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Nantenna – A Review

Aakash Shah[1], Payal Furia[2], Tejas Shanbhag[3], Ayush Shah[4]

Student, Electronics, DJSCOE, Mumbai, India [1, 2, 3, 4]

Abstract: In a world looking for newer options to sustain renewable energy sources, efficient extraction of solar energy is a primary objective. A nantenna electromagnetic collector (NEC) is a device which can effectively absorb radiations of any wavelength and give out radiations of the required wavelength. They can replace the traditional photovoltaic cells to give a much higher efficiency of around 80%.The paper describes the working of nantennas with the use of MIIM diodes and throws light on some astounding applications this technology can have.

Keywords: Nantenna, Solar, Infrared, MIIM Diodes.

I. INTRODUCTION

An idea first proposed by Robert L. Bailey in 1972, gave us an insight about the emergence of Nantennas as the future devices of converting solar power into electrical energy. At that time the efficiency and economics of this proposal was not known but theoretically, it proved to be a boon for the dwindling and uneconomical technology used in the market using photo-voltaic cells.

Nantenna is a nanoscopic rectifying antenna which is designed as to absorb specific wavelengths that are proportional to the size of nantenna. Currently the nantennas processed in Idaho National Laboratories are able to absorb wavelengths in the range of 3-15 µm. On paper, nantenna can absorb any wavelength of light effectively provided that the incident light wavelength is proportional to the size of the nantenna designed for that specific wavelength. Ideally, nantenna should be used to absorb wavelengths corresponding to light at wavelengths between 0.4-1.6µm, because these wavelengths have higher energies than far infra-red and also they make up about 85% of the solar radiation spectrum.
A paper that gave us insight into this topic is 'Solar Nantenna Electromagnetic Collectors' by Dale. K. Kotter, Steven. D. Novak, W. Dennis Slafer and Patrick Pinhero.[1]The authors start by giving a basic definition of the subject by emphasizing on its most important application which is providing an efficient approach for producing electricity from the sun. Then the paper points out the advantages of the nantenna electromagnetic collectors over the conventional photovoltaic cells. It further gives an overview of the theory of operation of the device along with the use of MIIM diodes for high frequency rectification. Further, proof of the concept is provided through validating the NEC concept and creating a small scale prototype. After providing different prototypes available with the wide range of applications of the device, it ends on the future prospects of the device.
Sun is the most perennial and constant source of energy on Earth. Approximately 30% of this energy is reflected back to space, 19% of it is absorbed of atmospheric gases and reflected back to the Earth and 51 % of the energy is absorbed by the Earth and organic life. These radiations, both absorbed and reflected, account for ranges of 7 to 10 µm.

This energy from the sun is underutilized by the photovoltaic cells currently in use and thus their maximum conversion efficiency is just limited to 30%.

Nantenna comes into this arena to solve this particular crisis. As the importance of harvesting the solar energy dawns with every passing day, efficient conversion of solar energy into electrical energy is the need of the hour. Nantennas theoretically provide the very same solution, with their conversion ratios reaching maximum of 85% on paper, though the currently manufactured nantenna arrays have been able to achieve 50% conversion. In the second and the third section we have explained the operation of nantennas and the technologies currently used.

II. HOW DOES A NANTENNA OPERATE?

Light propagates as EM wave at a certain frequency. Nantennas can absorb any specific wavelengths corresponding to the size of the nantenna. The absorption occurs at nantenna resonance frequency. The oscillating electric field of the incident light causes the electron in the nantenna to move back and forth at the same frequency as the incoming light. This movement of electrons causes an alternating current in the nantenna circuit. A cyclic plasma movement of the free electrons is induced. Electromagnetic modelling of a spiral antenna illustrates that current flow is towards the antenna feed point which

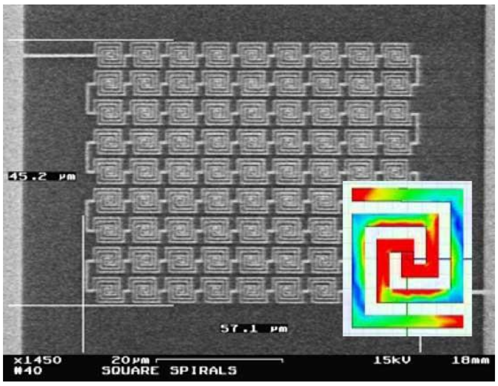

Figure 1: Array of loop nantennas, (inset) Flow of THz current to feed point of antenna. Red represents highest concentrated E-field.

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has the lowest impedance and thus power loss is is reduced. The entire electric field is concentrated at the center thus providing convenient point for energy transmission and collection. The electromagnetic characteristics of the antennas allow them to exhibit gain and directionality to effectively collect and concentrate energy the angular reception characteristic of the nantenna results in a wider angle of incidence exposure to thermal radiation as compared to typical photo-voltaic cells. Thus any flux falling within the radial pattern of the nantenna is absorbed.

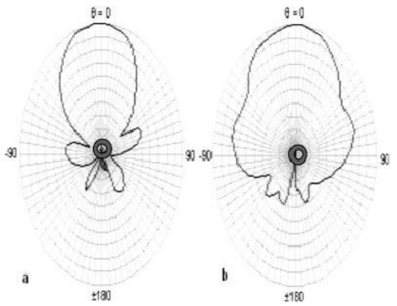

Figure 2: Typical electromagnetic radiation pattern of antenna. The physical size of the antenna is represented by the ring and the effective electrical size of the antenna is the radiation pattern.

From the figure 2 it is clear that the electric area of the nantenna is much larger than its physical area. This provides the designers a mechanism to increase the efficiency of the antenna arrays by expanding the radial field. Ideally, nantennas absorb light at the wavelengths between 0.4 and 1.6 um this causes an alternating current in the THz region. This alternating current has to be converted into DC current. Antennas do not have any mechanism for this energy conversion. A diode of some kind is used. The frequency/speed of light transmission into electricity depends upon the skin effect which causes the effective resistance of the conductor to increase at higher frequencies where the skin depth is smaller, thus reducing the effective cross-section of the conductor. Since the frequency of the current is in TeraHertz, commercial grade components cannot be used without significant losses.

III. CURRENT TECHNOLOGY USED

MIIM DIODES

The MIIM diodes are a type of 'tunnel diodes' that were in existence since the 60's, known for the technology behind it, 'quantum tunneling' [6].It has never been researched further and developed for mass production. Quantum Tunneling is the technology behind MIM and MIIM diodes.

As the name suggests, quantum tunneling can be explained with quantum mechanics and not classical mechanics. When the electron reaches the barrier, the insulator in between the metal strips, it absorbs energy from the surroundings in order to pass through the insulator. In doing that, a part of the electron beam passes through the barrier, but another part reflects back. However, due to the energy absorption, the reflected electron beam has far more energy than it originally has. As a result, the speed is much higher than on a normal conductor or semiconductor.

Analytical model- RLC circuits:

The circuit analog of a Nantenna Electromagnetic collector (NEC) is shown in the figure 3 shown below.
Inductance is provided by the metal loops to the NEC as current is induced by thermally-excited radiation.

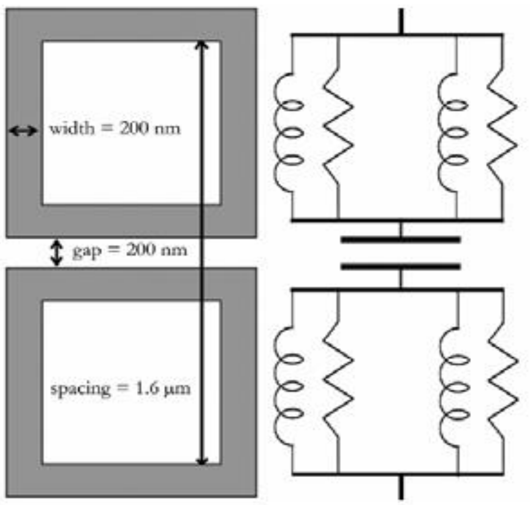

Figure 3:

There are gaps between the metallic loops and which acts as capacitors with a dielectric fill. The requirement for a resistance is vital since the antenna is composed of lossy metallic elements on the dielectric substrate. As a result, we get a resonance "tuned" behavior from the resulting RLC circuit. The proper selection of element and substrate materials is important since it contributes to the RLC parameters and the electro-optical characteristics of the NEC circuit while the surrounding media shapes and optimizes the spectral response.

PRESENT STRUCTURE:

Standard semiconductor integrated circuit fabrication techniques were used to fabricate laboratory scaled Silicon wafer prototype. E-beam lithography was used to fabricate the arrays of loop antenna metallic structures. The manufacturing process is described below:

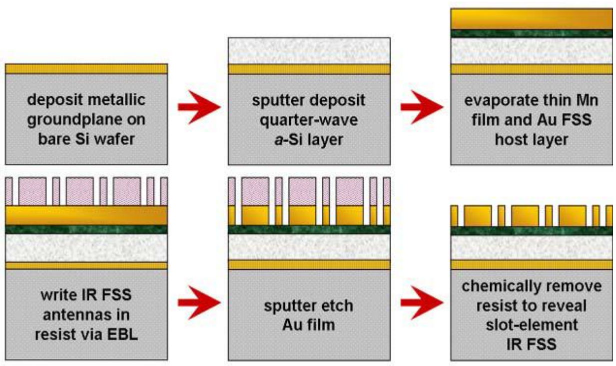

Figure 4

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The nantenna consists of three main parts: the ground plane, the optical resonance cavity, and the antenna. The antenna absorbs the EM wave, the ground plane acts to reflect the light back towards the antenna, and the opticalresonance cavitybends and concentrates the light back towards the antenna via the ground plane.

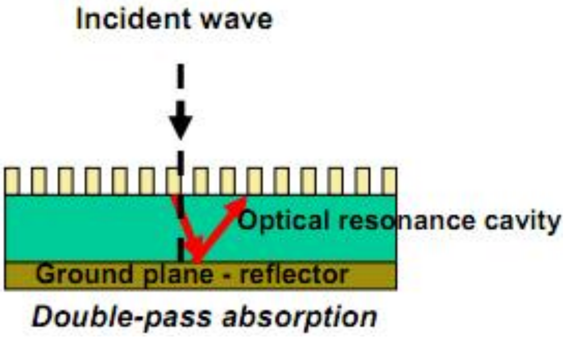

Figure 5

Some manufacturing techniques used presently are

Lithography model:
This is a process which was carried out by Idaho National Labs. Firstly, a bare silicon wafer is taken and a metallic ground plane is deposited on it. This process is followed by a sputter deposited amorphous silicon layer. The deposited layer is about a quarter of a wavelength deep. For the antenna, a thin manganese film is deposited along with a gold frequency selective surface (to filter wanted frequency). Resist is applied later and patterned via electron beam lithography. After removing the resist, the gold film is successfully etched.

Roll-to-roll manufacturing:
Since the use of electron beam lithography was found out to be slow and expensive, a new method was introduced based on master plan. This master pattern in effect mechanically "stamps" the precision pattern onto an inexpensive flexible substrate and thereby creates the metallic loop elements seen in the laboratory processing steps. A number of 4-inch square coupons have been produced using this process which is semi-automated. These coupons are further combined to form a broad flexible sheet of nantenna arrays.

IV. FUTURE APPLICATIONS

This technology has far reaching applications which can revolutionize use of renewable energy sources. Dr. STEVEN NOVACK (Physicist, Idaho National Laboratory) who is currently working on this technology claims that one day nantennas could be used to absorb infrared energy available in the room convert it into electricity which could be further used to cool the room.[5] Thus violating the second law of thermodynamics. These nantenna arrays are quite small thus they could be fitted into the skin of our devices or clothes. For instance, a solar nantenna shirt could be used to absorb our own body heat and keep us cool. A hybrid car with nantenna fitted into it can charge up by soaking the infrared radiations from the earth during the night time. They can be fitted on rooftops or used as wallpapers to control the temperature of the building and run the electronics devices.

Industries generate a huge amount of waste which is in the form of heat energy. Even our computers radiate a lot of heat. Nantennas can be designed to absorb this heat energy and produce electricity from it on a large scale.

This technology could be a very practical replacement to solar panels and traditional fossil fuels. Solar panels rely on the band gap of element and thus can absorb a very small portion of the solar spectrum. Thus giving maximum 20% efficiency. Moreover, additional mechanism is required to convert this into usable electricity, thus making it costly. A prototype device made by using this technology gives about 95% efficiency[4].They aren't dependent on the band gap and thus can absorb any frequency range from the entire spectrum. Ideally, nantennas would be used to absorb light at wavelengths between 0.4 and 1.6 μm because these wavelengths have higher energy than far-infrared (longer wavelengths) and make up about 85% of the solar radiation spectrum.

V. CONCLUSION

This paper provides an insight in general terms regarding the emergence and growth of Nantenna in commercial as well as industrial applications. The major issue solved using Nantenna is that it can successfully and effectively absorb electromagnetic waves of very short wavelength and thus provides an efficient solution for converting solar energy into electrical energy. All the researchers need to ensure that the fabrication of nantenna into smaller and flexible versions is made possible. Also, the limitations related to the rectifying element can also be eliminated by finding a proper material that could operate in THz frequencies. The research in this field is at intermediate stages and it may take time for it to come into the market for practical application.

However, the advances in this field cannot be ignored and possibility of an efficient power source from solar energy is not far away.Though the technology is at elementary stages, research and development in this technology will prove extremely beneficial to all, industrialists and general masses alike.

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