates to form a continuous film. Here we measured the resistance of the copper film which is found to be 0.22 kohm/□. Resistance of ZnO film has also been measured which behaves like open circuit at room temperature.

**Figue 6: Schematic of two probe method to measure electrical conductivity**

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**Figure7: Electrical conduction seen using digital multimeter in two cases**

1. **CONCLUSION**

In this project we prepared metal (copper) and semiconductor nanoparticles using chemical method and their structural and optical properties have been investigated. Structural properties of both nanoparticles were studied using XRD patterns. XRD confirms the synthesis of nanopartcles. In Optical study, we found that absorbance peak in ZnO nanoparicles is because of its optical bandgap whereas in copper nanopartcles, it is due to surface plasmon resonance. The electrical measurements also justified the unique nature of metal and metal oxide nanostructures.

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