INDUCED OPTICAL BISTABILITY IN A COMPOSITE OF ELLIPSOIDAL METAL/DIELECTRIC NANOPARTICLES OF DIELECTRIC CORE

By

TOLASA TAMASGEN HIRPHA

SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN PHYSICS
(CONDENSED MATTER PHYSICS)
AT
JIMMA UNIVERSITY
JIMMA, ETHIOPIA
JUNE, 2015

© Copyright by TOLASA TAMASGEN HIRPHA, 2015

JIMMA UNIVERSITY
DEPARTMENT OF
PHYSICS

The undersigned hereby certify that they have read and recommend to the School of Graduate Studies for acceptance a thesis entitled "**Induced Optical Bistability In a Composite Of Ellipsoidal Metal/Dielectric Nanoparticles Of Dielectric Core**" by **TOLASA TAMASGEN HIRPHA** as a requirement for the degree of **Master of Science in Physics(Condensed Matter Physics)**.

Dated: June, 2015

Supervisor: _____
DR.SISAY SHEWAMARE AND MR.GETNET MELESE

Readers: _____
Dr.SISAY SHEWAMARE AND Mr.GETNET MELESE

_____
Tolasa Tamasgen Hirpha

JIMMA UNIVERSITY

Date: **June, 2015**

Author: **TOLASA TAMASGEN HIRPHA**

Title: **Induced Optical Bistability In a Composite Of Ellipsoidal Metal/Dielectric Nanoparticles Of Dielectric Core**

Department: **Physics**

Degree: **M.Sc.** Convocation: Year: **2015**

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

THE AUTHOR RESERVES OTHER PUBLICATION RIGHTS, AND NEITHER THE THESIS NOR EXTENSIVE EXTRACTS FROM IT MAY BE PRINTED OR OTHERWISE REPRODUCED WITHOUT THE AUTHOR'S WRITTEN PERMISSION.

THE AUTHOR ATTESTS THAT PERMISSION HAS BEEN OBTAINED FOR THE USE OF ANY COPYRIGHTED MATERIAL APPEARING IN THIS THESIS (OTHER THAN BRIEF EXCERPTS REQUIRING ONLY PROPER ACKNOWLEDGEMENT IN SCHOLARLY WRITING) AND THAT ALL SUCH USE IS CLEARLY ACKNOWLEDGED.

This work is dedicated to:My Mother Daditu Urgessa, My brother Hirkissa Temesgen, my sister Eyael Befikadu and my sweet heart Meaza Girma.

Almighty God bless all of my family forever And I love you all!

You work for generation, you live in generation and you are generation.

Table of Contents

List of Tables

List of Figures

Abstract

In this thesis, we studied the enhancement factor of local field for ellipsoidal metal composite, and optical induced bistability of metal/dielectric composites with in linear host matrices which has not been studied in the literature so far. Using the calculated enhancement factor of local field and the cubic equation of the optical induced bistability of the composite material, the parameters of the bistability domain are calculated. The analytical and numerical results show that the enhancement factor of local field is extremely enhanced and the optical induced bistability increased its domain. It is shown that the local field in metal ellipsoidal particles with dielectric core in an external varying electric field has two maxima at two different frequencies. The second maximum becomes more important with increment in the metal fraction. At high metal fraction, the two bistability domains merge and form one entire bistability domain.

Key words: Dielectric function, optical bistability, enhancement factor, depolarization factor

Acknowledgements

First of all, I would like to thank the Alfa-Omega Almighty GOD in which I am success due to his blessings that I have been able to accomplish on this research work.

Next, I would like to express my gratitude, appreciation and respect to my advisor, Dr.Sisay Shewamare for his guidance, invaluable advice and kindness throughout my study.

Besides, I would like to express my heartfelt appreciation and respect to my co-advisor, Mr.Getnet Melese for his unreserved support while I am carrying out this thesis work.

I am respectfully grateful to my Mother Dadhitu Urgessa for she showed me a great true love and strength that made me always to love her through the span of my life. You Mam you are always in my heart, so no one can take you away from me except God.

And also I say thank you all my brothers Hirkissa Temesgen, Sileshi Temesgen and all my youngest brothers. Exceptionally I thank my brother Hirkissa Temesgen sponsoring financially every my expense during my stay in Jimma University without any discouraging me either psychologically and financially. Brother, I say thank you and I love you and respect you.

To my dearest wife, Meaza Girma, for all your patience, courage, and sacrifice of loneliness you put up with when I was completely occupied in this pursuit. I love you and I am honestly humbled by your never-ending support.

Finally, I am grateful to all my friends and colleagues who support me in every aspect directly or indirectly for their constructive advice and appreciation for the success of my thesis work, especially, Sori Abdissa for his support on how to use LATEX and MATLAB. And I am also reverently thankful to Jimma University and Department of Physics.

Chapter 1

Introduction

Recent advances in nanotechnology have allowed the development of robust, and highly sensitive and selective detection methods that are expected to address some deficiencies of conventional detection technologies. Within this context gold (Au), and silver (Ag), nanoparticles have emerged as a powerful tool in sensing and imaging optical applications due to their surprising optical properties. Although silver exhibits many advantages over gold, such as higher extinction coefficients, sharper extinction bands, higher ratio of scattering to extinction, and extremely high field enhancements., it has been employed far less in the development of sensors, with the exception of sensors based on surface enhanced spectroscopes. The reason for this is the lower chemical stability of silver nanoparticles when compared to gold. As a consequence, silver nanoparticles are rapidly gaining in popularity and several research groups have began to explore alternative strategies for the development of optical sensors and imaging labels based on the extraordinary optical properties of these metal nanoparticles [1].

Interaction of light with nanocomposites reveals novel optical phenomena indicating unrivalled optical properties of these materials. The linear and nonlinear optical

response of metal nanoparticles is specified by oscillations of the surface electrons in the Coulomb potential formed by the positively charged ionic core. During the last century optical properties of nanoparticles have extensively been studied and metal-dielectric nanocomposites have found various applications in different fields of science and technology. Since the optical properties of metal nanoparticles are governed by surface plasmon resonance (SPR), and they are strongly dependent on the nanoparticles' size, shape, concentration and spatial distribution as well as on the properties of the surrounding matrix. Control over these parameters enables such metal-dielectric nanocomposites to become promising media for development of novel non-linear materials, nanodevices and optical elements [2].

The physical requirements for optical bistability (OB) are an intensity-dependence, refractive index and an optical feedback mechanism. A system is said to be optically bistable if it can exhibit two steady output states for the same input intensity over some range of input values. The switching up and down operations typical in a hysteresis cycle originates from the rise of instability. A physical state is said to be unstable when, after displaying the system a little from this steady point, the system does not return to it and goes further from it. In other words, for an unstable state, even the slightest perturbation removes the system from it. The searches for instabilities turn out to be crucial in the study of optical bistability (OB) phenomena not only from the theoretical viewpoint but also for the possibilities for practical and technological applications. Since its first discovery in late 1970's, optical bistability has been found existing in many different optical systems. One of the simplest examples of bistable systems is a Fabry-Perot resonator with the cavity filled with a medium that presents saturable absorption or nonlinear dispersion [3],[4, 5].

These optical properties of silver nanoparticles have been recently studied extensively and metal dielectric composite have found various applications in different fields of science and technology site. The original study of the effective optical properties of composite materials were to the analysis of linear media and by considering the contribution of the local field of the particle it is extended to study of the materials with nonlinear part. This is strongly dependent on the nanoparticles size, shape, volume fraction, spatial distribution and the properties of the surrounding matrix. Control over these parameters enables such metal/dielectric nanocomposite to become promising media for development of precious/novel nonlinear materials in nano devices and optical elements [6, 7, 8].

The two main purposes of metal/dielectric composite are: allowing light to enter deeply in the metals, and achieving metal localization which in turn leads to an enhancement of nonlinear response. Another interesting property of metal nanoparticle is the presence of extinction bands in the visible or infrared that results from the so-called plasmon resonances. These resonances do not exist in bulk metals and can be explained to be a consequence of the confinement of free electrons in a space smaller than one-wavelength of light which can be controlled by changing the shape of the nanoparticle and its orientation with respect to the electric field. Furthermore, very small concentration of the nonlinear part contributions can be treated as real and as small perturbations (low field approximation can be assumed) leading which can be assumed to be resulting in linear behavior [9, 10, 11, 12].

Nonlinear optical properties are very important in many different applications in areas of science and technology, such as nano nonlinear microscopy [13], ultra fast laser system [14], wavelength conversion [15], optical routing and switching based on

optically induced bistability both on network [16, 17], and on chips [18]. It is known that metals have fast and strong nonlinear response [19], and can be good element for nonlinear optical applications when they are composed with dielectrics [20, 21].

It has been commonly acknowledged that all-optical devices at the micrometer and nanometer scales is a promising way towards realization of next-generation ultrafast communication and signal processing systems beyond today's microelectronics devices, which have gradually encountered limitation in bandwidth and speed. Optical switching is an essential component in the all-optical network. A feasible approach to all-optical switching is based on optical bistability, an important subject in nonlinear optics [22]. Optical bistability offers many intriguing applications, such as optical memory and optical transistor [23, 24, 25, 26, 27], and among others. In recent years there has been a great interest in exploring and realizing optical bistability in nonlinear nanophotonic systems.

The aim of this study is a detailed theoretical and numerical analysis of the local field enhancement, induced optical bistability and the bistability domain in small metal/semiconductor particles in the electrostatic approximation in the composite of metal/dielectric core for ellipsoidal nanoparticle. We account for a cubic nonlinearity in the polarization with respect to the local electric field. In unit 5, Section 1, we analyze the local field enhancement inside an ellipsoidal metal/dielectric particle embedded into a dielectric matrix when the incident electric field is parallel to one of the ellipsoid axes. In unit 6, Section 1 we study the enhancement factor and IOB of a two-layer nonlinear dielectric ellipsoidal particle covered by a metal shell. Lastly in unit 6, Section 2, is devoted to the analysis of the IOB domain for these particles.

1.1 Statement of the problem

In this thesis work, we have addressed the following:

• How the optical induced bistability is affected in small ellipsoidal metal/dielectric composite embedded in host matrix.

• How to calculate and study the effect of the enhancement factor in optical bistability, and to explore the effects in ellipsoidal metallic/dielectric composite inclusion.

1.2 Objectives

1.2.1 General objectives

The general objective of thesis work is:

• To study the enhancement and the optical induced bistability in the small ellipsoidal metal/dielectric composite analytically and numerically.

1.2.2 Specific objectives

The specific objectives are:

• To study the optical induced bistability in small ellipsoidal nanometal/dielectric composites embedded in dielectric host matrix.

• To investigate the enhancement of local field in small ellipsoidal nanometal/dielectric composites embedded in dielectric host matrix.

1.3 Significance of the study

This study has a contribution for the advancement of Nanodevice and Nanotechnology of the novel optical properties of nanomaterials. It will provide good opportunity on

knowledge and application for the researcher and other who are interested to do more investigation on the optical nanotechnology.

1.4 Scope of the study

The study have addressed enhancement factor that can have affected by varying depolarization factor and frequency, and a dielectric core of host matrix, dependence of induced optical bistability on the incident field supply.

Chapter 2

Literature Review

Nanoscience is a new emerging area of science that involves studying and working with matter at nanoscale, on the order of 10^{-9}m. Structures in nanoscale, called nanostructures, are considered at the borderline of the smallest of human made-devices and the largest molecules of living systems. Nanostructures include all shapes: wires, rods, dots-formed from all of the industrially important semiconductor materials [7].

Nonlinear optics is the study of phenomena that occur as a consequence of the modification of the optical properties of a material system by the presence of light. Typically, only laser light is sufficiently intense to modify the optical properties of a material system. The beginning of the field of nonlinear optics is often taken to be the discovery of second-harmonic generation by Franken, et al. (1961), shortly after the demonstration of the first working laser by Maiman in 1960 [28].

Nonlinear optical phenomena are "nonlinear" in the sense that they occur when the response of a material system to an applied optical field depends in a nonlinear manner on the strength of the optical field. For example, second-harmonic generation occurs as a result of the part of the atomic response that scales quadratically with the strength of the applied optical field. Consequently, the intensity of the light generated

at the second-harmonic frequency tends to increase as the square of the intensity of the applied laser light [4].

Certain nonlinear optical systems can possess more than one output state for a given input state. The term optical bistability refers to the situation in which two different output intensities are possible for a given input intensity, and the more general term optical multistability is used to describe the circumstance in which two or more stable output states are possible. Interest in optical bistability stems from its potential usefulness as a switch for use in optical communication and in optical computing. Optical bistability was first described theoretically and observed experimentally using an absorptive nonlinearity by Szke, et al. (1969). Optical bistability was observed experimentally for the case of a refractive nonlinearity real $\chi^(3)$ by Gibbs, et al. (1976) [4, 7, 5].

The first studies reported about optical bistability in laser diode come from the sixties. Main works were done during eighties, most relevant are recompiled on mainly in passive optical bistability; following some of the previous works on optical semiconductor oscillators and amplifiers. It has been an intensive research topic due to the huge potential applications of these devices in different fields of technology, such as optical computing and optical communications and for the practical advantages of laser amplifiers: the presence of gain, fast response, low optical power requirements to achieve bistability etc. As a matter of fact, in optical computing, the nonlinear behavior exhibited by the laser amplifier leads to the possibility of using this kind of devices as basic components in the developing of logic gates. In the other hand, in optical communications these devices could be employed in optical switching applications, optical signal regeneration and optical head packet processing, in addition the

usual use in long range links [29].

Optical bistability has been predicted by theory or demonstrated by experimental studies to exist in waveguide-ring resonators [27], photonic crystal cavities [30, 31, 32], subwavelength metallic gratings [33], metal gap waveguide nanocavities [34], and nanoantenna with amorphous silicon filled in the gap [35]. It is important to achieve a deeper understanding of the basic physics of optical bistability at the nanoscale in order to design and realize high-performance nanophotonic switching devices.

The interaction of light with metal surface results in the collective oscillation of the surface free electrons. This phenomenon is called surface plasmon resonance. A strong resonance occurs roughly at the electromagnetic frequency, where, $\varepsilon_r = -2\varepsilon_m$ thus determining the surface plasmon resonance (SPR) frequency, where ε_r is dielectric function at resonance occur,ε_m is metallic dielectric function. For gold (Au), silver (Ag), and copper (Cu), the resonance condition is fulfilled at visible frequencies, making them the plasmonic metals of choice for optical applications. Different from the spectrum of bulk metals, the spectrum of noble nanoparticles have a very strong UV/visible absorption band. This absorption band results when the incident photon frequency is in resonance with the collective excitation of the conduction electrons and is known as localized surface Plasmon resonance [36].

Chapter 3

Background

3.1 Fundamentals of the optics

In order to describe more precisely what we mean by an optical nonlinearity, let us consider how the dipole moment per unit volume or polarization $\widetilde{P}(t)$ of a material system depends on the strength $\widetilde{E}(t)$ of an applied optical field. In particular, the linear polarization provides an extensive description of the light-matter interaction when the intensity of the incident radiation is sufficiently small; whereas the nonlinear optical response of a medium depends on the strength of the applied optical field, $\widetilde{E}(t)$ [28].

Polarization is the dipole moment per unit volume of a material system which depends on the strength $\tilde{E}(t)$ of an applied optical field. In the case of conventional (i.e. linear) optics, the induced polarization depends linearly on the electric field strength in a manner that can often be described by the relationship

$$\widetilde{P}(t) = \varepsilon_o \chi^1 \widetilde{E}(t) \tag{3.1.1}$$

where $\widetilde{P}(t)$ is linear polarization, χ^1 is a linear susceptibility and ε_o is the permittivity of the free space.

In nonlinear optics, the optical response can often be described by generalizing the linear expression of polarization $\widetilde{E}(t)$ as a power series in the field strength $\widetilde{E}(t)$ as

$$\widetilde{p}(t) = \varepsilon_o \chi^1 \widetilde{E}^1(t) + \varepsilon_o \chi^2 \widetilde{E}^2(t) + \varepsilon_o \chi^3 \widetilde{E}^3(t) + ... \tag{3.1.2}$$

where generalizing polarization

$$\widetilde{p}(t) = \widetilde{P}^1 + \widetilde{P}^2 + \widetilde{P}^3 + ... \tag{3.1.3}$$

where χ^2 and χ^3 are second order and third order nonlinear optical susceptibilities. Nonlinear optics is a field of optics that describes the changes of the optical properties of materials in the presence of light. This behavior is contrary to everyday experience, but is firmly rooted in the interaction of light with matter at atomic scales. An effect resulting from nonlinear optics arises from light at large intensities within materials. These nonlinear properties produce a plethora of interesting phenomena such as wave mixing and bistability. In this chapter, a basic introduction to nonlinear optics is provided. Nonlinear optics is a rich field that provides many useful applications in fundamental science and technology; however, focus is given on optical materials and phenomena directly related to content of this thesis.

3.2 Nonlinear optical materials

Nonlinear optical materials give rise to a multitude of phenomena that have important applications in technology and science. One fundamental example is harmonic generation, in which light combines to form new light at integer multiples of the input frequency. Materials capable of harmonic generation are of practical importance since they are able to generate or detect light at frequencies that are not available in

current optical devices. Another fundamental example is optical bistability, in which the intensity of the output light can take two distinct stable values for a given input, creating an optical two-state system. Bistable devices, such as optical logic gates and memory, are critically important for optical computing, which promises much faster computation than in current electronic devices [28].

The degree of optical nonlinearity in a material depends upon the strength of the optical field, and varies in different materials. Due to very small nonlinearities in naturally occurring materials, large optical fields are necessary to realize measurable nonlinear phenomena. The necessity of high intensity sources to observe the effects of optical nonlinearity severely limit its use in practical applications, especially in low-powered devices. To realize such devices, the enhancement of nonlinear material properties is required. Recently, there has been interest in characterizing the optical response of subwavelength metallic structures containing nonlinear dielectric materials [37].

According to preliminary evaluation, the enhancement factor can reach values within the range 200-300. This means that for the laser radiation the local strength of the electric fields inside the particles can reach the values of inter atomic fields. This in turn requires account of the nonlinear part of the dielectric function of the metal and dielectric. It is also planned to obtain the factor for the induced optical bistability (IOB) effect which favor for the increasing the enhancement factor and evaluate for the induced optical bistability[12].

The macroscopic electric field in a medium alone does not completely describe the response of the medium to an applied external electric field. Because that, the external field drives the bound charges of the medium apart and induces a collection

of dipole moments. In an optically dense medium, the interaction of the induced dipoles in the medium is determined by taking into account of the local field factor. The local field is considered by starting from nature of macroscopic properties of the medium [4].

In our work, the main objective is to obtain the enhancement factor for the metallic particles of ellipsoidal shape: the ellipsoidal dielectric particles covered by the metal shell for the host matrices with optical induced bistability effect. The results will be presented in the form of 3D graphs with the aim to find the ranges of parameters where enhancement factor has the largest value. This means that for the laser radiation, the local strength of the electric fields inside the particles can reach the values of inter atomic fields. This in turn requires account of the nonlinear part of the dielectric function of the metal and dielectric. It is also planned to obtain the factor for the optical induced bistability effect which favor for the increasing the enhancement factor and evaluate for the OIB.

Chapter 4

Methodology and Materials

4.1 Methodology

We have employed numerical and computational simulation methods using MATLAB program by developing suitable computer codes to study how depolarization factor L affect the enhancement factor in the metal/dielectric/semiconductors. These research works have been carried out analytically and numerically.

4.2 Materials

For the analytical and numerical simulation MATLAB Soft ware was used to develop program code for our model equation and simulating the dielectric function of the composite materials. To make our result effective we have compared with physics thesis published nationally and internationally. Mathematica software was used to manage long analytical and numerical expression for scientific work and to simplify bulged equations into figural expressions.

Chapter 5

Analytically and numerically study of enhancement factor in the small ellipsoidal metal/dielectric with composite of dielectric core

The optical response for a collection of free electrons can be obtained from the Lorentz harmonic oscillator model by simply 'climbing the springs' that is by setting the spring constant k is equal to zero. Therefore, for ω is incident frequency and dielectric function for free electron is given by;

$$\varepsilon(\omega) = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2 + i\nu\omega}, \tag{5.0.1}$$

where $\varepsilon(\omega)$ is dielectric function as a function angular velocity, ω_p is plasma frequency and ε_∞ is a dielectric constant.

Let an electromagnetic wave shined/impinge on a metal particle in the form of a rotational ellipsoid embedded in a dielectric host matrix. The dielectric function of the particle is assumed to depend on the frequency ω and the local electric field (inside the particle) and can be presented in the form

$$\varepsilon(\omega, \overrightarrow{E}) = \varepsilon(\omega) + \chi(\omega)|\overrightarrow{E}|^2, \tag{5.0.2}$$

where $\varepsilon(\omega, \overrightarrow{E})$ is a dielectric function as the function of angular frequency and electric field, $\chi(\omega)$ is the complex Kerr coefficient, and the linear parts of the dielectric function is

$$\varepsilon(\omega) = \varepsilon^{'}(\omega) + i\varepsilon^{''}(\omega). \tag{5.0.3}$$

And let us have both real and imaginary parts from above equations as follows for real parts we have the following equation

$$\varepsilon^{'}(\omega) = \varepsilon_{\infty} - \frac{\omega_p^2}{\omega^2 + \nu^2}, \tag{5.0.4}$$

and for imaginary parts also we have the following equation

$$\varepsilon^{''}(\omega) = \varepsilon_{\infty}^{''} + \frac{\omega_p^2 \nu}{\omega(\omega^2 + \nu^2)}. \tag{5.0.5}$$

5.1 The Enhancement Of Local Field In The Small Ellipsoidal Metal/Dielectric Particles

In a dilute gas of atoms the electric field $\overrightarrow{E}$ that produces the induced dipole moment on an atom is simply the applied electric field. In a solid, however, all of the dipole moments produced on other atoms in the solid make a contribution to the field acting on a given atom. The value of this microscopic field at the position of the atom is called the local field. The local field $\overrightarrow{E}_{LF}(\overrightarrow{r})$ is different from the applied electric field $\overrightarrow{E_0}$ and from the macroscopic electric field $\overrightarrow{E}$ (which is the average of the microscopic field $\overrightarrow{E}_{LF}(\overrightarrow{r})$ over a region that is large compared to a unit cell). Clearly, the contributions to the microscopic field from the induced dipoles on neighboring atoms vary considerably over the unit cell [6].

From the size dependence of the surface plasmon (SP) frequency, it is quite obvious that metal nanoparticles with non-spherical shape will show several SP resonances in their spectra. For instance, ellipsoidal particles with axes a = b = c spherical posses three SP modes corresponding to polarizabilities along the principal axes. Moreover, an increase in the axis length leads to the minimization of the depolarization factor (L). For a spherical particle $L_a = L_b = L_c = \frac{1}{3}$ [5]. Thus, if the propagation direction and polarization of the electromagnetic wave do not coincide with the axes of the ellipsoid, the extinction spectra can demonstrate three separate SP bands corresponding to the oscillations of the free electrons along these axes.

However, if the incident light is polarized parallel to one of the axes, only one single SP band exist corresponding to the appropriate axis. Tn the case where two SP resonances are observed the band lying at higher wavelengths is referred to as the long axis, while the small axis demonstrates resonance at shorter wavelengths compared to the single resonance of a nanosphere of the same volume. The spectral separation of the two surface plasmon bands of the ellipsoidal nanoparticle strongly depends on its aspect ratio which is defined as the ratio of the long to the short axes. At the same time, it is clearly seen that for prolate and oblate spheroids having the same aspect ratio, the positions of SP resonances are different. Namely, the spectral separation between SP bands is higher for the nanoparticles having a zeppelin-like shape [5].

5.1.1 Depolarization factor

The most general smooth particle, one without edges or corners of regular shape, is an ellipsoid with semiaxes $a > b > c$. To check these results we notes that the sphere

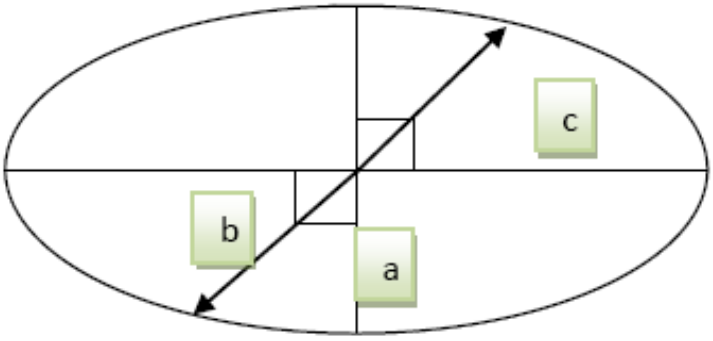

Figure 5.1: Ellipsoid for length axes for $a > b > c$ and depolarization factor for b = c and $L_2 = L_3$, and b = a and $L_1 = L_2$

is a special ellipsoid for $a = b = c$. Only when the particle is in free space ($\varepsilon_m = \varepsilon_0$) are its depolarization factors independent of composition. In the nature we note that there is no perfect sphere. Therefore, as we said a special class of sphere is ellipsoid when its depolarization is given by,

$$L_1 = L_2 = L_3 = \frac{a^3}{2} \int_0^\infty \frac{dq}{(a^2+q)^{\frac{5}{2}}} = \frac{1}{3} \tag{5.1.1}$$

where **dq** is coordinate derivation along the length axis. **q** is coordinate , **a** is an axis length.

A special class of ellipsoids is the spheroids, which have two axes of equal length; therefore, only two of the geometrical factors of L_1, L_2, L_3 is independent because of the relation

$$L_1 + L_2 + L_3 = -abc \int_0^\infty \frac{dq}{f(q)} = 1 \tag{5.1.2}$$

where a, b and c are the length of the axes.

The prolate (cigar-shaped) spheroids, for which b = c and $L_2 = L_3$, are generated by rotating an ellipse about its major axis; the oblate (pancake-shaped) spheroids,

for which b = a and $L_1 = L_2$, are generated by rotating an ellipse about its minor axis.

5.2 Enhancement Factor Of Local Field For Metal/Dielectri Composite

Consider a composite system that consists of an ellipsoidal shaped dielectric core of dielectric constant ε_d, a metal/semiconductor particle with dielectric function ε_m embedded in host matrix having a dielectric function ε_h is as shown Fig.5.1. Using this we will derive the enhancement factor A.

For the derivation, we use Laplace's equation in spherical coordinate. For our case we want to derive enhancement factor A for ellipsoid particle by using this spherical coordinates as reference. Now, we have to use the depolarization factor to shift spherical into ellipsoid shape particle [5].

To simplify our derivation we have set the following two basic cases :

1. The potential is the same for r = r_1 and r = r_2 and it is continuous at boundary
2. Displacement vector is continuous and the same at the boundary for r = r_1 and r = r_2.

Using Laplace's equation in spherical coordinates [5, 6] the potential is given by:

$$\Phi(r,\theta) = \sum (A_n r^n + B_n r^{-n+1}) P_n(\cos\theta) \tag{5.2.1}$$

where A and B are constants that can be determined using boundary conditions.

After certain manipulations, we got the following three basic equations for my numerical manipulation for certain range of radius difference.

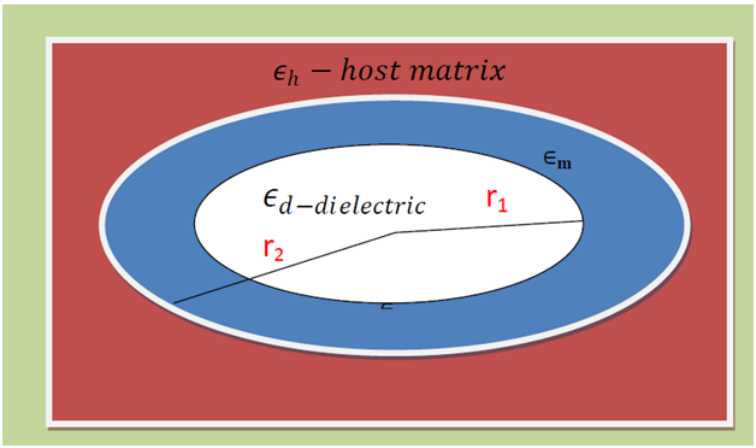

Figure 5.2: The construction of ellipsoidal by the combination of dielectric ε_d in core, metallic dielectric ε_m outside coverage of dielectric and finally host matrix ε_h external coverage of dielectric and metallic

However,the distribution of the electric potential in the system is described by the following expressions for they are the solutions of the Laplace equations of the dielectric core, metal and the host matrix, respectively.

$$\Phi_1 = -E_h A r \cos\theta, r \leq r_1 \tag{5.2.2}$$

$$\Phi_2 = -E_h (Br - \frac{C}{r^2}) \cos\theta, r_1 \leq r \leq r_2 \tag{5.2.3}$$

$$\Phi_h = -E_h (r - \frac{D}{r^2}) \cos\theta, r > r_2 \tag{5.2.4}$$

Here Φ_1 ,Φ_2, and Φ_h are potentials in the dielectric core, metal,and the host matrix, respectively, $\overrightarrow{E}_h$ is the applied field, r and θ are the spherical coordinates of the observation point(the z-axis is chosen along the vector $\overrightarrow{E}_h$), r_1 ,r_2 are radiuses of the dielectric core and the metal shell,respectively. A,B,C,D are unknown coefficients.

Their solutions are derived using Laplace equations of the metal/dielectric inclusion and the host matrix, respectively. Here Φ is potential, $\overrightarrow{E}_h$ is the applied field, r and θ are the coordinates of the spherical coordinates (the beginning of the coordinate in the center of the inclusion and the z axis is along $\overrightarrow{E}_h$). We obtain a system of linear algebraic equations for unknown coefficients A and B from the continuity conditions of the potential and the displacement vector at the boundaries: metal-host matrix.

From the continuity conditions of the potential at the boundaries of dielectric core and metal/dielectric cover equation (5.2.2) and (5.2.3) becomes

$$A = B - \frac{C}{r_1^3} \tag{5.2.5}$$

Then, also from continuity conditions of the potential at the boundaries of metal/dielectric and host equation (5.2.3) and (5.2.4) also becomes,

$$B - \frac{C}{r_2^3} = 1 - \frac{D}{r_2^3} \tag{5.2.6}$$

From the continuity conditions of the displacement vector at the boundaries of dielectric core and metal/dielectric cover

$$A\varepsilon_d = \varepsilon_m(B + 2\frac{C}{r_1^3}) \tag{5.2.7}$$

and equation (5,2.9) of metal/dielectric function and host matrix.

By introducing the depolarization factor L in the equation (5.2.7) of spherical equation setting that have ellipsoidal shape and comparing with spherical shape of metal/dielectric particles,

$$LA\varepsilon_d = L\varepsilon_m B + (1 - L)\frac{C}{r_1^3} \tag{5.2.8}$$

Applying the boundary condition for the displacement vector at the metal/dielectric and host matrix interface, we get from equation (5.2.2) and (5.2.3)

$$\varepsilon_m(B + \frac{2C}{r_2^3}) = \varepsilon_h(1 + \frac{2D}{r_2^3}) \tag{5.2.9}$$

And introducing depolarization factor in equation (5.2.9),

$$L\varepsilon_m B + \varepsilon_m(1-L)\frac{C}{r_2^3} = L\varepsilon_h + (1-L)\frac{D}{r_2^3} \tag{5.2.10}$$

Let us put equation (5.2.6) into (5.2.10),

$$B = \frac{C}{r_1^3}\frac{(1-L)\varepsilon_m + L\varepsilon_d}{L\varepsilon_d - \varepsilon_m} \tag{5.2.11}$$

Also, put this equation (5.2.11) into (5.2.8), Here, new definition is happened what we called volume fraction in which it is the volume difference of two radial of

$$\frac{r_1}{r_2} = 1 - P$$

.

Again put (5.2.11)into (5.2.6),

$$\frac{C}{r_1^3}\frac{L\varepsilon_d + \varepsilon_m(1-L) - (1-P)(L\varepsilon_d + L\varepsilon_m)}{L(\varepsilon_d + L\varepsilon_d} = 1 - \frac{D}{r_2^3} \tag{5.2.12}$$

And the equation (5.2.10) is become,

$$\frac{C}{r_2^3}\frac{\varepsilon_m^2 L(1-L) + L^2\varepsilon_m\varepsilon_d + L(\varepsilon_d + \varepsilon_m)(1-L)(1-P)\varepsilon_m}{L(\varepsilon_d + \varepsilon_m)} = L\varepsilon_h + \varepsilon_h(1-L)\frac{D}{r_2^3} \tag{5.2.13}$$

By taking their ratio of (5.2.12) and (5.2.13) two equation we get,and simplifying we arrived on,

$$\frac{\varepsilon_m + LP(\varepsilon_d - \varepsilon_m)}{(L)\varepsilon_d\varepsilon_m(1-P) + LP\varepsilon_m(\varepsilon_d - \varepsilon_m) + P\varepsilon_m^2} = \frac{1 - \frac{D}{r_2^3}}{L\varepsilon_h + \varepsilon_h(1-L)\frac{D}{r_2^3}} \tag{5.2.14}$$

Let

a $= \varepsilon_m\varepsilon_d - P\varepsilon_m(\varepsilon_d - \varepsilon_m) + LP\varepsilon_m(\varepsilon_d - \varepsilon_m)$

b $= \varepsilon_m + LP(\varepsilon_d - \varepsilon_m)$

Now, the equation (5.2.14) is reduced into

$$\frac{b}{a} = \frac{1 - \frac{D}{r_2^3}}{L\varepsilon_h + \varepsilon_h(1-L)\frac{D}{r_2^3}} \tag{5.2.15}$$

Rearranging this (5.2.15) we get

$$\frac{D}{r_2^3} = \frac{(a - b\varepsilon_h)}{La + b\varepsilon_h(1-L)} \tag{5.2.16}$$

And also, putting (5.2.15) value we get

$$\frac{C}{r_2^3} = \frac{(\varepsilon_d - \varepsilon_m)\varepsilon_h}{La + b\varepsilon_h(1-L)} \tag{5.2.17}$$

By collecting all together we get the constant value of 'A' as,

$$A = \frac{\varepsilon_h\varepsilon_m}{La + b\varepsilon_h(1-L)} \tag{5.2.18}$$

To summarize from continuity condition for the potential and displacement at boundaries we obtained a constants A, B, C, and D using equation (2),(3)and (4).

$$A = \frac{\varepsilon_h\varepsilon_m}{La + b\varepsilon_h(1-L)} \tag{5.2.19}$$

$$B = \frac{C}{r_1^3}\frac{(1-L)\varepsilon_m + L\varepsilon_d}{\varepsilon_d - \varepsilon_m} \tag{5.2.20}$$

$$D = \frac{(a - b\varepsilon_h)}{a + b\varepsilon_h(1-L)}r_2^3 \tag{5.2.21}$$

$$C = \frac{(\varepsilon_d - \varepsilon_m)\varepsilon_h}{La + b\varepsilon_h(1-L)}r_2^3 \tag{5.2.22}$$

Here by substituting the value of both 'a' and 'b' into A value equation in which it is multiplied each terms to simplify into

$$A = \frac{\varepsilon_h \varepsilon_m}{\varepsilon^2(LP(1-L)) + \varepsilon_m[\varepsilon_h(1-L) - \varepsilon_h LP(1-L) + L\varepsilon_d(1-P) + L^2 P\varepsilon_d] + \varepsilon_h\varepsilon_d LP(1-L)} \tag{5.2.23}$$

Let us introduce the following notation:

$a_1 = LP(1-L)$,

$a_2 = \varepsilon_h(1-L) - \varepsilon_h LP(1-L) + L\varepsilon_d(1-P) + L^2 P\varepsilon_d$

$a_3 = \varepsilon_h\varepsilon_d LP(1-L)$

Therefore, the enhancement factor which is complex becomes

$$A = \frac{\varepsilon_h \varepsilon_m}{a_1\varepsilon_m^2 + a_2\varepsilon_m + a_3} \tag{5.2.24}$$

Recall that the dielectric function of the metal/dielectric inclusion is given by

$$\varepsilon_m = \varepsilon_m^{'} + i\varepsilon_m^{''} \tag{5.2.25}$$

The modulus of this equation is

$$\varepsilon_m^2 = \varepsilon_m^{'2} - \varepsilon_m^{''2} + 2i\varepsilon_m^{'}\varepsilon_m^{''} \tag{5.2.26}$$

By substituting this metallic dielectric into enhancement factor value of A, we get the following equation:

$$|A|^2 = \frac{[|\varepsilon_h|^2\varepsilon_m^{'2} + \varepsilon_m]^{''2}}{(a_1(\varepsilon_m^{'2} - \varepsilon_m^{''2}) + a_2\varepsilon_m^{'} + a_3)^2 + (2a_1 + \varepsilon_m^{'}\varepsilon_m^{''} + a_2\varepsilon_m^{''})^2} \tag{5.2.27}$$

This equation is called enhancement factor of unknown coefficient from our initial equation, where the metallic dielectric function from Lorentz classical model is given

by

$$\varepsilon_m^{'} = \varepsilon_\infty^{'} - \frac{1}{z^2 + \gamma^2} \tag{5.2.28}$$

$$\varepsilon_m^{''} = \varepsilon_\infty^{''} + \frac{\gamma}{z(z^2 + \gamma^2)} \tag{5.2.29}$$

Where, $\varepsilon_\infty^{'}$ and $\varepsilon_\infty^{''}$ are constants that can be depend on the type of metal and z is a dimensionless frequency, where (z=$\frac{\omega}{\omega_p}$ and $\gamma = \frac{\nu}{\omega_p}$).

Chapter 6

Result and Discussion

6.1 Enhancement factor of local field for ellipsoidal metal/dielectric composite core

Let us consider an individual composite of small metal/dielectric function and let an electromagnetic wave impinge on a metal particle in the form of a rotational ellipsoid embedded in a dielectric host matrix. The dielectric function of the particle is assumed to depend on the frequency ω and the local electric field E (inside the particle) and can be presented in the form

$$E_{LF} = A \cdot E_h, \tag{6.1.1}$$

where A is enhancement factor which is obtained to be:

$$\mathcal{A} = \frac{\varepsilon_h \varepsilon_m}{a_1 \varepsilon_m^2 + a_2 \varepsilon_m + a_3} \tag{6.1.2}$$

where

$a_1 = LP(1-L)$

$a_2 = \varepsilon_h(1-L) - \varepsilon_h LP(1-L) + L\varepsilon_d(1-P) + L^2 P\varepsilon_d$

$a_3 = \varepsilon_h \varepsilon_d LP(1-L)$

Used physical quantities	*Value assigned for each*
ε_h	2.25
ε_d	0.5
P	0.99
$\varepsilon_\infty^{'}$	4.6
$\varepsilon_\infty^{''}$	0
γ	0.0115
a_1	$L \cdot P(1-L)$
a_2	$\varepsilon_h(1-L) - \varepsilon_h LP(1-L) + L\varepsilon_d(1-P) + L^2 P\varepsilon_d$
a_3	$\varepsilon_h\varepsilon_d LP(1-P)$
$\varepsilon_m^{'}$	$\varepsilon_\infty - \frac{1}{(z^2+\gamma^2)}$
$\varepsilon_m^{''}$	$\frac{\gamma}{z(z^2+\gamma^2)}$
z	0.38 - 0.54
L	0.34 - 0.38

Table 6.1: The list of physical quantities and their value used to draw the figure

Now, we have to assign value for the parameters in (6.1.2) and set their value in table form;

Using above listed numerical value we have use to draw enhancement factor by varying depolarization factor L versus dimensionless frequency z of the following figure.

where, ω_p is plasma frequency, in which it given by: $\omega_p = \sqrt{\frac{Ne^2}{m_e\varepsilon_0}}$, which is called Drude plasma frequency, m_e mass of electron, N is used for number of electrons per unit volume (or is the concentration), e is the charge of an electron, P is the fraction volume.

From figure 6.1 we have to understood that for dielectric function ε_d kept at center of small ellipsoidal particle. The depolarization factor L and dimensionless frequency

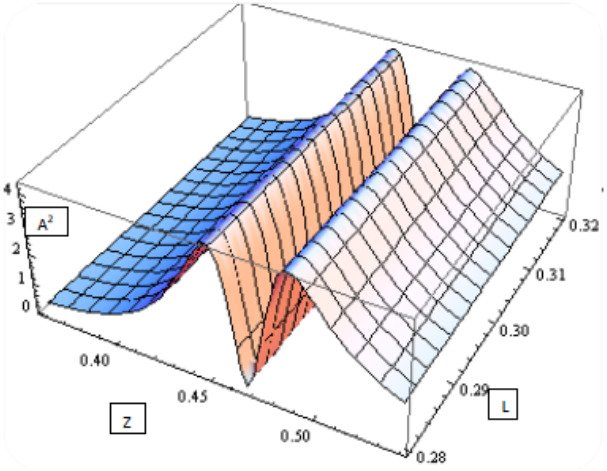

Figure 6.1: 3D plot for enhancement factor $|A|^2$ of a silver nanoparticle versus z and L; $\varepsilon_h^{'} = 2.25$, $P = 0.99$, $\varepsilon_h^{''} = 0$, $\varepsilon_\infty^{'} = 4.6$, $\varepsilon_\infty^{'} = 0$, $\gamma = 0.0115$, $\omega_p = 1.46 \times 10^{16} rad/sec$, $\nu = 1.68 \times 10^{14} rad/sec$.

z play a key role for enhancement by fixing depolarization as example at point $z_1 = 0.38, z_2 = 0.54$ and $L_1 = 0.34, L_2 = 0.38$. Therefore, as we see from fig 6.1 the dielectric function have an effect to enhance by presence local field in the region, to increased enhancement factor.

6.2 Enhancement factor of local field for ellipsoidal metal/dielectric composite in 2D for depolarization factor L

Now here, we will study (explore) the enhancement factor drawn for two dimension (2D), while Fig 6.1 is drawn for three dimensions (3D). The physical quantities used in fig 6.1 the same to Fig 6.2. But they have difference in plotting 2D and 3D in

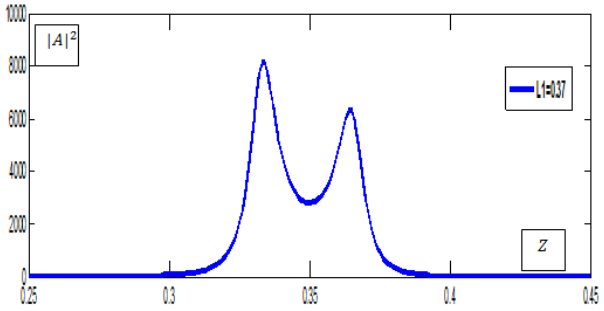

Figure 6.2: 2D plot of the enhancement factor $|A|^2$ of a silver particle versus z, L = 0.37; $\omega_p = 1.46 \times 10^{16} rad/sec$,$\nu = 1.68 \times 10^{14} rad/sec$

using depolarization factor. From, fig 6.2 it is shown that with the change of L from lower value to high value, namely, with the transition of from dielectric property to metallic property, the level values of the enhancement factor of the local field increase. Compared with the case of no dielectric layer, the metal-like dielectric layer makes the threshold values increase, while the dielectric like layer makes the level values decrease. Therefore,from Fig 6.2 enhancement factor for metallic dielectric function increased, while dielectric function make enhancement factor to decrease.

6.3 Enhancement factor of focal field for ellipsoidal metal/dielectric composite for oblate and prolate

The oblate shaped object have the equatorial diameter greater than the polar diameter, whereas, prolate having the polar diameter greater than the equatorial diameter. Using geometrical factor L for oblate $L_1 = 0.3$ and prolate $L_2 = 0.44$, as we have to

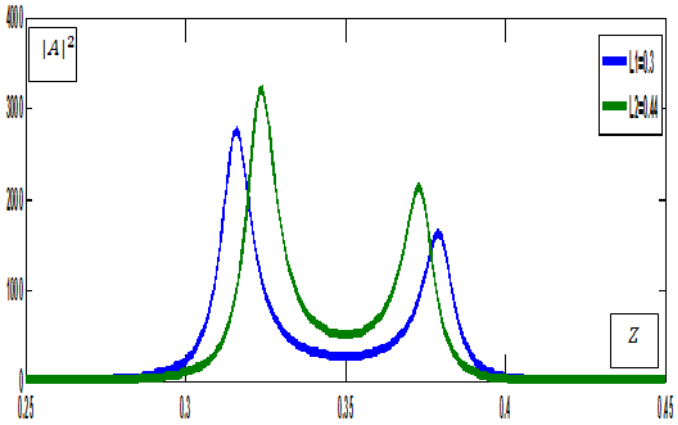

Figure 6.3: Enhancement factor for the oblate and prolate shape, when $L_1 = 0.3$ and $L_2 = 0.44$ and other quantities are the same to figure 6.2

see from figure 6.3 no effective change seen, except when the number value of L is increased and the enhancement increase from the transition of dielectric to metallic.

6.4 Enhancement factor of local field for ellipsoidal metal/dielectric composite for sphere, oblate and prolate shape

And let us see by combining for depolarization factor for perfect sphere, oblate and prolate shaped and it look like the following; In Fig.6.4, we present $|A|^2$ of composites of small ellipsoidal metal/dielectric separated by dielectric layer verses the resonant frequency z for three different depolarization factor values; $L_1 = 0.3$, $L_2 = 0.37$ and $L_3 = 0.44$. We find that the depolarization factor plays an important role in enhancement factor behavior. It is shown that with the change of L for oblate, prolate

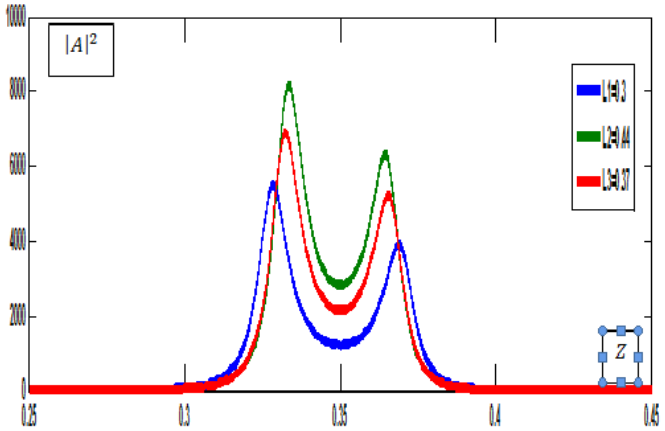

Figure 6.4: Enhancement factor for the oblate, pure Sphere and prolate shape respectively, when $L_1 = 0.3$, $L_2 = 0.37$ and $L_3 = 0.44$ and other quantities are the same to figure 6.2

and sphere, namely, with the transition of dielectric property to metallic property, the values of the enhancement factor of the local field stay the same in three of shapes.

6.5 Analytical description of induced optical bistability for ellipsoidal metal/dielectric composite core

As input intensity is increased, the field inside the cavity also increases, lowering the absorption that the field experiences and thus increasing the field intensity still further. If the intensity of the incident field is subsequently lowered, the field inside the cavity tends to remain large because the absorption of the material system has already been reduced. Note that over some range of input intensities more than one

output intensity is possible. This is called induced optical bistability which means that some nonlinear optical systems can produce two different output intensities for a given input intensities or, in particular, the given value of an external electric field may produce several values for the local field and the polarization. In this section, we consider the local field in metal ellipsoidal particles while accounting for the nonlinear part of $\varepsilon(\omega, E)$ and it is used in the presence of small field $\chi|E|^2$.consider that

$$A = \frac{\varepsilon_h \varepsilon_m}{La + b\varepsilon_h(1-L)} \tag{6.5.1}$$

By substituting the value of 'a' then ,

$$a = \varepsilon_d \varepsilon_m - P\varepsilon_m(\varepsilon_d - \varepsilon_m) + LP(\varepsilon_d - \varepsilon_m)\varepsilon_m \tag{6.5.2}$$

where $\varepsilon_d = \varepsilon_{do} + \chi|E|^2$ and ε_{do} is the real part of dielectric function

After multiplying the above equation we have to separate it in to its real and imaginary as

$$a = a_1 + Xa_3 + i(a_2 + Xa_4) \tag{6.5.3}$$

where

$a_1 = \varepsilon_{do}\varepsilon_m^{'}(1 - P + LP) + (\varepsilon_d^{'2} - \varepsilon_m^{''2}(P - LP))$,

$a_2 = \varepsilon_{do}\varepsilon_m^{''}(1 - P + LP) + 2\varepsilon_m^{'}\varepsilon_m^{''}(P - LP)$,

$a_3 = \varepsilon_m^{'}(1 - P + LP)$,

$a_4 = |E|^2\varepsilon_m^{''}(1 - P + LP)$ and

$X = \chi|\overrightarrow{E}|^2$

And from value of 'b',

$$b = \varepsilon_m + LP(\varepsilon_d - \varepsilon_m) \tag{6.5.4}$$

By substituting dielectric and metallic function and multiplying, we get

$$b = (a_5 + Xa_7) + ia_6 \tag{6.5.5}$$

where

$a_5 = \varepsilon_m^{'}(1 - LP) + \varepsilon_{do} LP$,

$a_6 = \varepsilon_m^{''}(1 - LP)$,

$a_7 = LP$

Substituting the above value for the enhancement factor A, (6.5.1) and taking its modulus, we get

$$|A|^2 = \frac{\varepsilon_h^2(\varepsilon_m^{'2} + \varepsilon_m^{''2})}{(a_8 + Xa_9)^2 + i(a_{10} + a_{11})^2} \tag{6.5.6}$$

where,

$a_8 = La_1 + (1 - L)\varepsilon_h a_5$,

$a_9 = La_3 + \varepsilon_h(1 - L)a_7$,

$a_{10} = La_2 + a_6(1 - L)\varepsilon_h$, and

$a_{11} = La_4$

The combination of all the above equation led us to find the particle at the particular point, starting from

$$\overrightarrow{E_{LF}} = A|\overrightarrow{E_h}| \tag{6.5.7}$$

Now by multiplying by χ both sides of the above equation after squaring

$$\chi|E|^2 = |A|^2 \chi|E_h|^2 \tag{6.5.8}$$

letting $X = \chi|E|^2$, and $Y = \chi|E|^2$ we obtain the following cubic equation for X;

$$\frac{aX^3 + bX^2 + cX}{\varepsilon_h^2(\varepsilon_m^{'2} + \varepsilon_m^{''2})} = Y \tag{6.5.9}$$

where,

$a = a_9^2 + a_{11}^2$,

$b = 2(a_8 a_9 + a_{10} a_{11})$

$c = a_8^2 + a_{10}^2$

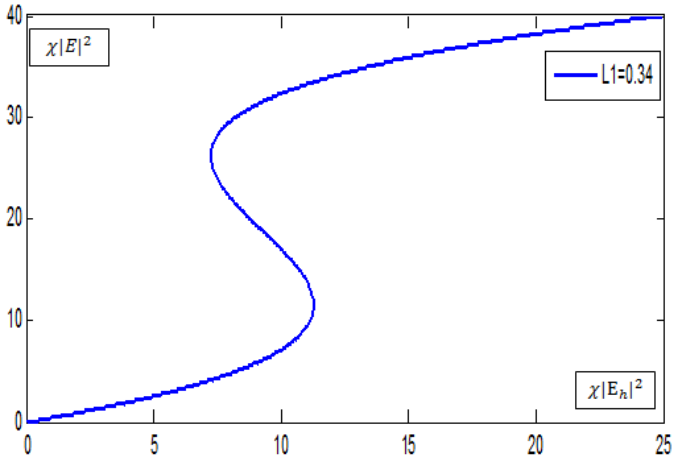

Figure 6.5: Induced optical bistability in composites of small ellipsoidal metal/dielectric in a linear host matrix for $L_1 = 0.37$, $\varepsilon_{do} = 0.6$, $\varepsilon_\infty = 4.5$, where the rest quantities are the same as figure 6.1 above and this figure is drawn for the local field $\chi|E|^2$ as a function of the applied field $\chi|E|_h^2$ at z = 0.2

Using the above equation we will draw the optical bistability curve. From fig 6.5 we understand that when we supply an intensity from an external source we get two stable output intensities. Therefore from (6.5.9) this stability we called bistability that is a real numbers, And there is one imaginary part which is absorbed. Further, we are interested only in the real and positive roots of the cubic equation above. If this equation has one real positive root, then the local field in the inclusion is a single-valued function of the applied field. If this (6.5.9) equation has three positive roots, then the local field is not a single-valued function of the applied field, and the system becomes unstable. This situation is called the induced optical bistability (IOB). IOB is usually illustrated in the Y - X plane and connected with S-like curves showing that three different values of the local field correspond to one value of the applied field.

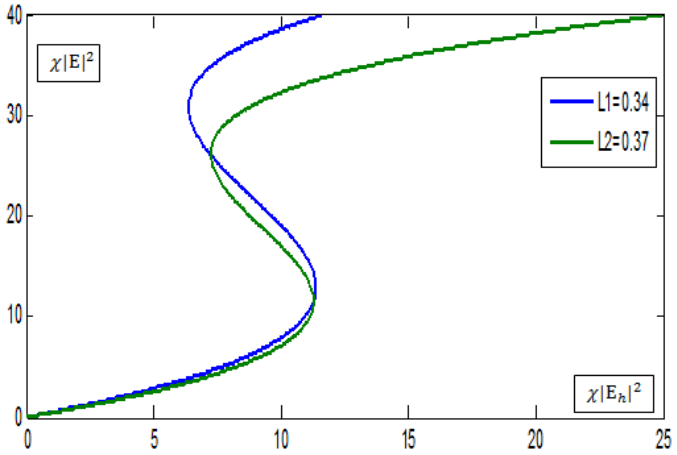

Figure 6.6: Induced optical bistability in composites of small ellipsoidal metal/dielectric in a linear host matrix for $L_1 = 0.34$, $L_2 = 0.37$, $\varepsilon_{do} = 0.6$, $\varepsilon_\infty = 4.5$, where the rest quantities are the same as figure 6.1 above and this figure is drawn for local field $\chi|E|^2$ as a function of the applied field $\chi|E|_h^2$ at z = 0.2

To obtain the general picture of the connection between the applied field, local field, and the frequency (z is constant), we decided to present a 2D graph involving these quantities. The 2D graph depicted in Fig. 6.6 is obtained with the help of above equation (6.5.9) and shows the most interesting region of these parameters (bistability), when three different values of the local field correspond to one value of the applied field.

While analyzing the bistability phenomena in the system, it is more convenient to consider the dependence of a local field on the applied field. Figure 6.6 shows such dependence for different depolarization factors obtained with the help of equation (6.6.9) at $z = 0.2$. One can see that the bistability region (three different values of $\chi|E|^2$ for one value of $\chi|E_h|^2$ widens, as the depolarization factor L increases.

The 2D graph depicted in Fig. 6.7 is obtained with the help of (6.5.9) equation

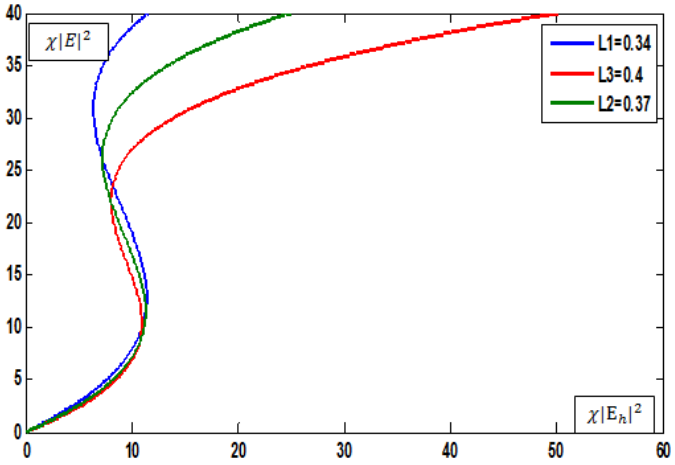

Figure 6.7: Induced optical bistability in composites of small ellipsoidal metal/dielectric in a linear host matrix for $L_1 = 0.34$, $L_2 = 0.37$, $L_3 = 0.4$, $\varepsilon_{do} = 0.6$, $\varepsilon_\infty = 4.5$,where the rest quantities are the same as figure 6.1 above and this figure is drawn by local field $\chi|E|^2$ as a function of the applied field $\chi|E|_h^2$ at z=0.2

and shows the most interesting region of these parameters (bistability), when three different values of the local field correspond to one value of the applied field.

6.6 Bistability Domain in Ellipsoidal Particles with Nonlinear Metal/dielectric Composite Core

The bistability domain in the plane $(z; \chi|E_h|^2)$ can be specified from an analysis of the roots of the cubic equation (6.5.9). We have two ways of finding the root location of a cubic equation for cubic equation (6.5.9). Now, we analyze the roots of (6.5.9) and find the IOB domain in the plane $(z; \chi|E_h|^2)$. And from (6.5.9), its solution is

$$Y = \frac{-2}{9}((b^2 - 3ac)(-b \pm \frac{\sqrt{b^2 - 3ac}}{3a}) + \frac{bc}{2}) \tag{6.6.1}$$

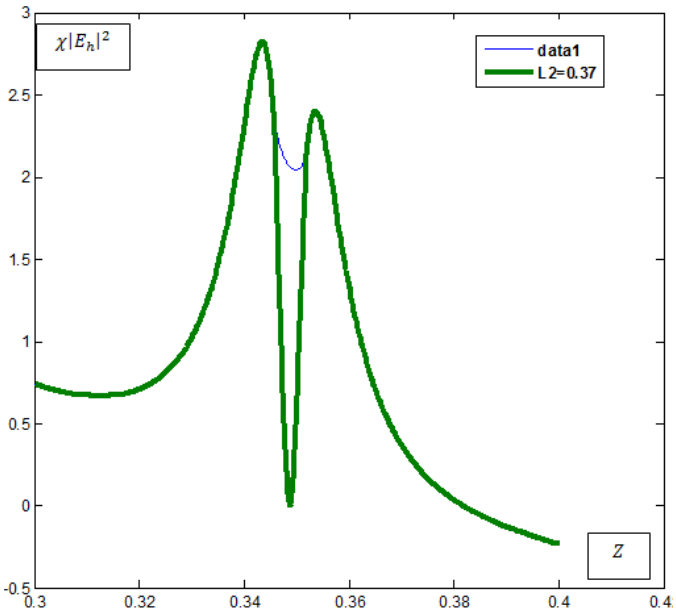

Figure 6.8: The ellipsoidal silver nanparticle with the parameters $L = 0.37$,$\varepsilon_h = 2.25$, $P = 0.99$,$\gamma = 1.15 \times 10^{-2}$,$\varepsilon_\infty = 4.5$.The induced optical bistability in the plane $(z, \chi|E|^2)$

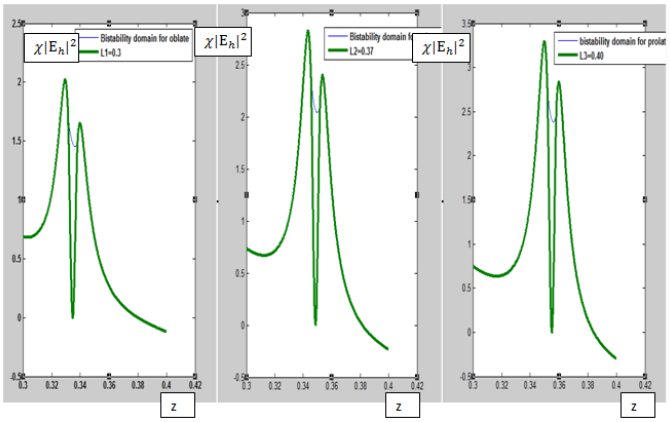

Figure 6.9: The ellipsoidal silver nanparticle with the parameters $L_1 = 0.33, L_2 = 0.37, L_3 = 0.39$, $\varepsilon_h = 2.25$, $P = 0.99$, $\gamma = 1.15 \times 10^{-2}$, $\varepsilon_\infty = 4.5$. The induced optical bistability domain in the plane for oblate, sphere and prolate $(z, \chi|E|^2)$

As we see from Fig 6.8 taken depolarization for spherical shape is $L = \frac{1}{3}$ as we saw [5]. Now for geometrical factor L the bistability domain have M-like shape where it start increasing from point (0.75 to 3) for $\chi|E_h|^2$ and (0.33 to 0.35) and decreased from (0.36 t0 0.4) for z. Between a point of z (0.34 to 0.36) we have the bistability domain in which we find a particle at a particular point.

As we have to see from Fig 6.8, for as we set z and L a particle have M-like shape. However, from Fig 6.9 we have seen the combined shape for oblate (bulged at its center) and prolate(bulged at its major axis),share the same characteristics of Fig 6.8 as we seen.

From fig 6.9 we understand for $(z, \chi|E|^2)$ frequency and intensity there is no change in bistability domain of silver nanparticle. Here, we have to see that from Fig 6.9 the combination of three nanoparticles shape display similar behavior and characteristics except they are different for different depolarization factor. The most interesting

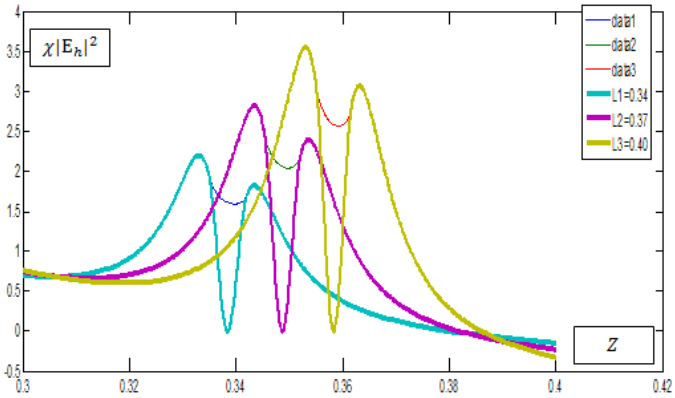

Figure 6.10: The ellipsoidal silver nanparticle with the parameters $L_1 = 0.33, L_2 = 0.37, L_3 = 0.39$, $\varepsilon_h = 2.25$, $P = 0.99$, $\gamma = 1.15 \times 10^{-2}$, $\varepsilon_\infty = 4.5$. The induced optical bistability in the plane $(z, \chi|E|^2)$

feature of these graphs is the appearance of two peaks of the enhancement factor at two (z=0.3,0.4); different frequencies. The positions and values of these maxima strongly depend on volume fraction P (for fixed other parameters).For $P = 0.99$. It becomes more important and with further increase in P, three of them become higher and move closer to each other along positive x-axis, where as further increase in P, three of them become lower and move parallel to each other and decrease to zero.

Generally, we conclude that the metallic/dielectric composite core for ellipsoidal nanoparticle shows induced optical bistability and bistability domain have the same result as spherical nanoparticle metallic/dielectric composite core. Instead of using the mathematical derivation of ellipsoidal shape, due to high degree of of or (due to symmetry) it is simple to use spherical nanoparticles to find enhancement factor, depolarization, IOB and bistability domain. Therefore, using spherical nanoparticle is preferable than ellipsoidal nanoparticle.

Chapter 7

Conclusions and Recommendation

We now discussed the main theoretical conclusions that follow from this study. From the first section we have to observed that for incident radiation (EMW) the dielectric function in ellipsoidal nanoparticle have a great effect on enhancement factor and it have two maximum peaks for depolarization factor L and dimensionless frequency z. The another fundamental point we discussed is optical bistability, in which the intensity of output light can take two distinct stable values for a given input incident radiation, creating optical bistable for real states output and one absorbed for imaginary part. The degree of optical nonlinearity in a material depends upon the strength of the optical field, and varies in different materials. From in third section as we have seen bistability domain for spherical and ellipsoidal nanoparticle are show the output result the same for input local electric field but they are not overlap one another, and shift their place to the left for oblate and to right for prolate in compared to spherical. However, even if they give us the same result for both geometrical shape, hence, using spherical shape is recommended than ellipsoidal. It is shown that the enhancement factor of the local electric field in metal spherical or ellipsoidal nanoparticles with dielectric cores imbedded in a dielectric matrix have two maxima on two

resonant frequencies. The second maximum for the inclusions with large dielectric cores covered by a thin metal shell is comparatively small. With increasing in a metal fraction in the inclusion, enhancement factor grow.

7.1 Recommendation

Due to very small nonlinearities in naturally occurring materials, large optical fields are necessary to realize measurable nonlinear phenomena. The necessities of high intensity sources to observe the effects of optical nonlinearity severely limit its use in practical applications, especially in low-powered devices. To realize such devices, the enhancement of nonlinear material properties is required. Therefore we recommend you anybody who interested to do his/her research related to nonlinear optics of nanoparticles in regard of enhancement factor, IOB and domain factor using experiment because future, generation need computer aided services without losing more time and energy using optical technology and nanotechnology. Our 21th century generation interested to use nanotechnological devices because of their smaller in size, faster in accessory, lighter to take everywhere, and cheaper to purchase with a great functionality. Therefore, let us unite and change our theoretical concept into practical to solve problem of our society that help them to use fewer raw materials and consuming less energy. We have recommended academic professionals and graduate students to do their research to solve problem of their community but not simply for graduation.

Bibliography

[1] Abdulrhman Al-Warthan b Kholoud M.M. Abou El-Nour a, Alaa Eftaiha b and Reda A.A. Ammar B. Synthesis and applications of silver nanoparticles. *Arabian Journal of Chemistry*, pages 3, 135–140, 2010.

[2] et.al A.Stalmashonak. Bistability in an Acousto-Optic Tunable Filter Operating with Short Optical Pulses. 2013.

[3] et.al A.S.B.Shambra. Optical Properties of Nanocomposites Containing Metal Nanoparticles.

[4] Ineke Malsh. Biomedical Applications of Nanotechnology. *The Industrial physicists*, 8(3), 2002.

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

[6] V.N.Mal'nev S.Shewamare, O.A.Buryi. Induced Optical Bistability In Small Metal And Metal Coated Particles With Nonlinear Dielectric Functions. *Ukr.J*, 56(4):657–660, 2012.

[7] R.S.Bennink Y.H.Yoon and R.W.Boyd. Accessing the optical nonlinearity of metals with metal-dielectric photonic bandgap structures. *Teubner, Leipzing*, 24:1416–1418, 1999.

[8] K.M. Leung, et al. Optical bistability of an aqueous aerosol particle detected through light scattering: theory and experiment. *Appl.Optics*, 29:3473, 1990.

[9] Ohad Levy D.Stroud D.J.Bergman. Theory of optical bistability in weakly nonlinear composite medium. 49:129–134, 1994.

[10] S. Arnold, T. R. Keeffe,K. M. Leung, L. M. Floan, T. Scalese and A. Pluchino. Optical bistability of an aqueous aerosol particle detected through light scattering: theory and experiment. *Appl. Optics*, 29:3473, 1990.

[11] R. Nathanshon Levy and D. J. Bergman. Electrical resonance and optical bistability in periodic composite materials. *J. Appl. Phys*, 77:4263–4273, 1995.

[12] Ohad Levy and D.J. Bergman. Harmonic generation, induced nonlinearity, and optical bistability in nonlinear composites. *Phys. stat. sol. (b)*, 52(3), 1995.

[13] B.R.Master. *Handbook of Biomedical Nonlinear Optical Microscopy*. press, 1995.

[14] C. Rulliere. *Femtosecond Laser Pulses: Principles and Experiments*. Springer, 2nd edition, 2004.

[15] L.S.Tan Q.Zheng,G.S He and P.N.Prasad. Multiphoton absorbing materials:Molecular designs, characterizations, and applications. *Chemical Review*, 108(2008):1245–1330.

[16] G.P.Agrawal. *Nonlinear Fiber Optics, Optics and Photonics Series*. Academic Press, 2003.

[17] G.P.Agrawal. *Lightwave technology components and devices.* Jhon Wiley and Sons, New Jersey, 2004.

[18] H.Nihei and A.Okamoto. Photonic crystal systems for high-speed optical memory device on an atomic scale. *Pro.SPIE*, 4416:470–473, 2001.

[19] S.Omi H.Tanji T.Tokizaki A.Nakamura S.Kaneko, K.Uchida and Y.Asaharaaj. Subpicosecond time response of third-order optical nonlinearity of small copper particles in glass. *Applied Physcs Letters*, 65:941–943, 1994.

[20] V. M. Shalaev. Nonlinear Optics of Random Media. *Springer-Verlag*, 2000.

[21] et.al A.P.Gonzalez-Marcos. Optical bistable devices as sensing elements, Unmanned/Unattended Sensors and Sensor Networks. *Edited by Edward M. Carapezza, Proceedings of SPIE*, 5611(SPIE, Bellingham, WA), 2004.

[22] D.J.Hagan G.Assanto, Z.Wang and E.W.Vanstryland. All-optical modulation via nonlinear cascading in type II second-harmonic generation,". *Appl. Phys. Lett*, pages 67(15) 2120–2122, 1995.

[23] D. A. Mazurenko, R. Kerst, J. I. Dijkhuis, A. V. Akimov, V. G. Golubev, D. A. Kurdyukov, A. B. Pevtsov and A. V. Sel'kin. Ultrafast optical switching in three-dimensional photonic crystals,. *Phys. Rev. Lett*, (91(21) 213903):2003.

[24] G. Priem, P. Dumon, W. Bogaerts, D. Van Thourhout, G. Morthier, and R. Baets. "Ultrafast optical switching in three-dimensional photonic crystals,". *Opt. Express*, (23)(13):9623–9628, 2005.

[25] Y. Wang, G. X. Li, H. L. Tam, K. W. Cheah, and S. N. Zhu. "Optical bistability and multistability in onedimensional periodic metal-dielectric photonic crystal,". *Appl. Phys. Lett.*, 21(211109):92, 2008.

[26] F. Yanik, S. H. Fan, M. Soljacic, and J. D. Joannopoulos. "All-optical transistor action with bistable switching in a photonic crystal cross-waveguide geometry,". *Phys. Rev. Lett.*, 28(24):2506–2508, 2003.

[27] F. Yanik, S. H. Fan, and M. Soljacic. "High-contrast all-optical bistable switching in photonic crystal microcavities,". *Appl. Phys. Lett.*, 83 (14):2739–2741, 2003.

[28] R.W.Boyd. *Nonlinear Optics*. Academic Press, 1992.

[29] H.M.Gibbs. *Optical Bistability: Controlling Light with Light, Quantum electronics-principles and applications*. Academic Press, 1985.

[30] G. A. Wurtz, R. Pollard and A. V. Zayats. "Optical bistability in nonlinear surface-plasmon polaritonic crystals,". *Opt. Lett.*, 97(5):057402, 2506–2508, 2006.

[31] C. J. Min, P. Wang, C. C. Chen, Y. Deng, Y. H. Lu, H. Ming, T. Y. Ning, Y. L. Zhou and G. Z. Yang. "All optical switching in subwavelength metallic grating structure containing nonlinear optical materials,". *Opt. Lett.*, 33(8):869–871, 2008.

[32] Y. Shen and G. P. Wang. "Optical bistability in metal gap waveguide nanocavities,". *Opt. Express.*, 16(12):8421–8426, 2008.

[33] Daniel J. Ironside. 'Orders of Magnitude Enhancement of Optical Nonlinear Phenomena in Subwavelength Metal-Dielectric Gratings',. *Washington University in St. Louis*, 2012.

[34] J Haes and Richard P Van Duyne. Preliminary studies and potential applications of localized surface plasmon resonance spectroscopy in medical diagnostics. *Expert Rev, Mol Diagnostics*, pages 527–537, 2004.

[35] A. El-Sayed (2007) Jain, Xiaohua Huang, Ivan H. El-Sayed ,Mostafa. Review of Some Interesting Surface Plasmon Resonance-enhanced Properties of Noble Metal Nanoparticles and Their Applications to Biosystems. Plasmonics. *Expert Rev, Mol Diagnostics*, pages 107–118, 2004.

[36] Y. B. Li,W.R. Xie, X.B. Shi, Q.S.Zeng, H.Y.Ou-Yang, Y.S.Chen. Appl Microbiol Biotechnol. *Appl.Optics*, pages 1115–1122, 2010.

[37] Leung K.M. Optical bistability in the scattering and absorption of light from nonlinear microparticles. *Phys.Rev.A*, 33:2486, 1986.

DECLARATION

I hereby declare that this thesis is my original work and has not been presented for a degree in any other University. All sources of material used for the thesis have been duly acknowledged.

TOLASA TAMASGEN HIRPHA

email:tolasatamasgen2014@gmail.com

This thesis has been submitted for examination with my approval as University advisor.

SISAY SHEWAMARE (Ph.D)

email:Sisayshewa20@yahoo.com

Jimma University