Dielectric Resonator Nano Antennas: A Review of Materials, Designs, and Applications

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ABSTRACT

In this paper, we present antenna design method to solve for the current distribution in a Dielectric Resonator Nantenna excited by an electric field with arbitrary polarization. We explore the potential benefits of designing CNT integrated Equilateral Triangular DR Nanoantenna Array which is fed via a 1x2 feed network. The scattered far-field amplitude, phase, and polarization of the antennas are extracted. The antenna design technique presented is an efficient method for probing the large design parameter space of such antennas, which have been proposed as basic building blocks for the design of ultrathin and nano-scale antennas.

Keywords: Equilateral Triangular Dielectric Resonator Nantenna, CNT, IR Sensor, Optical Nantenna, nanophotonics, 1x2 nantenna array.

I. INTRODUCTION

An antenna is a device that is to efficiently radiate and receive electromagnetic waves. There are several important antenna characteristics that should be considered when choosing an antenna for application such as Antenna radiation patterns, Power Gain, Directivity Polarization. Our society is in need of miniaturized efficient antenna for developing quantum communication system. Structurally and functionally miniaturized antenna play a vital role in developing efficient quantum communication system. In our research work, Graphite material (with relative permittivity=1, relative permeability =1, bulk conductivity =70000 Siemens/m) is chosen at nano scale because of thermal and structural stability of carbon nano tube (CNT) at quantum scale. Array of ETDR Nanoantenna and Graphite nano structures deployed within will result better antenna characteristics like spectral filtering, antenna coverage, antenna polarization, gain, bandwidth, cut off frequency and minimizes the impedance.

II. LITERATURE SURVEY

2.1. Ahmed A. Kishk "A triangular dielectric resonator antenna excited by a coaxial probe": In the search for dielectric resonators with good characteristics, different DRA shapes are investigated .It is found that some geometry might have a wider bandwidth or better linear polarization characteristics than others. In this paper, An Equilateral Triangular shape DRA is considered. An Equilateral Triangular Dielectric Resonator (ETDR) over a ground plane which is excited by a coaxial probe to provide a broadside radiation pattern. An approximate expression is used to compute the resonance frequency. Results were verified experimentally and numerically.

2.2. Waleed Tariq Sethi "dielectric resonator nanoantenna at optical frequencies": With the advent of nano-components fabrication technology, researchers and scientists are now able to fabricate optical antennas at a nano-scale, in order to establishing a wireless communication link at THz frequencies, and find solutions to the general design problems associated with higher frequency antennas. Drawing inspiration from antennas at microwaves and radio-frequency technologies, optical antennas capture and couple free available electromagnetic radiation in the visible and infrared wavelengths in the same way as radio electric antennas do at the corresponding wavelengths. In this paper, authors review some of the state of the art optical antennas, their fabrication techniques and propose a novel dielectric nano antenna design. Comparing to the traditional radio-frequency antennas, an equilateral triangular dielectric resonator nano-antenna (ETDRNA) is designed and simulated at 193.5 THz standard optical frequency. The proposed antenna is a planar structure having a multilayer geometry consisting of 'Ag' partial ground plane, a top and bottom 'SiO_2' substrate and a 'Si' equilateral triangular as a dielectric fed by a 'Ag' nanostrip transmission line. The simulated antenna achieves an impedance bandwidth of 2.58% (192.5-197.3 THz) and an end-fire directivity of 8.6 dBi, covering the entire standard optical transmission window at C-band. Numerical demonstrations prove the efficiency of the nano-antenna at the frequencies of interest, making it a viable candidate for electromagnetic communication in optical applications and nano-networks.

2.3. Jiangbo Zhang, Ning Xi, King W.C. Lai, Hongzhi Chen, and Yilun Luo "Single Carbon Nanotube based Photodiodes for Infrared Detection": The photo behavior of carbon nanotubes (CNTs) has attracted great attention because of their unique cylinder structure and outstanding electrical properties. Much experimental progress toward nanotubes based photodetector has been reported by author in this paper. The photocurrent response of single CNT based IR detector with symmetric electrodes shows that the photocurrent is dependent on the position of laser spot on the CNT. By using different metals (silver or palladium) as the contact electrodes to increase the difference between the two CNT-metal contacts, the measured photocurrent is able to be maximized.

2.4. Carmen Kar Man Fung "Design and experimental testing of nano antenna for carbon nano tube (CNT) based infrared sensors": In this paper author report the fabrication and experimental characterization of a nano antenna for carbon nano tube (CNT) based infrared (IR) sensors. By designing a nanosized antenna and integrating with CNT sensing element, the electric field intensity at the position of the sensing element can be enhanced and a very sensitive infrared nano sensor could be developed. The efficiency and characteristics of the nano antenna are studied experimentally by measuring the photocurrent response of the sensor before and after the nano antenna is implemented. The experimental result has shown the nano antenna increases the photocurrent by an order of magnitude. This implies that the electric field in the vicinity of the detector is enhanced by the nano antenna. The proposed fabrication process enables easily and directs integration of the nano antenna into the Manufacturing of infrared devices. Therefore, this opens the possibility developing high fidelity infrared sensors with a wide sensing range.

III. DESIGN CONSIDERATION

The three essential parameters for the design of a rectangular Nano strip Patch Antenna:

Resonant Frequency (fr):

The resonant frequency selected for this design will be in THz.[2]

Dielectric constant of the substrate (ε_r):

The dielectric material selected for our design is graphite which has a dielectric constant of 1. A substrate with a high dielectric constant is to be selected since it reduces the dimensions of the antenna.

Height of dielectric substrate (h):

It is essential that the antenna should not be bulky hence height should be less.

IV. SUMMARY

From the papers analyzed so far, it is observed that ETDR Nantenna gives better radiation pattern, bandwidth than circular & rectangular shape of DRAs. Also it has small size compare to other shapes operating in same frequency, which allows array design since large range for the spacing between the array elements is allowed. Introduction of array of ETDRA and fed via a 1x2 corporate feed network has given the standard optical c-band transmission window with good impedance-bandwidth and radiation pattern. On studying carbon nanotubes we found that the photocurrent is caused by the photovoltaic effect in single CNT based IR detector with symmetric electrodes. It is also concluded that signal to dark current ratio of a heterogeneous detector using heterogeneous electrodes is thousand times higher than the ratio of a homogeneous detector using homogeneous electrodes[4]. By designing a nanosized antenna and integrating with CNT sensing element, the electric field intensity at the position of the sensing element can be enhanced and so a very sensitive infrared nano sensor is developed.

V. PROBLEM IDENTIFICATION AND ISSUE OF EARLIER ARTICLE:[16]

Many different antenna geometries have been studied over the past few years. Among them are bow-tie antennas half-wave antennas, monopole antennas, particle antennas, Yagi Uda antennas, gap antennas, slot antennas, cross antennas and patch antennas. Although these studies established important groundwork, several challenges remain that must be addressed before optical antennas can become a widely deployable technology.

5.1 Pursuing the radiofrequency antenna analogy: How far has the optical analogy of radiofrequency antennas been accomplished? Top down nanofabrication tools such as electron-beam lithography and ion-beam milling have been widely used to downscale established radiofrequency antenna configurations to the optical frequency regime. However, unlike radiofrequency antennas, which are locally driven at the feed gap, early optical antennas were driven from the far-field. Antenna-mediated transduction has been explored mainly for infrared detection using, for example, a slot antenna or an open-sleeve dipole antenna.

5.2 Impedance matching. A major challenge in the design of optical antennas is impedance matching between the antenna and the source. For a source in the form of an atom or molecule, we find a largely reactive impedance of roughly 1 MΩ, which follows from treating the atom/ molecule as a plate capacitor of area 0.2 nm × 0.2 nm, and a plate separation of similar dimensions. On the other hand, the impedance of a typical metal nanostructure is mostly Ohmic and is extremely small (~3 Ω for a linear half-wave antenna) 1, 40. It is currently unclear how to compensate for this large impedance mismatch.

5.3 Electro-optical transduction: In the traditional radiofrequency and microwave regime, antennas are usually used to convert electromagnetic radiation into electric currents, and vice versa. However, most of the optical antennas studied so far operate on a 'light-in, light-out' basis. There are only a few studies that report the antenna-assisted Conversion of optical radiation into photocurrents. Antenna assisted electro-optical transduction can draw inspiration from high-frequency devices such as infrared whisker diodes based on metal–oxide–metal junctions, and from photon emission in scanning tunneling microscopy. Such infrared whisker diodes provide a route towards receiving electro-optical antennas24, whereas scanning tunneling microscopy defines a possibility for transmitting electro-optical antennas. The problem in metal–oxide–metal diodes is the high-frequency cut-off, which depends on the capacitance of the metal–oxide–metal junction.

5.4 Selection rules: We have already pointed out several important differences between optical antennas and classical radio wave antennas. For example, at optical frequencies, the penetration of radiation into metals can no longer be neglected, and consequently optical antennas respond to a scaled, effective wavelength rather than to the wavelength of the incoming radiation. In addition, at optical frequencies metals are very nonlinear materials, which makes it possible to mix and convert different frequencies. Finally, and most importantly, the localized fields near optical antenna structures have spatial dimensions that approach the length scale of atomic/molecular quantum wave functions.

5.5 Reproducibility and repeatability: Any progress in the application of optical antennas depends critically on the capacity to fabricate an optimal geometry with sufficient material quality and nano scale accuracy. Traditionally, the bottom-up colloidal synthesis approach has provided high-quality crystalline metallic nano particles of controllable shape and size to within a few nano metres. The colloidal particles show high-quality resonances ($Q > 10$) approaching the limits set by the metal dielectric properties.

VI. EXISTING NANO SCALE METHODOLOGY

6.1 Design antenna in NANO scale and CNT based: The nano antenna designed for our CNT based nano IR detectors as depicted in Figure 1. It consists of two symmetric thin metal wires which are separated by a nano metric gap. When the antenna is illuminated with an infrared source, a plane wave incident from above is collected over the entire area of the antenna and a standing wave current pattern is generated along two metal wires. The field in the vicinity of the electrically conducting object is finally enhanced. The CNT sensing element is then aligned to the position of the maximum estimated field near the antenna. The maximum radiation occurs at the point that is perpendicular to the antenna axis. After designing the antenna, the fabrication process of the CNT based IR detector with the nano antenna was developed and the schematic structure, which employs the nano assembly of CNTs and standard photolithography processes.

The single CNT sensor was first fabricated by using nano assembly to form the CNT across micro electrodes. A pair of symmetric micro electrodes was evaporated on the quartz substrate by using thermal evaporation. Titanium was used to improve the adhesion of gold to the substrate. The gap distance between the micro electrodes is from 1 to 3μm. Then a drop of CNT suspension was dispersed on the substrate and an ac voltage was applied. CNTs were then formed between the pair of micro electrodes by the di-electrophoresis force. CNT's responsibility to IR has been proposed as the Schottky barrier effect at the CNT-metal contact. When the IR irradiates the CNT, electrons and holes inside the CNT are excited by the photons and results in the generation of current. As a result, the current from the CNT-metal contact is affected by the concentration of the photo generated carriers in CNT under the incident IR excitation. Therefore, if the CNT-metal contact is placed to the position of the maximum field output near the antenna, then the current can be increased due to the increasing IR power at the sensing region. This alignment process can be performed by the following steps. Firstly, the CNT formation between the microelectrodes was observed by using an Atomic Force Microscope (AFM) so that the position of the CNT-metal electrode was known and estimated. Afterwards, a parylene C thin film layer was coated on the CNTs to act as an insulating layer for separating the antenna and the sensor.[4]

6.2 The Advantage of using parylene C:

C is that it can be deposited conformably at room temperature and it can also cover CNTs from contamination. The IR sensing ability of the CNT detector after packaging by parylene has been reported in [8].

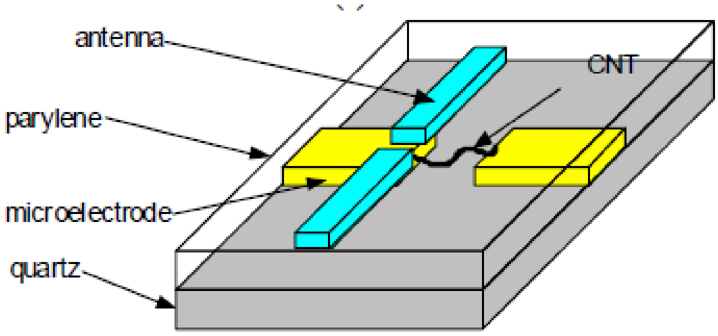

Fig.1 Schematic structure of a CNT based IR detector with a nanoscale antenna.[4]

The photocurrent response is increased while the electric field near the antenna is enhanced and it is influenced by the gain of the antenna. The gain increases while the size of the antenna is reducing. This is caused by the increasing the conductance of the antenna when the size of the antenna decreases. The conductivity directly affects the current distribution and also the electric field in the vicinity of the antenna. Therefore the gain of the antenna for IR detection significantly increases when the wave length and antenna length get smaller. Moreover, the gain of the antenna is also affected by several factors such as the length of the antenna, the alignment of the sensor to the maximum field output near the antenna, the material of the antenna, and the Separation distance between the sensor and the antenna. It has been reported that the response maximizes when the antenna length is a proper multiple of the half-wavelength of the incident radiation. Therefore, the antenna length effect on the field enchantment by the nano antenna has to be further studied.

VII. CONCLUSION

The design and fabrication process of a novel ETDRA, with 1x2 corporate feed network, CNT based IR detector has been presented. Sensitivity of sensor would be increased by Enhancement technology. The antenna in nano environment is more efficient and can be incorporated into the manufacturing process of present day infrared detectors. We are also assure that this integration will give good results in radiation pattern, impedance-bandwidth, return losses, high fidelity infrared sensors with a wide sensing range This hypothesis will bring a major breakthrough in sensor research. This will lead to a dramatic improvement in the performance of infrared imaging systems, which are important for future civilian and military applications.

VIII. REFERENCES

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