ABSORPTION COEFFICIENT AND ATTENUATION OF ELECTROMAGNETIC RADIATION IN NANOELLIPSOIDAL METAL IMMERSED IN TRANSPARENT MEDIA

Sisay Areda

A Thesis Submitted to

The Department of Physics

PRESENTED IN FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

JIMMA UNIVERSITY
JIMMA, ETHIOPIA
JUNE 2017

JIMMA UNIVERSITY
DEPARTMENT OF
PHYSICS

This is to certify that the thesis prepared by **Sisay Areda** Graduate Studies entitled "**Absorption coefficient and attenuation of electromagnetic radiation in nanoellipsoidal metal immersed in transparent media** " in fulfillment of the requirements for the degree of **Master of Science** complies with the regulations of the University and meets the accepted standards with respect to originality and quality. .

Dated: June 2017

Supervisor: _____
Dr. Menberu Mengesha

Readers: _____

_____

JIMMA UNIVERSITY

Date: **June 2017**

Author: **Sisay Areda**

Title: **Absorption coefficient and attenuation of electromagnetic radiation in nanoellipsoidal metal immersed in transparent media**

Department: **Physics**

Degree: **M.Sc.** Convocation: **October** Year: **2017**

Permission is herewith granted to Jimma University to circulate and to have copied for non-commercial purposes, at its discretion, the above title upon the request of individuals or institutions.

Signature of Author

To my family.

Table of Contents

Abstract

The absorption coefficient and attenuation of electromagnetic waves are studied analytically and numerically in a nanoellipsoidal metal dielectric composites. The dielectric constant of nano composite is solved analytically based on quasi-static limit, which assumes that the incorporated nano-ellipsoidal metal particles are very small compared to the light wavelength. In this limit, the scattered light is negligible and absorption is considered. The absorption coefficient of nano ellipsoidal silver in transparent media is studied by varying the geometrical factor and concentration of inclusions. The result shows that the maxima of absorption coefficient shifts towards the higher energy as value of the geometrical factor increases. However, the magnitude of the absorption coefficient decreases with an increment of the value of geometrical factor. Moreover, for a constant geometrical factor the increment in concentration of the nano ellipsoidal silver particles results with decrement of the magnitude of the absorption coefficient.

Acknowledgements

Completion of a study of such scale cannot be anticipated without contribution of many individuals and institutions. It would be thus fair to mention people and institutions that have lend a hand for the successful completion of the research project. I would like to thank God! for his help in all my way. First and foremost, my advisor, Dr. Menberu Mengesha , has been a wonderful mentor. I cannot thank Dr.Menberu enough for providing a positive and intellectually stimulating research environment that has enabled me to mature both scientifically and personally. I am grateful for you constant guidance, encouragement and trust in me through the many challenges I have encountered. In addition to all of the opportunities and support that He has provided in the computer writing skill.

I would like to express my heartfelt appreciation and respect to my co-advisor Mr. Hiwot Digafe for his unreserved support while carrying out this research work. I would like to thank my instructor and all staff members in the physics department for their support during my study. I am thankful to my friends and colleagues for their comments and support. I am thankful to Oromia education bureau for sponsoring my study leave. Finally, I express my deep gratitude to my dearest wife W/ro Ayale Bezabeh, fore her support throughout my study.

List of Figures

List of Tables

Chapter 1

General Background

With recent developments of nanoscience and nanotechnology, the correlation of composite properties with nanostructure has become a subject of great interest. As a result, much of work has been focused on nanocomposite materials [1]. Nanocomposite materials have attracted tremendous attention due to their potential applications in photonics, biochemistry, medicine, capacitors, micro fabrications, resonant coupling devices, fuel cells, and so on.

The integration of modern electronic devices for information processing and sensing is rapidly approaching its fundamental speed and band width limitations, which has become a series problem that impedes further advance in many areas of modern science and technology. Replacing the electronic signals by light as information carrier is believed to be one of the promising solutions [2-3]. However, the diffraction limit of light in dielectric media does not allow the localization of electromagnetic waves in nano- scale regions much smaller than the wavelength of light in the medium. In recent years, plasmonic devices, based on propagation of surface Plasmon - polaritions at a metal dielectric interface, have shown great potential to guide and manipulate light with metallic nanostructures at deep sub-wavelength scales. The linear and

nonlinear response of the medium strongly effects on the propagation of electromagnetic wave in the optical material and can even result in the permanent modification of its physical properties. Their optical features of the composite materials with metal nanoparticle structures that strongly depend on size, shape, distribution of nanoparticles as well as on surrounding dielectric matrix offering an opportunity for manufacturing are dominated by surface plasma oscillations. The external field drives the bound charges of the medium apart and induces a collection of dipole moments [4]. In an optically dense medium, the interaction of the induced dipoles are taken into account by a local field factor, that relates the macroscopic fields to the local ones. The light-field is considered by starting from the macroscopic properties of the medium where the linear polarization $P^{(1)}$ provides an extensive description of the light-matter interaction when a low radiation intensities are considered. The effective optical properties of composite materials were first devoted to the analysis of linear media and were recently extended to the study of materials with one nonlinear component under very restrictive conditions, that is, very low concentration of the nonlinear component with nonlinear contributions being treated as purely real and as low field approximation to the assumed leading linear behavior. Optical properties of randomly oriented nonlinear spherical metal particles in a dielectric host are explained by two different Maxwell-Garnet type approximations based on the net polarization is involved. These two methods lead to quite different spectral density functions. Moreover, we see that the geometry of the particles has a large influence or the spectral functions through the depolarization effect on the optical absorption and nonlinear optical susceptibilities.

1.1 Statement of the Problem

The optical properties of composite materials have been the subject of numerous studies in recent years due to their technological potential applications. Because of their potential uses in optical devices, the most commonly considered materials are made of nonlinear particles embedded in linear host. Dielectrics containing metallic nanoparticles are very promising materials for applications optoelectronics due to their unique linear and non - linear optical properties. These properties are dominated by the strong surface plasmon resonance of the metal nanoparticles. The surface plasmon resonance occurs when the electron and light waves couple with each other at a metal- dielectric interface. These are regarded as the collective oscillation of the nanoparticle electron. The spectral position of the surface Plasmon resonance in the compound materials can be designed with in a wide spectral range, from visible to near inferared, by choice of the electronic properties of the metal and the dielectric matrix [5, 6]or by manipulation of size [7, 8], shape [9, 10] and spatial distribution [11]of the metal clusters. This makes the composite materials attractive for some applications in technology. One of the main issues in this study is, therefore, to investigate the absorption coefficient with respect to the geometry and concentration for such materials. Even though different researches were conducted on this area the absorption coefficient and attenuation of electromagnetic waves as a function of geometry and concentration were not well understood. So the main focus of this project is to describe the absorption coefficient and attenuation of electromagnetic waves in nano-ellipsoidal metal in transparent dielectric host material.

1.2 Objectives

1.2.1 General objective

The main aim of this project is to understand the absorption coefficient of nano ellipsoidal metal dielectric composite materials with respect to their geometry and concentration of nano ellipsoidal metal in host matrix.

1.2.2 Specific objective

- To describe the influence of geometrical factor on absorption coefficient of the nano ellipsoidal metalic particles in dielectric host media;
- To observe the influence of concentration of identical ellipsoidal metallic nanoparticles on absorption coefficient in transparent dielectric media.

1.3 Significance of the study

The physics of metal-dielectric composites has recently gained increasing interest because of their unique linear and nonlinear optical properties, and their high application potential as nonlinear media and media for optical data storage. These properties find their application in optics, electronics, optoelectronics and material science. Thus understanding the optical properties such as absorption coefficient as a function of geometry and concentration of inclusions is helpful for characterization of the composite system. Moreover, knowledge of the features of interaction of electromagnetic radiation with composite or disperse materials is crucial for further advances in technology.

.

Chapter 2

Literature Review

2.1 Introduction

Since the inception of lasers, nonlinear optics has been a rapidly growing field of research in recent decades. It is based on the study of effects and phenomena related to the interaction of intense coherent light radiation with matter. In other words, nonlinear optics is the branch of optics that describes behavior of light in nonlinear media, that is, the media in which the dielectric polarization responds nonlinearly to the electric field of light. This non linearity is typically and only observed at very high light intensities. Such high powers of light made it possible to change the optical properties of the medium and also the light itself affected by change. The beginning of the field of nonlinear optics is taken to be the discovery of second - harmonic generation by Fraken et al. in 1961 [12] shortly after the demonstration of the first working laser by Maiman in 1960 [13]. The non linearities reside in the constitute relationships of Maxwell's equations. This enables us to adopt a macroscopic approach to the problem of determining absorption coefficient.

2.1.1 Electromagnetic Radiation in vacuum

The electric and magnetic fields are in phase and mutually perpendicular as a result of Maxwell's equations [14, 15]. Physically, Electric field results from electric charges or from time dependent magnetic fields, while magnetic fields result from electric currents or time - dependent electric field. Maxwell's equations can be manipulated to give classical wave equations from the time and space dependence of the electric and magnetic field. A major achievement of this picture was the relation derived between the speed of light and the product of the electric permittivity and magnetic permeability of free space:

$$\mu_0\epsilon_0 = \frac{1}{c^2} \tag{2.1.1}$$

Maxwell's equation are basic electromagnetic equations, that predict about the physical property of light. In vacuum,they are:

$$\nabla.\vec{E} = 0 \tag{2.1.2}$$

$$\nabla.\vec{B} = 0 \tag{2.1.3}$$

$$\nabla \times \vec{E} = \frac{-\partial \vec{B}}{\partial t} \tag{2.1.4}$$

$$\nabla \times \vec{B} = \mu_0\epsilon_0\frac{\partial \vec{E}}{\partial t} \tag{2.1.5}$$

Where,$\epsilon_0 = 8.854 \times 10^{-12}C^2m^{-1}J^{-1}$, and $\mu_0 = 4\pi \times 10^{-7}\frac{N}{A^2}$

After some manipulation Maxwell's equation can be recast in the following form to give classical wave equation:

$$\nabla^2\vec{E} = \epsilon_0\mu_0\frac{\partial^2 vecE}{\partial t^2} \tag{2.1.6}$$

$$\nabla^2 vecB = \epsilon_0 \mu_0 \frac{\partial^2 \vec{B}}{\partial t^2} \tag{2.1.7}$$

From the symmetrical relation ship between the magnetic and electric field, there are two quantities the scalar potential ϕ and the vector potential $\vec{A}$ from which $\vec{E}$ and $\vec{B}$ can be derived:

$$\vec{E} = -\nabla\phi - \frac{\partial \vec{A}}{\partial t} \tag{2.1.8}$$

$$\vec{B} = \nabla \times \vec{A} \tag{2.1.9}$$

Hence the vector potential also obeys the classical wave equation,

$$\nabla^2 \vec{A} = \mu_0 \epsilon_0 \frac{\partial^2 \vec{A}}{\partial t^2} \tag{2.1.10}$$

2.1.2 Electro magnetic radiation in material media.

The macroscopic aspects of the static and dynamics of the electromagnetic field of the material media are described by Maxwell's equation:

$$\nabla . \vec{D} = \rho_f \tag{2.1.11}$$

$$\nabla . \vec{B} = 0 \tag{2.1.12}$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \tag{2.1.13}$$

$$\nabla \times \vec{H} = J_f + \frac{\partial \vec{D}}{\partial t} \tag{2.1.14}$$

Where the electromagnetic properties of material media may be taken in to account through relations, $\vec{D} = \epsilon\vec{E}$, $\vec{B} = \mu\vec{H}$ and $\vec{J} = \sigma\vec{E}$ known as constitutive relations.

When an external electric field is applied to an insulator, the matter responds with an induced polarization that partially cancels the field due to out side charges. Although the charges in an insulator are not mobile as they are in conductor, an external field has the ability to displace the charges in length of polar bonds [14, 15]. The resulting net dipole moment per unit volume is called the polarization, and in linear electric materials it is proportional to the electric field. If there are N such molecules per unit volume the macroscopic polarization $\vec{P}$ is given by:

$$\vec{P} = N\vec{p} \tag{2.1.15}$$

$$\vec{P} = \epsilon_0\chi_e\vec{E} \tag{2.1.16}$$

$$\vec{D} = \epsilon_0(1 + \chi_e)\vec{E} \tag{2.1.17}$$

Similarly, when ordinary matter is placed in an external magnetic field, induced magnetization, $\vec{M}$, the magnetic dipole moment per unit volume, results. Unlike the polarization $\vec{P}$, the magnetization can either reinforce or oppose the applied field. The bound and free charges in electric polarization are analogous to the bound and free currents in magnetic polarization. The magnetic field $\vec{H}$ is given by:

$$\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M} \tag{2.1.18}$$

The bound currents are those due to the induced magnetic moments and the alignment of permanent moments, possessed by the atoms molecules that comprise the

sample.

$$\vec{M} = \chi_m \vec{H} \tag{2.1.19}$$

$$\vec{B} = \mu_0(1 + \chi_m)\vec{H} \tag{2.1.20}$$

Applying the curl operation to both sides of Equation (13), we obtain

$$\nabla \times (\nabla \times \vec{E}) = -\nabla \times \frac{\partial \vec{B}}{\partial t} = -\frac{\partial}{\partial t}\left(\nabla \times \vec{B}\right) \tag{2.1.21}$$

$$\nabla \times (\nabla \times \vec{E} = \nabla(\nabla.\vec{E}) - \nabla^2 \vec{E} \tag{2.1.22}$$

$$\nabla(\nabla.\vec{E}) - \nabla^2 \vec{E} = -\mu_0 \frac{\partial^2}{\partial t^2}\left(\epsilon_0 \vec{E} + \vec{P}\right) \tag{2.1.23}$$

$$\nabla^2 \vec{E} - \nabla(\nabla.\vec{E}) - \frac{1}{c^2}\frac{\partial^2 \vec{E}}{\partial t^2} = \frac{1}{\epsilon_0 c^2}\frac{\partial^2 \vec{P}}{\partial t^2} \tag{2.1.24}$$

for transverse fields (some times called solenoidal or radiation fields) satisfy,

$$\nabla.\vec{E} = 0 \tag{2.1.25}$$

Transverse equations therefore satisfy the inhomogeneous wave equation,

$$\nabla^2 \vec{E} - \frac{1}{c^2}\frac{\partial^2 \vec{E}}{\partial t^2} = \frac{1}{\epsilon_0 c^2}\frac{\partial^2 \vec{P}}{\partial t^2} \tag{2.1.26}$$

In classical physics Newton's second law describes the motion of particle. For charged particles in electromagnetic field the force referred to in Newton's second law is the Lorentz force [15],

$$\vec{F} = e(\vec{E} + \vec{V} \times \vec{B}) \tag{2.1.27}$$

In equation (2.1.27), the magnetic contribution to the Lorentz force is dropped. Because optical phenomena do not normally involve relativistic particle velocities, we can safely disregard the magnetic force. Under the influence of electromagnetic field the electron experiences a Lorentz force, and the equation of the force with out considering the damping force is,and the equation of motion is,

$$m\frac{d^2\vec{x}}{dt^2} = e\vec{E}(\vec{r},t) - K_s\vec{x} \tag{2.1.28}$$

When a field is applied, each atoms electron is displaced by some $\vec{x}$ from its original position. Thus each atom has a dipole moment,

$$\vec{p} = e\vec{x} \tag{2.1.29}$$

If the density of atoms is denoted by N, then the density of dipole moment is,

$$\vec{P} = N\vec{p} = Ne\vec{x} \tag{2.1.30}$$

The Maxwell equation (2.1.26) tells us how the electric field $\vec{E}$ depends up on the dipole moment density $\vec{P}$ of the medium. Newton's equation (2.1.27) tells us how the electron displacement $\vec{x}$ depends upon the $\vec{E}$. Equation (2.1,30) connects these basic equations by relating $\vec{P}$ to $\vec{x}$. The electron oscillator model thus ties together the Maxwell equation with Newton's law of motion. Solutions of these coupled equations will provide the model's predictions about the mutual interaction of light and matter. For linearly polarized wave the electric field at the position of the atom has the form,

$$\vec{E}(z,t) = \hat{\epsilon}E_0\cos(\omega t - kz) \tag{2.1.31}$$

If the electric field in equation (2.1.31) is to be a solution of coupled Maxwell-Newton equations, it must be the driving field in the Newton equation (2.1.28),

$$\frac{d^2\vec{x}}{dt^2} + \omega_0^2\vec{x} = \hat{\epsilon}\frac{e}{m}E_0\cos(\omega t - kz) \tag{2.1.32}$$

This equation has the solution,

$$\vec{x} = \hat{\epsilon}\left(\frac{\frac{e}{m}E_0}{\omega_0^2 - \omega^2}\right)\cos(\omega t - kz) \tag{2.1.33}$$

The polarization can also be described by polarizablity ,

$$\vec{p} = e\vec{x} = \beta(\omega)\vec{E} \tag{2.1.34}$$

Relating equations (2.1.32), (2.1.33) and (2.1.34) the polarizablity is given by,

$$\beta(\omega) = \frac{e^2}{m}\frac{1}{\omega_0^2 - \omega^2} \tag{2.1.35}$$

Thus the dipole moment density is,

$$\vec{P} = \hat{\epsilon}\left(\frac{\frac{Ne^2}{m}}{\omega_0^2 - \omega^2}\right)E_0\cos(\omega t - kz) \tag{2.1.36}$$

This solution for the polarization provides the source term on the right hand side of the Maxwell equation (2.1.26),

$$\left(-k^2 + \frac{\omega^2}{c^2}\right)\hat{\epsilon}E_0\cos(\omega t - kz) = -\frac{N\beta(\omega)\omega^2}{\epsilon_0 c^2}\hat{\epsilon}E_0\cos(\omega t - kz) \tag{2.1.37}$$

To satisfy this equation k must satisfy a more general dispersion relation

$$k^2 = \frac{\omega^2}{c^2}\left(1 + \frac{N\beta(\omega)}{\epsilon_0}\right) = \frac{\omega^2}{c^2}n^2(\omega) \tag{2.1.38}$$

The index of refraction with the absence of damping force is real and becomes,

$$n(\omega) = \left(1 + \frac{\frac{Ne^2}{m\epsilon_0}}{\omega_0^2 - \omega^2}\right)^{\frac{1}{2}} \tag{2.1.39}$$

In the presence of damping force equation (2.1.32) can be modified as,

$$\frac{d^2\vec{x}}{dt^2} - \gamma\frac{dx}{dt} + \omega_0^2\vec{x} = \hat{\epsilon}\frac{e}{m}E_0\Big[\cos(\omega t - kz) - j\sin(\omega t - kz)\Big] \tag{2.1.40}$$

Where γ in equation (2.1.40) is the damping constant.

$$\vec{x}(t) = \Re\hat{\epsilon}\frac{\frac{e}{m}E_0 e^{-j(\omega t - kz)}}{\omega_0^2 - \omega^2 - j\gamma\omega} \tag{2.1.41}$$

The polarizablity in damping case is complex and given by,

$$\beta(\omega) = \frac{\frac{e^2}{m}}{\omega_0^2 - \omega^2 - j\gamma\omega} \tag{2.1.42}$$

The complex nature of polarizablity leads to the complexity of the index of refraction.

$$n^2(\omega) = 1 + \frac{\frac{Ne^2}{m\epsilon_0}}{\omega_0^2 - \omega^2 - j\gamma\omega} = [n_{\Re}(\omega) + jn_{\Im}(\omega)]^2 \tag{2.1.43}$$

The electric field is given by,

$$\vec{E} = \hat{\epsilon}E_0 e^{-j(\omega t - kz)} \tag{2.1.44}$$

But the wave vector is,

$$k = \frac{\omega}{c}[n_{\Re}(\omega) - jn_{\Im}(\omega)] \tag{2.1.45}$$

Then,

$$\vec{E} = \hat{\epsilon}E_0 e^{\frac{-\omega}{c}n_{\Im}(\omega)z} e^{-j[\omega t - \frac{\omega z}{c}n_{\Re}(\omega)]} \tag{2.1.46}$$

The intensity is proportional to the square of the amplitude of the electric field and given by

$$I(\omega) = I_0 e^{-\sigma(\omega)z} \tag{2.1.47}$$

$\sigma(\omega)$ is the absorption coefficient or extinction coefficient, and given by,

$$\sigma(\omega) = 2[n_{\Im(\omega)}]\frac{\omega}{c} = \frac{Ne^2}{\epsilon_0 mc}\frac{\gamma\omega^2}{(\omega_0^2 - \omega^2)^2 + \gamma^2\omega^2} \tag{2.1.48}$$

2.2 Nonlinear Optics and polarization

2.2.1 The origins of polarization, oscillator model

Here we will take a simple classical approach to gain some interaction about polarizations, similar discussion may be applied to derivation of magnetization, where instead of E -dipoles we can take about magnetic dipoles. The ion electron dipole are constantly oscillating (electrons have thermal velocity that allows them to move away from the ions but then they are pulled back by the Coulomb force). Then electrons bound to ions would be pushed in the direction opposite to the applied field orienting the ion electron dipoles in the direction of the field . The electric field will act as a driving force applied to our oscillating dipoles. Then we can describe the distance between the electron and ion using the oscillatory equation

$$\frac{d^2x}{dt^2} + \omega_o^2 x = \frac{F}{m} \tag{2.2.1}$$

Where ω_o is natural frequency. But what happens when we add the external electromagnetic field? In a simplest case the EM wave propagate through the material. Its wavelength is significantly larger than the lattice constant or the size of the atoms so locally we can approximate electric field altering in space with a field that is locally constant in that space. In order to account for local field effect on the optical properties of a material, one needs to apply a proper model relating the model strongly depends on the medium. For example, local field in a homogeneous medium can be related local field to its macroscopic counterparts, namely, the average field and polarization [2-4,7,9-10]

$$E_{loc} = LE \tag{2.2.2}$$

Where L is the local field correction factor. The local field acting on a typical dipole of the medium, one surrounds the dipole of interest with an imaginary spherical cavity of radius much larger than the distance between the dipoles and much smaller than $.\lambda_{op}$ The contributions to the local field from the dipole situated within the spherical cavity are accounted for exactly, while the dipoles outside the cavity are treated as uniformly distributed, characterized by some average polarization as shown in Fig. 2. For material with linear optical response the local field determines the microscopic polarization$P(\omega)$, expressed as:

$$P(\omega) = \beta(\omega)E_{loc}(\omega) \tag{2.2.3}$$

Where a single microscopic$\beta(\omega)$is the polarizability,which implies that

$$P(\omega) = N\beta(\omega)E \tag{2.2.4}$$

Where N is the density of microscopic constituents.

$$neR = \frac{N}{v} \tag{2.2.5}$$

Where N the number of electrons per unit volume and Ne is the number of electrons per elementary constituents of the medium. The polarization can be expressed in terms of the external EM- field as follows:

$$P(\omega) = \chi_{eff}(\omega)E(\omega) \tag{2.2.6}$$

Hence, in order to express the effective susceptibility in terms of the microscopic polarizability, we have to express the local E-field in terms of the external electric-field. We have that the local electric-field can be expressed as [15-17]

(2.2.7)

For the local electric field E_{loc} in terms of the average macroscopic polarization P. We further derive the Lorentz-Lorentz = Clasuis-Mossoti, relation for the dielectric permittivity ε and microscopic polarizability β. The polarizability describes the distortion of the dipole field on an atomic scale induced by the interaction with the external oscillating field. Let us assume for now that the medium is lossless and dispersion less. We represent the dipole moment induced in a typical molecule (or atom) of the medium as

$$P = \beta E_{loc} \tag{2.2.8}$$

The macroscopic polarization of the material is given by

$$P = Nex = N\vec{p} \tag{2.2.9}$$

Where N denotes molecular (or atomic) number density. $p = ex$is known as electric dipole moment. Using equations (2.2.7) through (2.2.8) we find that the polarization and macroscopic field are related by:

$$P = N\beta(E + \frac{4\pi}{3}p) \tag{2.2.10}$$

We assume the polarization P to be linear in the average field:

$$p = \chi^{(1)}E \tag{2.2.11}$$

Where $\chi^{(1)}$ is the linear susceptibility of the medium. Substituting the expression (2.2.10) into (2.2.11), solving for $\chi^{(1)}$, and eliminating the field E, we find that

$$\chi^{(1)} = \frac{N\beta}{1 - \frac{4\pi}{3}N\beta} \tag{2.2.12}$$

Expressing the optical susceptibility of the medium

$$\chi^{(1)} = \frac{(\varepsilon^{(1)} - 1}{4\pi} \tag{2.2.13}$$

($\varepsilon^{1)}$ is the dielectric permittivity of the medium).we obtain the well-known Lorentz-Lorentz or Clausius-Mossoti relation

$$\frac{\varepsilon^{(1)-1}}{\varepsilon^{(1)+2}} = \frac{4\pi}{3}N \tag{2.2.14}$$

Through rearrangements of equation (2.2.14) we can express the linear susceptibility as:

$$\chi^{(1)} = \frac{\varepsilon^{(1)}+2}{3}N\beta \tag{2.2.15}$$

With the substitutions and rearrangements, we obtain the equation relating the local field to the average field:

$$E_{loc} = \frac{\varepsilon^{(1)}+2}{3}E \tag{2.2.16}$$

Where

$$L = \frac{\varepsilon^{(1)}+2}{3} \tag{2.2.17}$$

is known as the Lorentz local-field correction factor i.e., which is valid in the case of homogeneous media, where all the particles (molecules or atoms) are of the same sort. It is also valid in materials where the emitters enter as inclusions that do not influence the correlation between the host molecules or atoms [18- 20]. In order to describe more precisely what we mean by an optical non linearity, let us consider how the dipole moment per unit volume (polarization) of a material system depends on of an applied optical-field. In the case of linear (conventional) optics, the induced polarization linearly depends on E-field strength in a manner that can be described below; In linear optics, the polarization density depends linearly on the electric field strength in a manner that can often be described by the relationship,

$$P = \varepsilon_o \chi E \tag{2.2.18}$$

Where ε_o is the permittivity of free space and χ is the electric susceptibility of the medium. As the magnitude of the applied electric field increases, the linear relationship between P and E breaks down and we enter the realm of nonlinear optics. Then, the resulting polarization can be expressed as a series in increasing powers of the electric field. Mathematically, such a series can be expressed as,

$$P(t) = \chi_o[\chi^{(1)}E^{(1)}(t) + \chi^{(2)}E^{(2)} + \chi^{(3)}E^{(3)} + .. \tag{2.2.19}$$

Where we can ignore the vector nature of the fields as well as dispersion, for simplicity. The expansion coefficients, $\chi^{(1)}$ and$\chi^{(2)}$ etc., are identified as linear and nonlinear susceptibilities, respectively. In general, the nonlinear susceptibilities depend on the frequencies of the applied fields, but under our present assumption of instantaneous response, we take them to be constants. We shall refer to $P = \chi^{(2)}E^{(2)}$ as the second-order nonlinear polarization and $P = \chi^{(3)}E^{(3)}$ as the third-order nonlinear polarization. The second order nonlinear optional interactions can occur only in noncentrocymmetric crystals-that is, in crystals that do not display inversion symmetry. . Since liquids, gases , amorphous solids such as glasses and even many crystals display an inversion symmetry , $\chi^{(2)}$ vanishes identically for such media , and consequently such material cannot produce the second order nonlinear optical interactions. On the other hand, third order nonlinear optical interactions i.e. those described by $\chi^{(3)}$susceptibilities can occur for both centro-symmetric and non centro-symmetric media. We shall see in later sections of this paper how to calculate or describe the numerical values of the nonlinear susceptibilities for various physical mechanisms that lead to optical nonlinearities[1] For the present, we shall make a simple order of magnitude, estimate the size of these quantities for the common case in which the nonlinearities is electronic in origin [Armstrong et al 1962][17] One might expect that

the lowest order correction term $P^{(2)}$ would be compensated to the linear response $P^{(2)}$ when the amplitude of the applied field (E) is of the order of the characteristic atomic E-field strength

$$E_{at} = e/4\pi\varepsilon_o a_o^2 \tag{2.2.20}$$

Where e is the charge of the electron and $a_o = \varepsilon_o h^2/me^2\pi$ is the Bohr radius of the hydrogen atom. Numerically, we find that $E_{at} = 5.14 \times 10^{11} v/m$ We thus expect under conditions of non-resonant excitation the second order susceptibility$\chi^{(1)}$ will be the order of$\chi^{(1)}/E_{at}$ For condensed matter $\chi^{(1)}$is the order of unity, and we hence expect$\chi^{(2)}$ will be the order of $1/E_{at}$ or that$\chi^{(2)} = 1.94 \times 10^{-12} v/m$

Similarly, we expect $\chi^{(3)}$ to be the order of

$$\chi^{(3)} = \chi^{(1)}/E_{at}^2 = 3.78 \times 10^{-24} m^2/v^2 \tag{2.2.21}$$

This result can be justified either as an empirical fact or more rigorously noting that is the product of the atomic number density N and atomic polarizability. The number density N of condensed matter is of the order of $(a_0)^{-3}$, and the nonresonant polarizability is of the order of $(a_0)^3$. We thus deduce that is the order of unity [3]. We then find that and

$$\chi^{(2)} \approx (4\pi\varepsilon_o)^3 \hbar^4/m^2 e^5 \tag{2.2.22}$$

We emphasize that polarization is macroscopic quantity, which derives from a suitably defined small scale spatial average of the corresponding microscopic quantity, the polarizability. [14, 16,19, 13]. The ratio between the polarization and polarizability is simply the number of the elementary components of the medium per unit volume. The E-field inducing the polarization is not the macroscopic external field of the incoming radiation, which is introduced by Lorentz. The constitute Eqn. that includes the

response of the material to the applied EM- field is written as:

$$D = \varepsilon_o E + P \tag{2.2.23}$$

The term ε_o represents the vacuum contribution caused by the external E-field and P is the electrical polarization of the matter. The macroscopic polarization created by the dipoles adds to the vacuum contribution and sums up to the displacement $\vec{D}$. For different frequencies, different types of oscillators will dominate the response and the strength E of this response, the polarization P and the electric displacement D in a pure dielectric and in a linear approximation are related by

$$P = \chi^{(1)} E \tag{2.2.24}$$

2.2.2 Lorentz model

Lorentz model is a theory in which electrons and ions in materials were treated as harmonic oscillators which are under the influence of deriving local electric field and certain damping force . Based on this consideration the expression for dielectric function of the particle can be obtained as [24];

$$\varepsilon^1 = 1 + \chi^1 = \varepsilon_\infty + \frac{\omega_p^2}{\omega_0^2 - \omega^2 - i\gamma\omega} \tag{2.2.25}$$

where ω is the frequency of the applied field, ω_0 is resonance frequency of the oscillator and $\omega_p = \sqrt{\frac{Ne^2}{m\epsilon_0}}$ is the plasma frequency, m is electron effective mass, γ is the damping parameter and ε_∞ is dielectric function when oscillation is at much higher frequencies.

2.2.3 Drude model

This is a theory which modifies the Lorenz model to free electrons by letting zero the value of the force constant to the Lorentz oscillator so $\omega_0 = 0$ in equation (2.2.25)

gives the Drude dielectric function for free electron [25].

$$\varepsilon^1 = \varepsilon_\infty + \frac{\omega_p^2}{\omega^2 - i\gamma\omega} \tag{2.2.26}$$

With real and imaginary parts

$$\varepsilon^{'} = 1 - \frac{\omega_p^2}{\omega^2 + \gamma^2} \tag{2.2.27}$$

$$\varepsilon^{''} = 1 - \frac{\omega_p^2 \gamma}{\omega(\omega^2 + \gamma^2)} \tag{2.2.28}$$

2.2.4 Nonlinear metal dielectric composites and optical constants

The relation between the optical constants: the index of refractions and permittivities with real and imaginary parts (n, k) and $(\varepsilon', \varepsilon")$ are described here. One can use either the complex refractive index or the permittivity depending on the purpose. There is a better intuitive understanding of n and k (real and imaginary parts of index of refractions) because they are related to the phase velocity and attenuation of plane waves in matter. Metals like silver, copper, aluminum and gold in their molecular micro geometric or nanostructured level embedded in the host with proper radii ratio for these composites. These sets are given by: $N = n + ik$ where n is the real part of the index of refraction and k is the imaginary part of the complex refractive index. And $\varepsilon = \varepsilon' + i\varepsilon"$,where ε' is the real part of the dielectric constant and $\varepsilon"$ is the imaginary part.

2.2.5 The Maxwell-Garnett effective medium theory

Effective medium theories are models which describe composite heterogeneous materials through effective material properties determined based on certain approximations

and applying statistical averaging method to the microscopic Maxwell equations. Maxwell - Garnett effective medium approximation is the easiest and widely used model for calculating effective dielectric quantities of composite materials consisting many components [21-23] . And in this model the embedding or background material is considered as host medium or matrix and the embedded components are considered as inclusions. The Maxwell - Garnett approximation is applicable to linear medium with inclusions whose size is very small compared to the wavelength of light waves in the effective medium so that the electric field in the inclusions is assumed to be uniform and the inclusions are separated by large distances in other words their concentration is very dilute so the particles are assumed to be non interacting. For a medium composed of a single type or identical ellipsoidal inclusions embedded randomly in a host material Maxwell-Garnett formula for the effective dielectric function is given by [24]

$$\varepsilon_{eff} = \frac{(1-f)\varepsilon_h + f\beta\varepsilon_i}{1-f+f\beta} \tag{2.2.29}$$

$$\beta = \frac{1}{3}\sum \lambda_k \tag{2.2.30}$$

$$\lambda_k = \frac{\varepsilon_h}{\varepsilon_h + L_k(\varepsilon_i - \varepsilon_h)} \tag{2.2.31}$$

where $k = 1, 2, 3$ represent the three principal axis of the ellipsoidal inclusions, L_k is geometrical factor of the ellipsoids to the k^{th} principal axes of the ellipsoids, β is the polarizability ε_i and ε_h are respectively the dielectric functions of the inclusions and the host material.

2.2.6 Absorption coefficient

When a particle is illuminated by a beam of light with specified characteristics ,the amount and angular distribution of the light scattered by the particle, as well as the amount absorbed ,depends in a detailed way on the nature of the particle that is its shape, size, and the materials of which it is composed. Absorption is a process by which the excited elementary charges transform part of the incident electromagnetic energy in to other forms (thermal energy for example) when the matter is illuminated by electromagnetic wave. Interaction between light and metals takes place between the optical electric field and the conduction band electrons of the metals. Some of the light energy transferred to the lattice in the form of heat via collisions. Hence ,the properties of metals can be characterized by two optical constants: refractive index n and extinction coefficient, k, that result in the complex refractive index, ,where:

$$\tilde{n} = n + ik \tag{2.2.32}$$

The refractive index is defined as the ratio of phase velocity of light in vacuum to the phase velocity of light in the given medium . The extinction coefficient is related to the exponential decay of the wave it passes through the medium. Both of the constants vary with wavelength and temperature. Hence , the expression for an electromagnetic wave in an absorbing medium contains both of these parameters and can be expressed as follow:

$$\vec{E} = E_0 e^{\frac{-2\pi kx}{\lambda_0}} e^{i(\frac{2\pi nx}{\lambda_0} - \omega t)} \tag{2.2.33}$$

where E_0 is the amplitude of the wave measured at the point $x = 0$ in the medium, E is the instantaneous value of the electric vector measured at a distance x from the first point and at some time t , ω is the angular frequency of the source, and $\lambda_0$is

the wavelength in vacuum. The absorption coefficient is related to the extinction coefficient by:

$$\alpha = \frac{4k}{\lambda_0} \tag{2.2.34}$$

The complex dielectric constant ε for metals is given by:

$$\varepsilon = \varepsilon_1 + i\varepsilon_2 \tag{2.2.35}$$

where the dielectric constants are related to the optical constants by:

$$\varepsilon_1 = n^2 - k^2, \qquad \varepsilon_2 = 2nk \tag{2.2.36}$$

2.2.7 Mie theory

When Gustav Mie wrote his classic paper on light scattering by dielectric absorbing spherical particles in 1908 he was interested in explaining the colorful effects connected with colloidal Gold solutions. Nowadays, the interest in Mie's theory is much broader. Interests range from areas in physics problems involving interstellar dust, near-field optics and plasmonics to engineering subjects like optical particle characterization. Mie theory is still being applied in many areas because scattering particles or objects are often homogeneous isotropic spheres or can be approximated in such a way that Mie's theory is applicable.

2.2.8 Bruggeman's modern formula

Without any loss of generality, we should consider the study of conductivity for a system made up of spherical multi component inclusions with different arbitrary conductivities. Then the Bruggeman's formula takes the form. For circular and

spherical inclusions [18-21]

$$\sum \sigma_i \frac{\sigma_i - \sigma_e}{\sigma + (n-1)\sigma_e} = 0 \tag{2.2.37}$$

Where σ_i and σ_e are respectively the fraction and the conductivity of each component of the medium n is an arbitrary number of components the sum over $\sigma_i (\sum \sigma_i = 1)$ is unity. For Elliptical and ellipsoidal inclusions

$$\frac{1}{n}\delta\beta + \frac{(1-\sigma)(\sigma_m - \sigma_e)}{\sigma + (n-1)\sigma_e} = 0 \tag{2.2.38}$$

For randomly oriented inclusions,

$$\beta = \frac{1}{n}\sum_{j=1}^{n} \frac{\sigma - \sigma_e}{\sigma_e + L_j(\sigma - \sigma_e)} \tag{2.2.39}$$

Where β is the polarizability, and L_j denotes the appropriate doublet or triplet of depolarization factors which is governed by the ratios between the axis of the ellipse / ellipsoid. In the case of sphere

$$L_1 = \frac{1}{3}, \quad L_2 = \frac{1}{3}, \quad L_3 = \frac{1}{3} \tag{2.2.40}$$

The sum overL_j is unity. Let us consider the crosshatched volume of conductivity σ_1 take it as sphere of volume V and assume it is embedded in a uniform medium with effective conductivity σ_e. If the electric field far from the inclusion is E_0, then elementary considerations lead to a dipole moment associated with the volume.

$$P \backsim v\frac{\sigma_1 - \sigma_e}{\sigma_i - 2\sigma}E_0 \tag{2.2.41}$$

This polarization produces a deviation from E0, if the average deviation is to vanish, the total polarization summed over the two types of inclusion must vanish. Thus

$$\sigma_1\frac{\sigma_1 - \sigma_e}{\sigma_i - 2\sigma_e} + \sigma_2\frac{\sigma_2 - \sigma_e}{\sigma_i - 2\sigma_e} = 0 \tag{2.2.42}$$

Where σ_1 and σ_2 are respectively the volume fraction of material 1 and 2. This can be easily extended to a system of dimension n that has an arbitrary number components. All cases can be combined to yield equation (2.5.1) In Maxwell Garnett Approximation, the effective medium consists of a matrix medium and inclusion with the Maxwell Garnett equation reads, [12]

$$(\frac{\varepsilon_{eff} - \varepsilon_m}{\varepsilon_{eff} + 2\varepsilon_m}) = \sigma(\frac{\varepsilon_i - \varepsilon_m}{\varepsilon_i + 2\varepsilon_m}) \tag{2.2.43}$$

Where ε_{eff} the effective dielectric constant of the medium is, $\varepsilon_i$is the one of the inclusions and ε_m the one of the matrix is the volume fraction of inclusions. The Maxwell Garnett equation is solved by

$$\varepsilon_{eff} = \varepsilon_m \frac{2\sigma_i(\varepsilon_i - \varepsilon_m) + \varepsilon_i + 2\varepsilon_m}{2\varepsilon_m + \varepsilon_i + \sigma_i(\varepsilon_m - \varepsilon_i)} \tag{2.2.44}$$

so long as the denominator does not vanish. For the derivation of the Maxwell equation we start with an array of polarizable particles. .By using the Lorentz local field concept, we obtain the Clasius- Mossoti relation:

$$\frac{\varepsilon - 1}{\varepsilon + 2} = \frac{4\pi}{3} \sum N_j \beta_j \tag{2.2.45}$$

As the model of Maxwell Garnett is composition of a matrix medium with inclusion, we enhance the equation.

$$\frac{\varepsilon_{eff} - \varepsilon_m}{\varepsilon_{eff} + 2\varepsilon_m} = \sigma_i(\frac{\varepsilon_i - \varepsilon_m}{\varepsilon_{eff} + 2\varepsilon_m}) \tag{2.2.46}$$

Validity: In general terms the Maxwell Garnett EMA is expected to be valid at low volume fraction σ_i since it is assumed that the domains are spatially separated[20,21].

h

Chapter 3

Materials and Methodology

3.1 Materials

The study is purely theoretical. An intensive survey of literature from published articles, books, thesis and dissertation will be carried out based on the project title. MATLAB and MATHEMATICA software's and computers are additional instruments used to accomplish this project

3.2 Methodology

3.2.1 Analytical

In this thesis one of the method or approach used to solve the problem is analytical method. That is the absorption coefficient of the composite(nano ellipsoidal metal inclusions in non absorbing dielectric host) is solved analytically.

3.2.2 Computational (graphical)

To interpret the result and to observe the effect of geometrical factor and the concentration of nano ellipsoidal metal in the non absorbing host media computational and graphical methods are employed.

Chapter 4

Absorption Coefficient and attenuation of electromagnetic waves in nano ellipsoidal metal dielectric composite

4.1 Introduction

The reduction in the intensity of electromagnetic radiations as it propagates with in the material media is called attenuation. Any process that results in a reduction in the electromagnetic intensity measured after propagation through a material contributes to the observed optical attenuation. Since the optical properties of metal nano particles are governed by surface plasmon resonance (SPR), they are strongly depend on the nano particles size, shape, concentration and spatial distribution as well as on the properties of the surrounding matrix. Control over these parameters enables such metal dielectric nano composite to become promising media for the development of novel nonlinear materials, nano devices and optical elements. In this study we are interested to describe a composite material with identical nano ellipsoidal metalic

particles are aligned uniformly in a transparent dielectric host material. This material share in common two important features. First in metals the delocalized valence electrons find them selves confined in regions much smaller than their natural delocalization length. This drastically modifies their quantum motion as proposed by optical beams; second because the size of the metal is much smaller than the wavelength and their dielectric constant very different from that of transparent dielectric. The distribution of of the electric field that acts on and polarizes the changes inside these crystallites can be vastly different from the macroscopic Maxwell's fields in the composite. The absorption coefficient of this nano ellipsoidal metal dielectric composite is determined from the dielectric function. Another physical quantity which is crucial for determining the dielectric function is the polarizability of the nano ellipsoidal metal particle and it can be obtained from the electrical potential distribution in the inner and outer of the ellipsoidal particles.

In treating this system the dipole-dipole interaction between the particles is considered very small assuming dilute concentration of nano ellipsoidal particle in the host matrix. Moreover, the electric field $\vec{E_0}$ is applied parallel to one of the axis of ellipsoidal, (that is $\vec{E_0} \parallel b$ for $a > c > b$). The potentials due to the applied field are [21]

$$\phi_I = P\phi_0, \qquad P = \frac{\epsilon_h}{\epsilon_h + L_3(\epsilon_m - \epsilon_h)} \tag{4.1.1}$$

$$\phi_h = Q\phi_0, \qquad Q = \frac{abc}{2}\left(\frac{\epsilon_h}{\epsilon_h + L_3(\epsilon_m - \epsilon_h)}\right)\int_\xi^\infty \frac{dq}{(c^2+q^2)f(q)} \tag{4.1.2}$$

where ϵ_m and ϵ_h are the dielectric constant of the metal and the host matrix, ϕ_0 ϕ_I, and ϕ_h are the potentials of the external field, inside the metalic particle and the host

matrix respectively. Where,

$$\phi_0 = -E_0 \left(\frac{(b^2+\xi)(b^2+\eta)(b^2+\delta)}{(a^2-b^2)(c^2-b^2)} \right) \tag{4.1.3}$$

with $\int_{\xi}^{\infty} \frac{dq}{(c^2+q^2)f(q)} = \frac{2L}{abc}$ and as the result,

$$P = \frac{\epsilon_h}{\epsilon_h + L(\epsilon_m - \epsilon_h)}, \qquad Q = \frac{\epsilon_h - \epsilon_m}{\epsilon_h + L(\epsilon_m - \epsilon_h)} \tag{4.1.4}$$

4.2 Extiniction and absorption coefficients

The presence of nano ellipsoidal particles in the transparent host media has resulted in the extiniction of incident beam. If the medium in which the particles are embedded is non absorbing the incident beam can either be absorbed with in the particle or scattered by the particle. Attenuation of electromagnetic waves in a strictly homogenous medium is the result of absorption which is accounted for quantitatively by the imaginary part of the complex refractive index. The absorption coefficient of the nano ellipsoidal particle is related to the absorption cross-section C_{abs} and is proportional to the particle volume, V. Therefore; for aggregated small absorbing Rayleigh particles extiniction is determined mostly by absorption, $\alpha_{ext} = \alpha_{abs} = NC_{abs}$, where N is the particle concentration. The absorption cross-section for an ensemble of randomly oriented nano ellipsoid in the transparent host matrix is

$$C_{abs} = \frac{1}{3} kVIm \left[\frac{\epsilon_h - \epsilon_m}{\epsilon_h + L_1(\epsilon_m - \epsilon_h)} + \frac{\epsilon_h - \epsilon_m}{\epsilon_h + L_2(\epsilon_m - \epsilon_h)} + \frac{\epsilon_h - \epsilon_m}{\epsilon_h + L_3(\epsilon_m - \epsilon_h)} \right] \tag{4.2.1}$$

The absorption coefficient is given by:

$$\alpha_{abs} = NC_{abs} = NkV\Im\beta \tag{4.2.2}$$

where β, is the dipole polarizability, ϵ_m is the dielectric function of the metalic ellipsoidal nano particle and ϵ_h is the dielectric function of the host material. $V = \frac{4\pi}{3}abc$,

and k is the wave number. For metalic nano particles the dielectric function is governed by Drude model. The dielectric function of the host material ϵ_h is considered to be positive and has real value. According to Drude model, with respect to dimensionless variables the real and imaginary part of the dielectric constant of the metal are given by:

$$\epsilon_{mr} = \epsilon_\infty - \frac{1}{z^2 - \delta^2}, \qquad \epsilon_{mi} = \frac{\delta}{z(z^2 - \delta^2)} \tag{4.2.3}$$

with $z = \frac{\omega}{\omega_p}$ and $\delta = \frac{\tau}{\omega_p}$ where τ is the damping frequency due to electrons collisions.

$$\beta_r = \frac{1}{L}\left(1 - \frac{\epsilon_h(\epsilon_h + L(\epsilon_{mr} - \epsilon_h))}{\mid L^2(\epsilon_{mr}^2 + \epsilon_{mi}^2) + 2L\epsilon_h\epsilon_{mr}(1-L) + \epsilon_h^2(1-L)^2 \mid}\right) \tag{4.2.4}$$

$$\beta_i = \frac{L\epsilon_h\epsilon_{mi}}{\mid L^2(\epsilon_{mr}^2 + \epsilon_{mi}^2) + 2L\epsilon_h\epsilon_{mr}(1-L) + \epsilon_h^2(1-L)^2 \mid} \tag{4.2.5}$$

The inspection of the real and imaginary part of the polarizability shows that both real and imaginary part of the polarizability depends on the geometrical factor. The components of the polarizability decreases with an increment of geometrical factor. The resonance condition is achieved at $\epsilon_h + L(\epsilon_{mr} - \epsilon_h) = 0$, assuming taht the imaginary dielectric constant of the metal is much smaller than the real part of the dielectric constant. As the result the real part of the nano ellipsoidal metalic particle is

$$\epsilon_{mr} = \left(\frac{L-1}{L}\right)\epsilon_h \tag{4.2.6}$$

The effective dielectric function of this system in terms of polarizability of the nano ellipsoidal metal particle can be obtained from the Maxwell-Garnet equations:

$$f\beta = \frac{\epsilon_h - \epsilon_m}{\epsilon_h + L(\epsilon_m - \epsilon_h)} \tag{4.2.7}$$

with $f = N\frac{4\pi}{3}abc$ is the volume fraction. N is the number of particles in the volume. With this, the real and imaginary parts of the effective dielectric function of the composite is:

$$\epsilon_r = \left(1 + \frac{f\beta_r}{1 - 2fL\beta_r}\right)\epsilon_h \tag{4.2.8}$$

$$\epsilon_i = \frac{f\beta_i\epsilon_h}{1 - 2fL\beta_r} \tag{4.2.9}$$

4.3 Absorption coefficient of the composite system

In the vicinity of the resonance the dielectric constant of the composite may be written as

$$\epsilon = \epsilon_r + i\epsilon_i \tag{4.3.1}$$

The refractive index n and absorption coefficient $\alpha(\omega)$ are deduced from the complex dielectric constant ϵ in the usual manner, using $n^2 - k^2 = \epsilon_r$, $2nk = \epsilon_i$, and $\alpha = \frac{2\omega k}{c}$. Relating these physical quantities one obtain

$$n = \left[\frac{1}{2}(\epsilon_r + \sqrt{\epsilon_r^2 + \epsilon_i^2})\right]^{\frac{1}{2}} \tag{4.3.2}$$

$$k = \left[\frac{1}{2}(\sqrt{\epsilon_r^2 + \epsilon_i^2} - \epsilon_r)\right]^{\frac{1}{2}} = \frac{\epsilon_i}{2\left[\frac{1}{2}(\epsilon_r + \sqrt{\epsilon_r^2 + \epsilon_i^2})\right]^{\frac{1}{2}}} \tag{4.3.3}$$

$$\alpha(\omega) = \frac{2\omega}{c}\left[\frac{1}{2}(\sqrt{\epsilon_r^2 + \epsilon_i^2} - \epsilon_r)\right]^{\frac{1}{2}} = \frac{\omega\epsilon_i}{c\left[\frac{1}{2}(\epsilon_r + \sqrt{\epsilon_r^2 + \epsilon_i^2})\right]^{\frac{1}{2}}} \tag{4.3.4}$$

4.4 Numerical calculation of the absorption coefficient of the composite

The variation of the absorption coefficient with geometrical factor and concentration of nano ellipsoidal metal inclusions is graphically or numerically obtained using equations (4.2.3-4.3.4) when the inclusions are uniformly oriented in the non absorbing dielectric host media. The calculation is made using the following optical parameters $\epsilon_\infty = 4.5$, $\epsilon_h = 2.5$, $\delta = 0.0115$, $\omega_p = 1.4 \times 10^{16} s^{-1}$ considering silver nano ellipsoidal particles.

Figure 4.1 shows the variation of the absorption coefficient of the composite for different values of geometrical factors. It is observed that the maximum of the absorption coefficient shifts toward the higher frequency as the geometrical factor increases. Moreover, we want to observe the influence of geometrical factor and concentration nano ellipsoidal inclusions. Figure 4.2 and 4.3 describe the spectra for different values of geometrical factor and volume fraction concentration of nano ellipsoidal metal inclusions.It is observed that the magnitude of the absorption coefficient increases, as the number of ellipsoidal metal particles increases in the host matrix. Figure 4.4: shows the spectra of absorption coefficient for fraction of nan ellipsoidal metal concentration for f=0.002, 0.004, and 0.006 for a given constant geometrical factor. The numerical calculation shows that the magnitude of the absorption coefficients increases as the concentration of metals increases with in the host media. This clearly reveals that one can vary the magnitude of absorption coefficient by varying the geometrical factor concentration of the metal inclusions. This makes the composite system a novel material for developing various optical devices and technological applications.

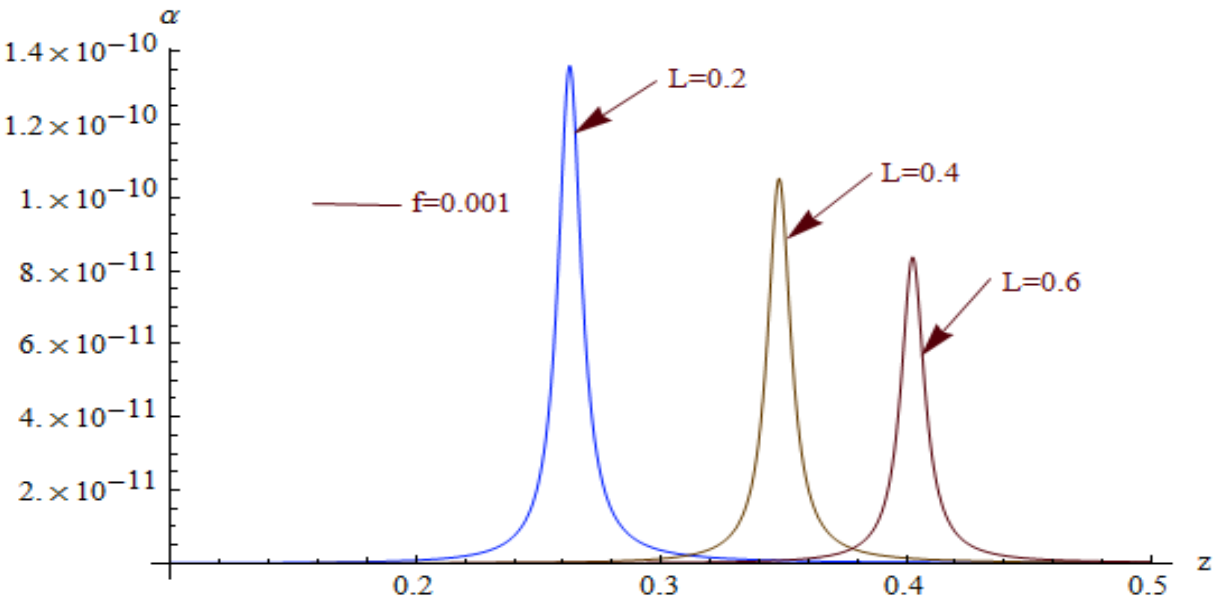

Figure 4.1: *Absorption coefficient of the nano ellipsoidal particle inclusions in the host matrx as a function of geometry*

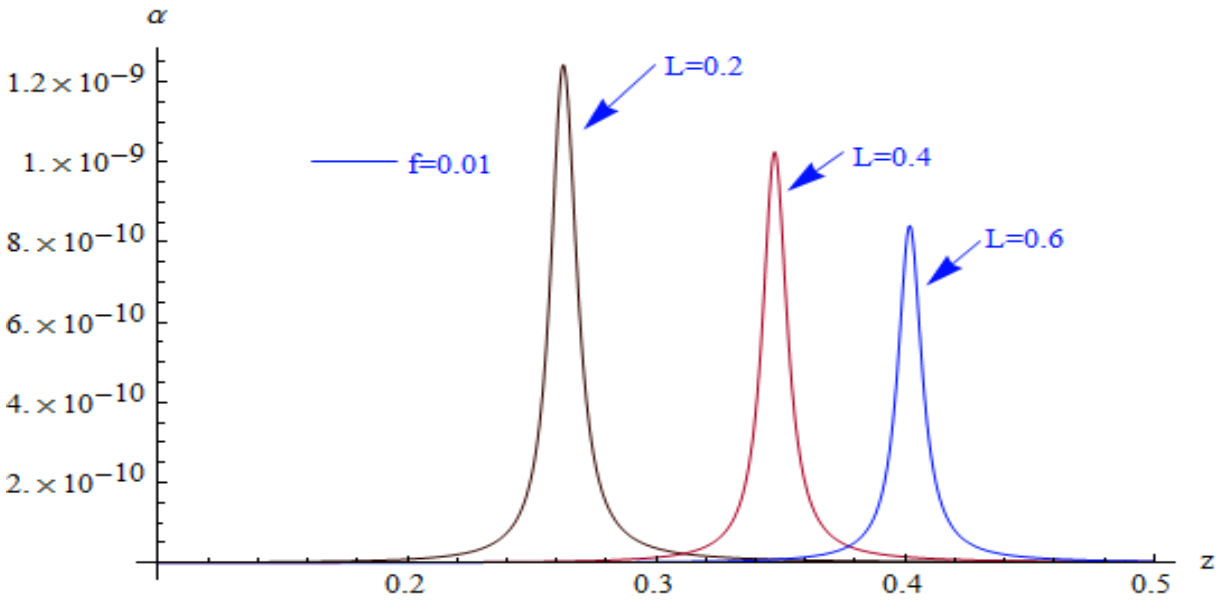

Figure 4.2: *Absorption coefficient of the nano ellipsoidal particle inclusions in the host matrx as a function of geometry and concentration*

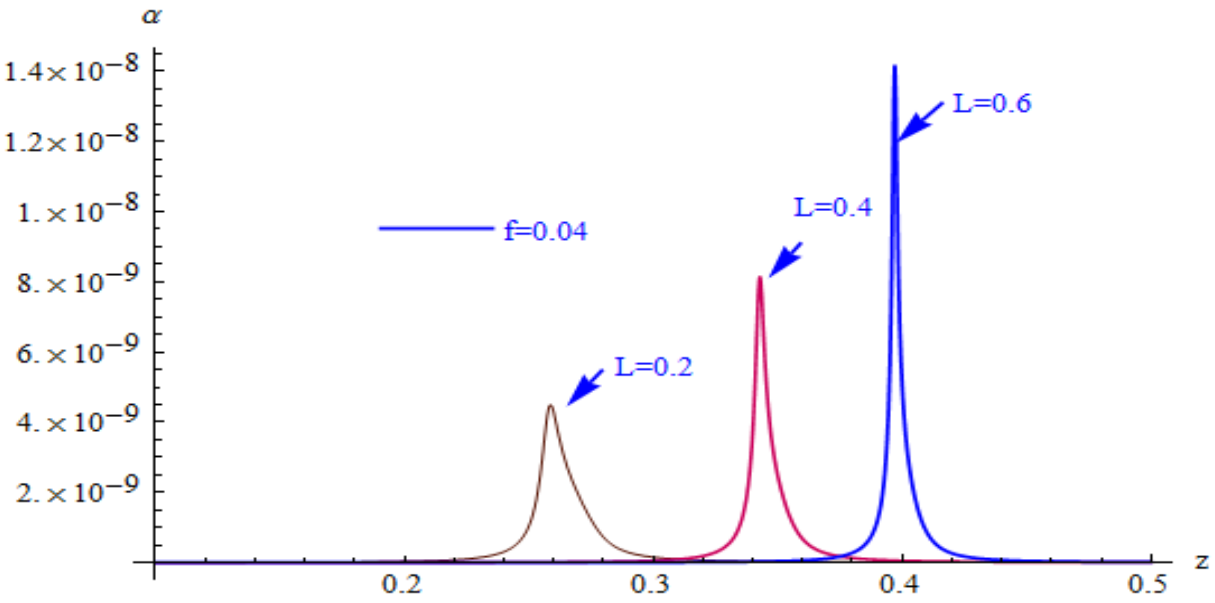

Figure 4.3: *Absorption coefficient of the nano ellipsoidal particle inclusions in the host matrx as a function of geometry and concentration*

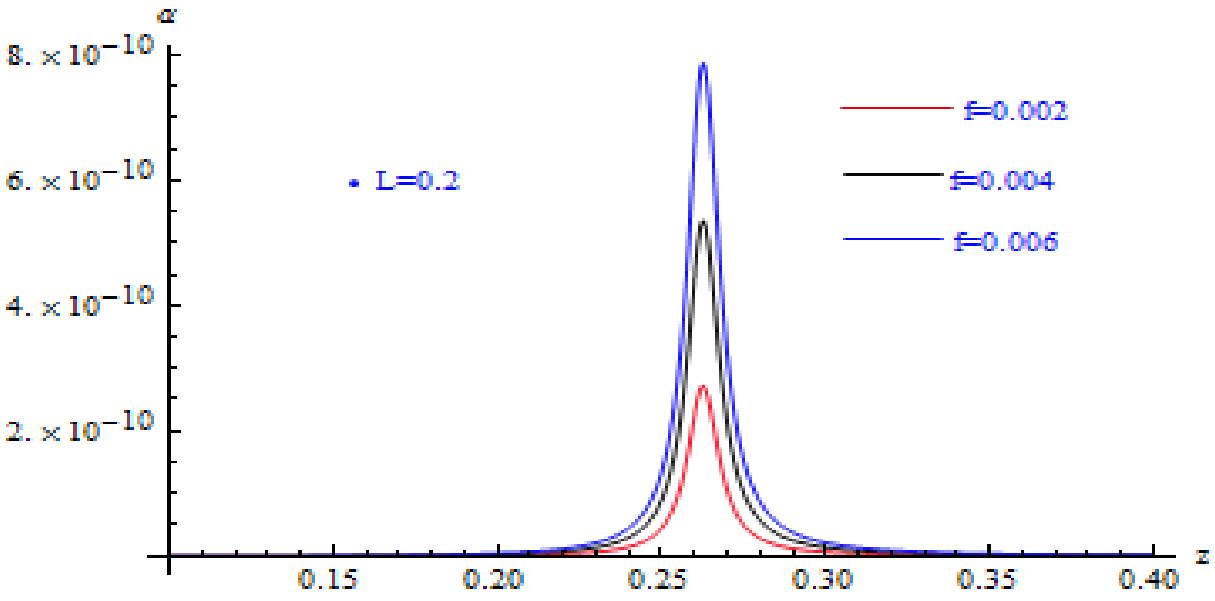

Figure 4.4: *Absorption coefficient of the nano ellipsoidal particle inclusions in the host matrx as a function of geometry and concentration*

Chapter 5

Conclusion

In this study I focused on composite medium consisting identical which are nanoellipsoidal metal embedded in transparent dieclectric material. The effects on the absorption coefficient and attenuation of electromagnetic wave in the composite due to the changes in geometrical factor and concentration of the inclusions computed and analyzed in the figures 4.1-4.4. As we seen in this study the maximum of the absorption coefficient shift toward the higher frequency as the geometrical factor increased. We have also seen in this study the absorption coefficient increase as the concentration of the nanoellipsoidal inclusion in the composite increases for the given geometrical factor (L=0.2). Nanoellipsoidal metal dieclectric composites are needed for different applications which require a frequency range for operation and attenuation of light. These important properties are obtained by properly designing the nano particles composition, size, concentration, orientation and the nature of embedding material.

Bibliography

[1] L.H. Mancini and C.L. Espositoeds, "Nanocomposite preparation properties and performance" (Nova science publishers, Iuc., New York 2003)

[2] Barnes WL. Dereux A and Ebbesen TW, "Surface Plasmon Subwave length optics", Nature 424824 - 30 TW (2003)

[3] Gramotnev DK and Bozhevolny WT, plasmonics beyond the diffraction limit Nature photon, 483 - 91(2010')

[4] Zia R. schuller JA. Chandran A and Brongersma ML Plasmonics the next chip - scale technology Mater. Today, 920 - 72 (2006)

[5] Mic.G. Beitage Zur optic truber medien, speziell kollidaler Metallosungen, Ann. Phys., 25 - 377 - 445(1908)

[6] Shalaev. V.M. Kawata.s' Nanophotkonics with surface plasmons, Advances in mano - optics and Nano - photonics Elsevier, Uk(2007)

[7] Brongersma. ML:kik PG. surface Plasmon Nanophotonics: springer series in OPTICAL SCIENCES 131: springer: Berlin, DE. 2007

[8] Tominasa. J.,Tsaj. DP. Optical Nahotechinologies.The Manipulation of surface and local Plasmon's,Topics in Applied physics. Vol.88, Springer: Berlin (2003)

[9] Righini.M. Girard, C., Quidaut, R: Light - induced manipulation with surface plasmons,J. Opt.A:pure Appl.Opt.10.093001(2008)

[10] Wang,J.,Blau. WJ: Inorganic and hybrid nanostructures for optical limiting,J.Opt.A:Pure Appl.Opt 11.024001(2009)

[11] Kreibig. U., Vollmer.M: Optical Properties of Metal clusters Springer series in Material sience. Vol.25, springer, Berlin (1995)

[12] P.A.Franken, A.E.Hill,C.W. Peters, and G.weinerich, Phys.Rev.Lett.7,118(1961)

[13] T.M. Maiman, R.H. Hoskins, C.K. Asawa, and V.Evtuhov, Phys. Rev. 1231151(1960)

[14] JEANNE,L.McHALE, "Molecular spectroscopy",prentice-HALL,Inc.,1999.

[15] J.D. Jackson, classical electro-dynamics, 3rd ed., Witey, Newyork, (1998)

[16] P.W. Millonni, "Lasers",John wiely and sons,1988.

[17] Gordon M.Barrow, "Introduction to molecular spectroscopy", McGRAW-Hill,1962.

[18] N. N. Lepeshkin et al, Optical Nonlinearities of Metal-Dielectric Composites, Journal of Nonlinear Optical Physics and Materials 8(2), 191-210 (1999)

[19] H.M.Gibbs.SL.Mccal,T.N.C Venkatesan. Phys. Rev . lett .36(1976)113

[20] N.Kalyaniwalla,J.W.Haus,R.Inguva,M.H.Birnboin,Phys.Rev.A42(1990) 5613.

[21] A.E.Neeves,M.H.Birnboim,J.Opt.Soc.Am.B43(1989)787.

[22] K.M.Leung,Phys.Rev.A33(1986)2461.

[23] O.A. Buryi,l.G.Grechko,V.N.Mal'nev,Sisay Shewamare,Ukr.J.Phys.56 (2011) 311.

[24] T.Pan,J.P. Huang,Z.Y.Li,Phys .B301(2001)190.

[25] C.F. Bohren, D.R. Huffman, Absorption and Scattering of Light by Small Particles, Wiley, New York, 1983.

[26] Wenshan,Caijshlaev,Vladimir(November2009).Optical materials.

[27] Granqvist,C.Gj Hunderi,O(1978)"Conductions of inhomogeneous materials: Effective medium theory with dipole-dipole interaction

[28] Stloyd,D.(1975)"Generalized effective medium approach to the conductivity of an inhomogeneous materials".

[29] WEIGLHOTER,W.S;Lakhtakia,A,Michel,B.(1998)"Maxwell-Garnett and Bruggeman formalisms for a particle composite with bianisotropic host medium".

[30] Choy,Tuck.C.(1999)Effective medium Theory(1st edis.) Oxford; Oxford University press 15B N978-19-851892-1.

.

JIMMA UNIVERSITY
COLLEGE OF NATURAL SCIENCES
PERFORMANCE CERTIFICATE FOR MASTER'S DEGREE

Name of Student: **Sisay Areda** ID No. **SSMSC 00912/06**

Graduate Program: **Summer, MSc.**

1. Course Work Performance

Course Code	Course Title	Cr. hr	Number Grade	Rank **	Remark
Phys799	**MSc. Thesis**	**6**			

** Ecellent, Very Good, Good, Satisfactory, Fail.

Thesis Title

Absorption coefficient and attenuation of electromagnetic radiation in nanoellipsoidal metal immersed in transparent media

2. Board of Examiners decision Mark × in one of the boxes. Pass [×] Failed [ ]

   If failed, give reasons and indicate plans for re-examination.

   _____

   _____

3. Approved by: Name and Signature of members of the examining Board, and Deans, SGS

Committee member	Name	Signature	Date
Chairman	_____	_____	_____
External Examiner	_____	_____	_____
Internal Examiner	_____	_____	_____
Major Advisor	_____	_____	_____
_____		_____	_____
Dean, School of Graduate Studies(SGS)		Signature	Date

School of Graduate Studies
Jimma University
College of Natural Sciences
MSc. Thesis Approval Sheet

We the undersigned, number of the Board of Examiners of the final open defense by **Sisay Areda** have read and evaluated his/her thesis entitled "**Absorption coefficient and attenuation of electromagnetic radiation in nanoellipsoidal metal immersed in transparent media**" and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfilment of the requirements for the degree Master of Science in **Physics (Condensed Matter Physics)**.

Name of the Chairperson	Signature	Date
Name of Major Advisor	Signature	Date
Name of Internal Examiner	Signature	Date
Name of External Examiner	Signature	Date

SCHOOL OF GRADUATE STUDIES