International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:7, No:11, 2013

The Analysis of Nanoptenna for Extreme Fast Communication (XFC) over Short Distance

Shruti Taksali

***Abstract*—**This paper focuses on the analysis of Nanoptenna for extreme fast communication. The Nanoptenna is basically a nano antenna designed for communication at optical range of frequencies. Since, this range of frequencies includes the visible spectrum of the light, so there is a high possibility of the data transfer at high rates and extreme fast communication (XFC). The shape chosen for the analysis is a bow tie structure due to its various characteristics of electric field enhancement.

***Keywords*—**Nanoptenna, communication, optical range, XFC.

I. INTRODUCTION

THE conventional radio and microwave antenna cannot operate at optical range of frequencies because of the high amount of losses associated with it and the assumption of perfect electrical conductor is no longer valid since metal losses are high at this region. With the changing times and increasing modernization in technologies there is always an increasing demand of high speed communication which is just impossible with the present microwave antennas limited with frequency in the range of gigahertz. So, an antenna at nano scale is designed for communication at optical range of frequency i.e. in terahertz range for extreme fast communication. The term 'Nanoptenna' is derived from the combination of the technologies such as antenna, nanotechnology and optical communication, which indicates the antenna as a specially designed nano device for communication at optical frequencies. This could be of any shape such as sphere, triangles, square, etc. But for the electric field enhancement the bow tie structure is used. Bowtie nanoptenna is designed to improve the optical disparity among nano objects and light. Near the tip, the bow tie antenna with a gap of around 20nm can reach an intensity enhancement of more than 1000. Therefore, bowtie structure is preferred `because it allows the enhancement of input signal with extremely high intensities in the chasm which is well suited for electric field enhancement. In other words, it offers both extraordinary field confinement and a broadband spectral response. In contrast to the other antenna geometries, bowties seem to offer the largest electric field enhancements in the near field region and the smallest spatial extent for the field, that is, a single sharp optical spot such that maximum portion of the electromagnetic energy is localized in the chasm of the antenna. This characteristic of bowties is important for the applications with a requirement of a very intense spatially confined Optical spot. It basically consists of consists of two gold triangular pieces, each with a length of 82nm, separated with a chasm of nanometer range, whose apexes face each other in the configuration of a miniature bowtie. Instead of gold, other material such as silver and alloy could be used but only gold provides the best optical properties for the Nanoptenna. Typically, an optical antenna interacts with a receiver or transmitter in the form of a discrete quantum system, such as an atom, molecule, or ion. Because the antenna enhances the interaction between the receiver or transmitter and the radiation field, it may control the light-matter interaction on the level of a single quantum system. On the one hand, the presence of the antenna modifies the properties of the quantum system, such as its transition rates and, in the case of a strong interaction, even the energy-level structure. On the other hand, the properties of the antenna depend on the properties of the receiver/transmitter. Thus, the two must be regarded as a coupled system [1]. Therefore, nanoptenna will bring a revolutionary change in the field of communication. The absence of nanoptenna in the present technology word is just because of their small scale size. As the practical dimensions of an antenna is of the order of a wavelength of light, so it requires fabrication accuracies more or equivalent to at least 10nm. The commencement of nanotechnology will provide access to this length scale with the introduction of novel top-down nanofabrication tools (e.g. focused ion beam milling and electron-beam lithography) and bottom-up self-assembly schemes [2], [3]. So, with the help of these fabricating tools nanoptenna is likely to enhance the communication speed and therefore enabling extreme fast communication but limited to short distance in the scale of centimeters only. Till now researches have been done on fast communication through optical fibers but in fact speed of light is about 32% (roughly) slower in optical fibers than in free space due to its refractive index which is generally greater than one. Hence, it created the need of free space optics for extreme fast communication which could be possible through Bowtie nanoptenna which is designed to improve the optical disparity among nano objects and light. This nanoptenna does not amplify radio waves, but takes energy from a nano range beam of near -infrared light and squeezes it into a manometer chasm separating the two gold triangular pieces. The result is a concentrated speck of light that is a thousand times more intense than the incoming near-infrared beam and thus providing the scope of extreme fast communication with the higher data speeds of data transferring rates.

ShrutiTaksali is with the JECRC UDML College of Engineering, Jaipur, Rajasthan, India, (Phone: 01426 227002 / 03 / 04 / 12 / 13 / 16 / 17, Fax: +91 950 985 1100, 0141 2770803, e-mail: shrutz03@gmail.com).

II. CONCEPT AND LOGIC OF NANOPTENNA

Till now lasers with its properties of narrow line width and high modulation bandwidth have been the basics of extreme fast optical communication which has overcome the LED because of its both suitable physical properties and practical reasons. But, lasers itself has some drawbacks when short distance communication is considered which does not require narrow linewidths. Generally, they require more space, high powers and of course gain saturation limits the rate of stimulated emission [4]. On the other hand, LEDs are limited by rate of spontaneous emission which is electromagnetic environment dependent. Since the main focus of this paper is on extreme fast communication, the emphasis is laid on faster speed of data rates. The use of gold bow tie nanoptenna can produce much higher magnitude rates faster than stimulated emission in Lasers. In this way; it could achieve much higher modulation speed because of a faster rate of spontaneous emission and thus improving quantum efficiency. Till now optical communication has been possible through mainly because of optical fibers which suffer from dispersion or other non linear distortions taking place in it. This limitation is removed by nanoptenna as it involves free space communications which is not affected by these distortions but is limited by line of sight communication because of absorption and reflection from materials. As the main focus of this paper is extreme fast communication over short distance, it could be used in variety of applications such as cancer therapy, biosensing and detection, high speed data storage, nano imaging, solar cells and photodetectors [5]-[11]. In fact in diseases similar to cancer therapy, it converts incident infrared light into heat energy and thus damaging the defected cells.

Since, here it is assumed that the shape of nanoptenna is a bow tie structure, because near the apex with a gap in the range of nanometer, it can provide an intensity enhancement of more than thousand. Therefore, bowtie structure is preferred `because it allows the enhancement of input signal with extremely high intensities in the gap which is well suited for electric field enhancement. So it is centrally feed through a localized oscillator which in turn creates oscillations in the structure originating maximum electric field in one triangle and minimum in the other depending on the cycle of input pulse from localized oscillator. These plasmonic oscillations spread throughout the structure but charges at the width of the triangle tries to concentrate at its apex and hence provides enhanced maximum electric field at the chasm between the triangles enabling the detection of single molecules. In other words it can be described as the electric field enhancement through bow tie nanoptenna. Fig. 1 shows the working of a nanoptenna.

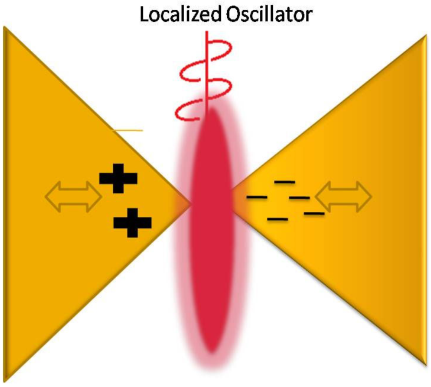


Fig. 1 Working of Nanoptenna

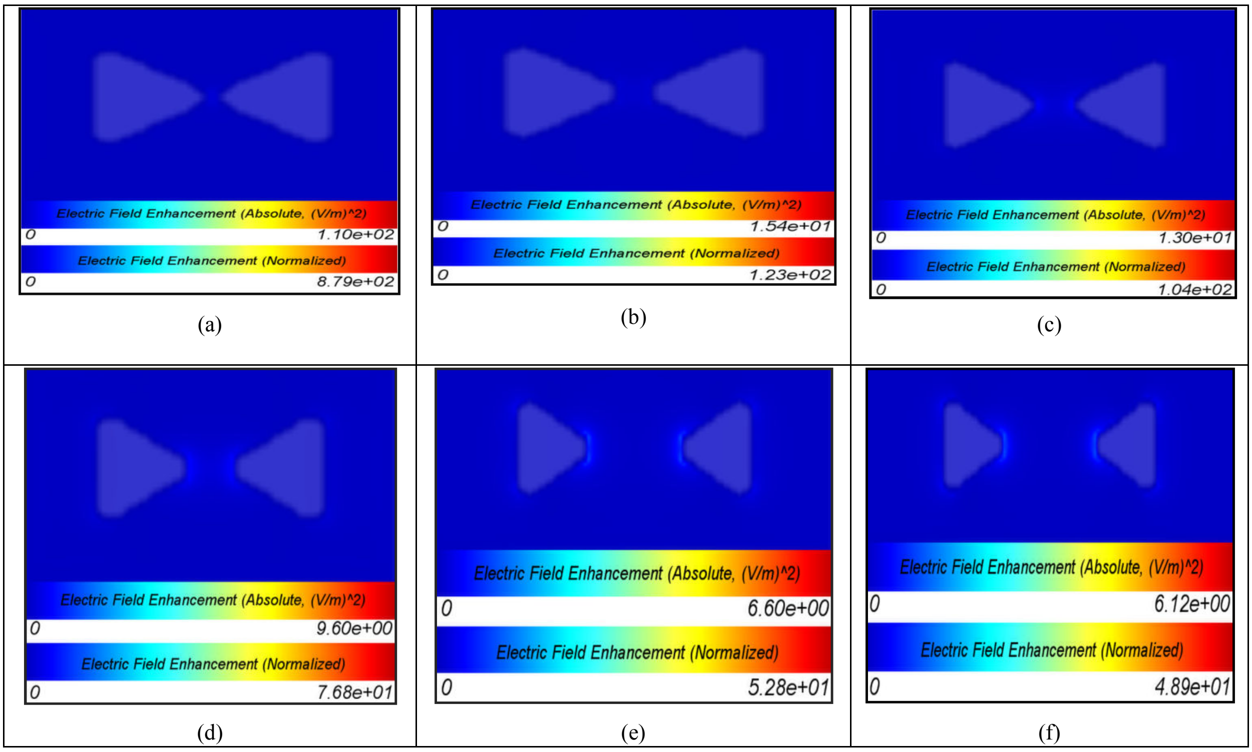
III. DESIGNING OF NANOPTENNA FOR XFC

For extreme fast communication it is necessary to have high modulation speed with a fast spontaneous emission rate which could be possible through a nanoptenna producing frequency in the range of terahertz. For its designing and characterization, nanoplasmonics toolkit is considered and Gaussian pulse is used as a source which is a wave packet of a specified width incident on the antenna at t=0. Its central wavelength is chosen as 600nm which is the wavelength corresponding to the central frequency of the pulse. Its temporal width is full width half maximum duration of the pulse, which is chosen as 2 femtoseconds. The duration i.e. the number of widths characterizes the finite time of emission of the pulse. Thus the pulse is at zero amplitude at t=0, t=duration and the peak occurs at t=duration/2.

Gold has been used as a basic particle for nanoptenna due to its inherent optical properties and has a dielectric constant of 5. The top substrate is the dielectric layer having a dielectric constant of 2.2 directly beneath the bowtie antenna and the bottom substrate is the dielectric layer with a dielectric constant of 2 beneath the top substrate layer.

The bow tie nanoptenna consists of two gold triangular pieces, each with a length of 82nm and a gap ranging in the range of nanometer, whose apexes face each other in the configuration of a miniature bowtie. As it is known that perfect bow tie edges are impossible to fabricate; the edges are rounded with a specified radius of curvature. We have chosen cell size buffer as 45nm, which is a buffer between walls of computational cells, and bow tie structure so that perfectly matched layer (PML) can never interfere with near field bowtie dynamics. The thickness of PML is chosen as 28nm, which is a boundary condition that triggers absorption all radiation impingent on the walls of the computational cell.

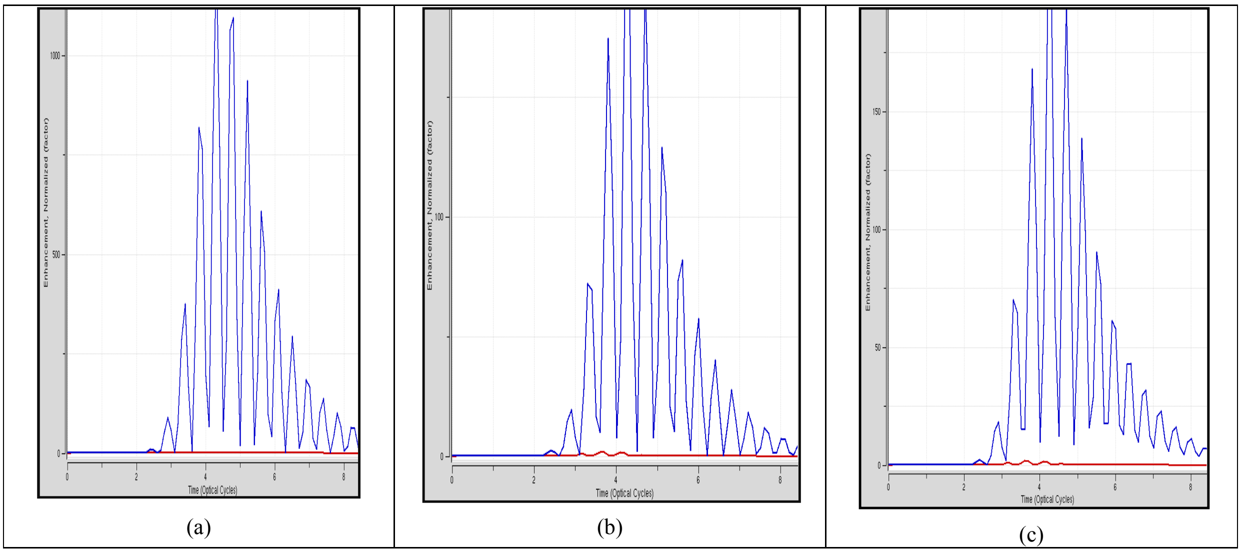
Since, bow tie structure consists of a gap in the range of nanometer which plays a vital role in the intensity enhancement, so keeping the geometry of bow tie as constant and varying the gap length, various results about intensity enhancement can be found which is crucial for XFC. Initially, various structures were visualizes for various gap lengths between the two triangles which indicates the electric field enhancement as shown in Fig. 2. Then, next step was to extract the knowledge of this electric field enhancement with respect to time which is well described in the Fig. 3. Now, different applications would require different operating frequencies. So, the behavior of nanoptenna for electric field enhancement with respect to frequency becomes crucial and is shown in the Fig. 4. In short, the bow tie structure is studied by varying gap lengths between the two triangles of the structure for electric field enhancement which could further lead to extreme fast communication applications making the advancements in the technologies.



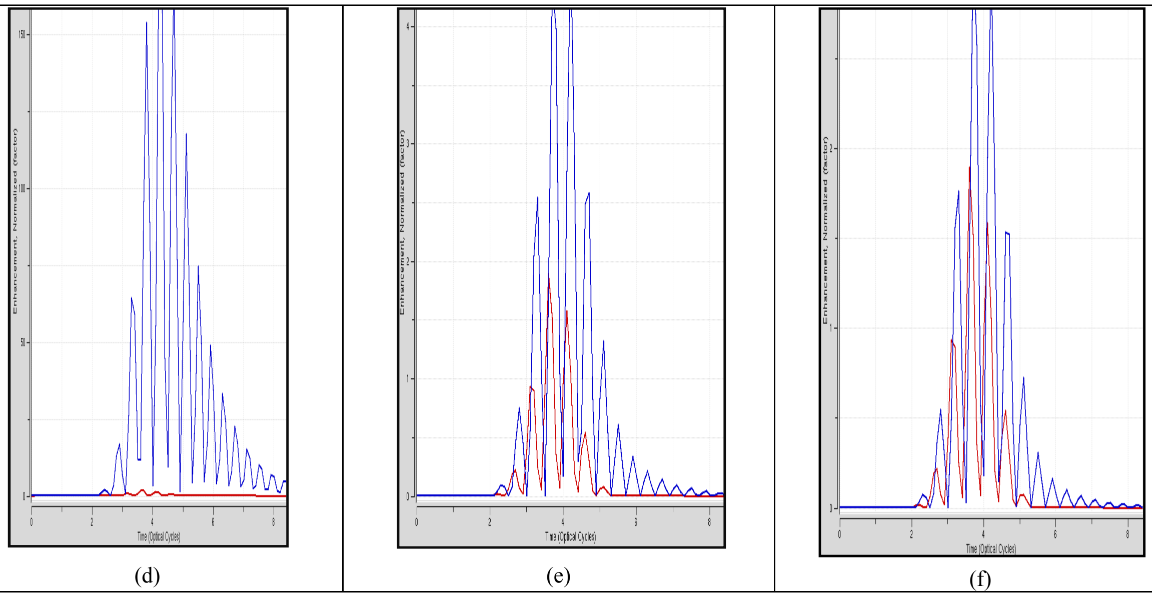
(a) (b) (c)

(d) (e) (f)

Fig. 2 The analysis of nanoptenna with a bow tie structure for various gaps (a) gap length=10nm, (b) gap length=20nm, (c) gap length =30nm, (d) gap length=40nm, (e) gap length=100nm, (f) 120nm

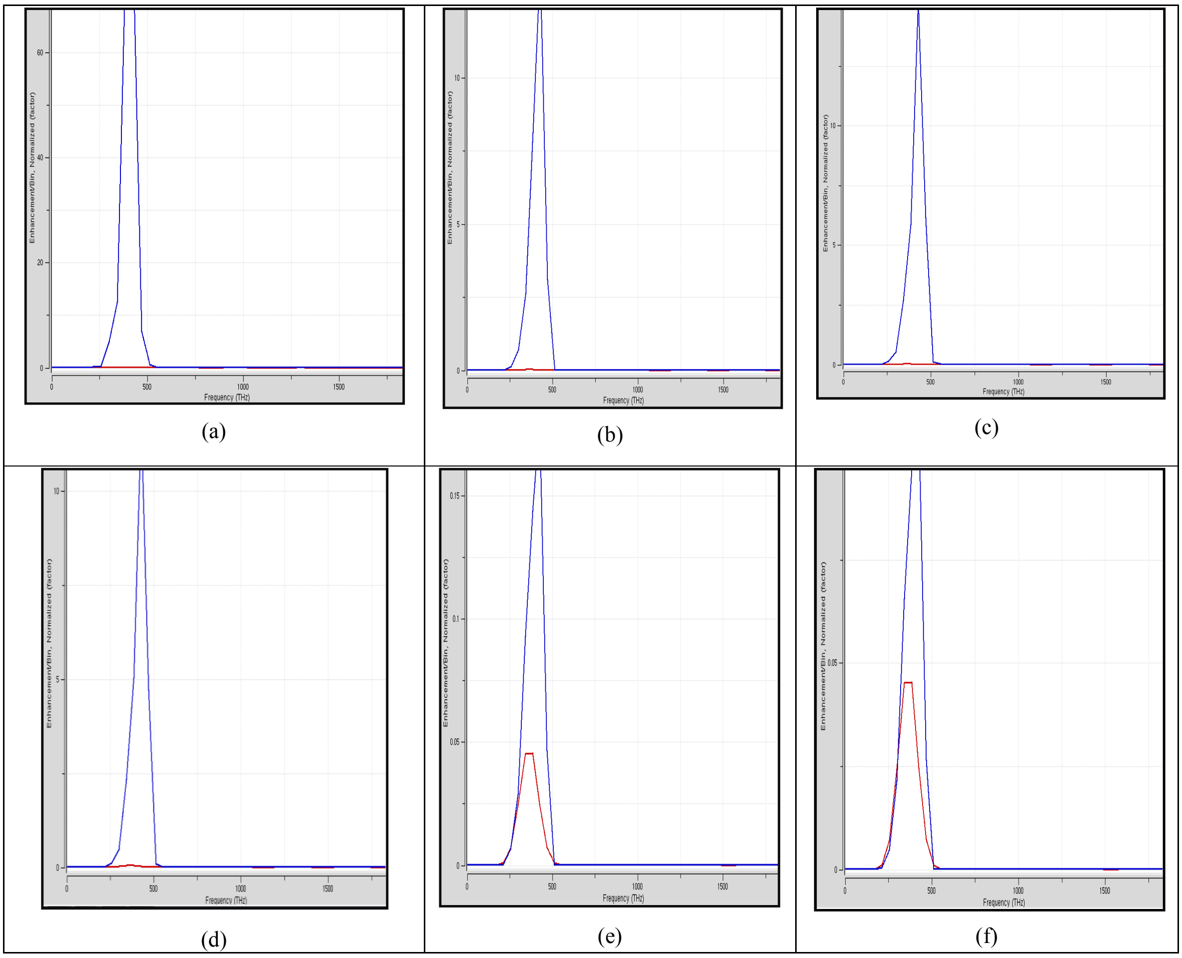


(a) (b) (c)



(d) (e) (f)

Fig. 3 Plot of normalized electric field enhancement against time (optical cycles) for gap lengths (a) 10 nm, (b) 20 nm, (c) 30 nm (d) 40nm, (e) 100nm, (f) 120nm



(a) (b) (c)

(d) (e) (f)

Fig. 4 Plot of normalized electric field enhancement against frequency for gap lengths a) 10 nm, b) 20 nm, c) 30 nm d) 40nm, e) 100nm, f) 120nm

Fig. 3 basically shows the various plots of intensity enhancement against time or optical cycles which would be helpful in determining the number of cycles taken by an input pulse for calculating the necessary output. Fig. 4 basically shows plot of normalized electric field enhancement against frequency for various gap lengths. It can be seen as the gap length is less than 100nm then; the intensity factor for red spectrum has near zero value but as the gap length increases to 100 or more than it, then there is maximum peak for red spectrum but peak for blue spectrum decreases. But for the gap length of near about 40nm there is a maximum peak for blue spectrum and red spectrum has a slight enhancement factor. Thus if there is a need of enhancement factor for both red and blue spectrum(high frequency in the range of Terahertz) then gap length of 40nm yields the best results. But if there is a requirement of enhancement factor for red spectrum (highest wavelength in nm) then gap length of 100nm or more than it satisfy the requirement.

IV. RESULTS AND CONCLUSION

From the various graphs it can be concluded the gap length plays a vital role in the bow tie structure for intensity enhancement. If the extreme fast communication is to be increased to a certain distance then gap length should be increased to 100nm or more according to line of sight. If XFC is to be done over a short distance with extreme fast speed then a gap length around 40 nm yields the best results. Since at this gap length there is a maximum enhancement factor for blue spectrum which consists of high frequency in the range of Terahertz and thus supporting high modulation speed with fast spontaneous emission rate. If nanoptenna is of shape other than bowtie then it would be just impossible to have this intensity enhancement of higher magnitude.

Table I below clarifies the comparison between various gap lengths for a bow tie structure which shows that gap length of 40nm can perform in a versatile manner for various applications of XFC. Since, conventional microscope cannot perform well at nanometer scale, so nanoptenna will bring a revolutionary change in the extreme fast communication.

TABLE I
COMPARISON TABLE OF BOW TIE NANOPTENNA FOR VARIOUS GAP LENGTHS

S.no.	Gap length(nm)	Normalized Electric field in 3D structure	Normalized enhancement factor against time(optical cycles)		Normalized enhancement factor against Frequency (THz)	
			Blue spectrum	Red spectrum	Blue spectrum	Red spectrum
1	10	8.79e+02	1225	0	65	0
2	20	1.23e+02	900	0	14	0
3	30	1.04e+02	185	0	12.5	0
4	40	7.68e+01	165	0.1	12.2	0.01
5	100	5.28e+01	4.2	1.8	0.19	0.04
6	120	4.89e+01	4.1	1.9	0.18	0.05

ACKNOWLEDGMENT

The author would like to thank Dr. Ram Rattan (Principal, JECRC UDML College of Engineering) and management of JECRC Foundation for their kind support and encouragement.

REFERENCES

[1] Taminiau, T. H., Stefani, F. D. & van Hulst, N. F. Enhanced directional excitation and emission of single emitters by a nano-optical Yagi–Uda antenna. *Opt. Express* 16, 10858–10866 (2008).

[2] Tang, L. *et al.* Nanometer-scale germanium photodetector enhanced by a near-infrared dipole antenna. *Nature Photon*.**2,** 226–229 (2008).

[3] Anger, P., Bharadwaj, P. & Novotny, L. Enhancement and quenching of single molecule fluorescence. *Phys. Rev. Lett.* 96**,** 113002 (2006)

[4] Nikhil Kumar, 'Spontaneous Emission Rate Enhancement Using Optical Antennas', eecs technical report 2013.

[5] Asia-Pacific Workshop on Near Field Optics, Near-field optics: principles and applications:the second Asia-Pacific Workshop on Near Field Optics, Beijing, China, October 20-23, 1999.Singapore ; River Edge, N.J: World Scientific, 2000.

[6] P. Anger, P. Bharadwaj, and L. Novotny, "Enhancement and Quenching of Single-Molecule Fluorescence," Physical Review Letters, vol. 96, no. 11, Mar. 2006.

[7] S. Kühn, U. Håkanson, L. Rogobete, and V. Sandoghdar, "Enhancement of Single-Molecule Fluorescence Using a Gold Nanoparticle as an Optical Nanoantenna," Physical Review Letters, vol. 97, no. 1, Jul. 2006.

[8] P. Bharadwaj and L. Novotny, "Spectral dependence of single molecule fluorescence enhancement," Optics Express, vol. 15, no. 21, p. 14266, 2007.

[9] W. Zhu, M. G. Banaee, D. Wang, Y. Chu, and K. B. Crozier, "Lithographically fabricated optical antennas with gaps well below 10 nm," Small, vol. 7, no. 13, pp. 1761–1766, 2011.

[10] D. Wang, T. Yang, and K. B. Crozier, "Optical antennas integrated with concentric ring gratings: electric field enhancement and directional radiation," Opt. Express, vol. 19, no. 3, pp. 2148–2157, 2011.

[11] W. A. Challener, C. Peng, A. V. Itagi, D. Karns, W. Peng,Y.Peng, X. Yang, X. Zhu, N. J. Gokemeijer, Y.-T. Hsia, G. Ju, R. E. Rottmayer, M. A. Seigler, and E. C. Gage, "Heat- Assisted magnetic recording by a near-field transducer with efficient optical energy transfer," Nature Photonics, vol. 3, no. 4, pp. 220–224, Mar. 2009.