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# Solar Nantenna

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**ABSTRACT**

An efficient approach for producing electricity from the abundant energy of the sun is discussed. The Nantenna Electromagnetic Collectors (NEC) [1] devices target mid-infrared wavelengths, where conventional photovoltaic (PV) solar cells are inefficient and where there is an abundance of solar energy. The initial concept of designing NEC was based on scaling of radio frequency antenna theory. This NEC is basically a Nano antenna which collects the sun radiation and thermal radiation and converts it into electrical signal. The aim is to realize a low-cost device that will collect and convert this radiation into electricity, which will lead to a wide spectrum, high conversion efficiency, and low-cost solution to complement conventional photovoltaic (PV) solar cells.

## Introduction

Solar power is freely available & it should use for generation of electricity as our nonrenewable energy sources are going to exhaust. Full spectrum incident and reflective (readmitted) electromagnetic (EM) radiation originating from the sun provides a constant energy source to the earth. Approximately 30% of this energy is reflected back to space from the atmosphere, 19% is absorbed by atmospheric gases and reradiated to the earth's surface in the mid-IR range (7-14 um), and 51% is absorbed by the surface or organic life and reradiated at around 10 um [2]. Several approaches have been pursued to harvest energy from the sun. Conversion of solar energy to electricity using photovoltaic cells is the most common. An alternative to photovoltaic is the rectenna, which is a combination of a receiving antenna and a rectifier. The initial rectenna concept was demonstrated for microwave power transmission by Raytheon Company in 1964 [2].It has been demonstrated that optical antennas can couple electromagnetic radiation in the visible in the same way as radio antennas do at their corresponding wavelengths [3]. Nantenna proposed by Robert L. Bailey in 1972[7]. Idaho National Laboratories has designed a nantenna to absorb wavelengths [1]. Nantennas absorbabout 85% of the solar radiation spectrum [8]. The major technical challenges are to develop economical manufacturing methods for large-scale fabrication of antenna-based solar collectors &to improve the efficiency of rectification of antenna inducedterahertz currents to a usable DC signal. [1]

### *Limitations of Photovoltaic Technology*

Traditional p-n junction solar cells are the most common of the solar energy harvesting technologies. The basic physics of energy absorption and carrier generation are a function of the materials characteristics and corresponding electrical properties (i.e. band gap). A photon need only have greater energy than that of the band gap in order to excite an electron from the valence band into the conduction band. These higher energy photons will be absorbed by the solar cell, but the difference in energy between these photons and the silicon band gap is converted into heat (via lattice vibrations — called phonons) rather than into usable electrical energy. For a single-junction cell this sets an upper efficiency of ~20%.

### *Efforts for Increasing Frequency*

The current research path of implementing complex, multi junction PV designs to overcome efficiency limitations does not appear to be a cost-effective solution. Even the optimized PV materials are only operational during daylight hours and require direct (perpendicular to the surface) sunlight for optimum efficiency. The efficiency can be increase up to 50%. [1, 5]

### *Economical Alternative To PV*

The alternative energy harvesting approach based on nantennas that absorb the incident solar radiation. Nantennas rely on natural resonance and bandwidth of operation as a function of physical antenna geometries. The NECs can be configured as frequency selective surfaces to efficiently absorb the entire solar spectrum. Rather than generating single electron-hole pairs as in the PV, the incoming electromagnetic field from the sun induces a time-changing current in the antenna. Efficient collection of the incident radiation is dependent upon proper design of antenna resonance and impedance matching of the antenna. Recent advances in nanotechnology have provided a pathway for large-scale fabrication of nantennas. [1]

## Construction

Nantenna is basically a square loop antenna as in figure.

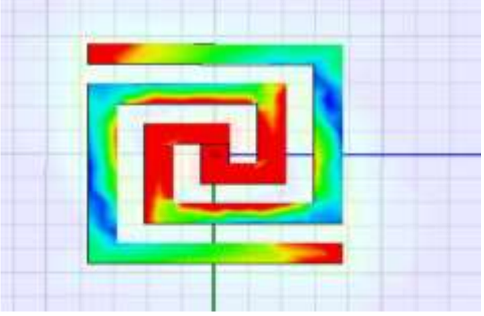

**Figure1. Flow of THz currents to feed point of antenna. Red represents highest concentrated E field. [1]**

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Nantenna element captures electromagnetic energy from naturally occurring solar radiation and thermal earth radiation. The size of the antenna is relative to the wavelength of light we intend to harvest. Figure 1 was acquired from modeling the electromagnetic properties of an infrared spiral antenna. At the center feed point is present which has very low impedance. This provides a convenience point to collect energy and transport it to other circuitry for conversion.

### Working

The basic theory of operation is as follows: The incident electromagnetic radiation (flux) produces a standing-wave electrical current in the finite antenna array structure. Absorption of the incoming EM radiation energy occurs at the designed resonant frequency of the antenna [4].

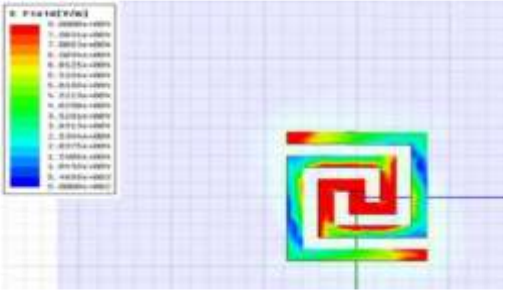

**Figure 2. Field overlay plot of a square-spiral nantenna at infrared wavelengths.**

When an antenna is excited into a resonance mode it induces a cyclic plasma movement of free electrons from the metal antenna. The electrons freely flow along the antenna generating alternating current at the same frequency as the resonance. Electromagnetic modeling illustrates the current flow is toward the antenna feed point. In a balanced antenna, the feed point is located at the point of lowest impedance. The e-field is clearly concentrated at the center feed point. This provides a convenience point to collect energy and transport it to other circuitry for conversion. [1]

### Radiation Pattern

The nantenna radiation pattern displays angular reception characteristics, resulting in a wider angle of incidence exposure to thermal radiation than typical PV. Antennas have electromagnetic radiation patterns, which allow them to exhibit gain and directionality and effectively collect and concentrate energy, as illustrated in Figure 2. As illustrated in Fig 2, the electrical size of the antenna (comprised of radiation beam pattern) is much larger than the physical size of the antenna.Any flux from the sun that falls within the radial beam pattern of the antenna is collected. This property is a critical antenna characteristic that optimizes energy collection from the sun as it moves throughout the horizon. Thus, it may be possible to reduce the need for mechanical solar tracking mechanisms. It also provides designers another mechanism to increase the efficiency of antenna arrays through the expansion of the radial field.

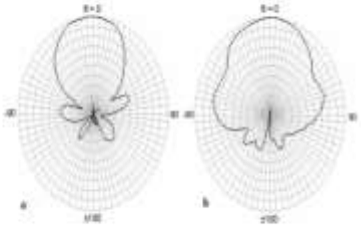

**Figure 3. Typical electromagnetic radiation patterns of antenna.[1]**

### Energyconversion Method

Antennas by themselves do not provide a means of converting the collected energy. This will need to be accomplished by associated circuitry such as rectifiers. Infrared rays create an alternating current in the nantenna at THz frequencies. Commercial grade electronic components cannot operate at that switching rate without significant loss so performing high frequency rectification is necessary. This requires embedding a rectifier diode element into the antenna structure. One possible embodiment is metal-insulator-insulator-metal (MIIM) tunneling-diodes.

The MIIM device consists of a thin barrier layer and two dielectric layers sandwiched between two metal electrodes with different work functions. The device works when a large enough field causes the tunneling of electrons across the barrier layers. A difference in the work function between the metal junctions produces non-linear effects resulting in high-speed rectification. The thinner the insulated layers become the higher the non-linear effects. [1]

### Array of the Solar Nantenna

To forming the solar panels this solar nantenna is going to connect in array so we get the wide radiation pattern and maximum energy is going to collect. The output of the rectifiers can be dc-coupled together, allowing arrays of antennas to be networked together to further increase output power capacity. This is conceptually illustratedin Figure 4 where the solar nantenna is connected by dc coupling and the wire which used for connection is thousand atoms thick.

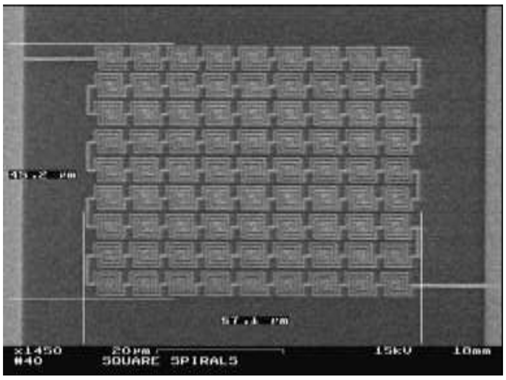

**Figure 4. An array of nantennas printed in gold and imaged with a scanning electron microscope. The deposited wire is roughly a thousand atoms thick. A flexible panel of interconnected nantennas may one day replace heavy, expensive solar panels. [1]**

### Master Pattern

One of the most important aspects of fabricating the NEC is an understanding of the tolerances required to make structures behave like antennas at infrared wavelengths. Tolerances were derived through extensive modeling studies evaluating impacts of changing the geometric parameters including: antenna wire width/depth, antenna periodicity, gap size between adjacent antennas, etc. Many parameters are co-dependent and required use of optimization algorithms. The resulting NEC geometry was incorporated into a master template (see Figure 5) fabricated on an 8-inch round silicon wafer. The template consists of approximately 10 billion antenna elements. The fidelity between the nantenna design and the replicated master template is excellent[1]

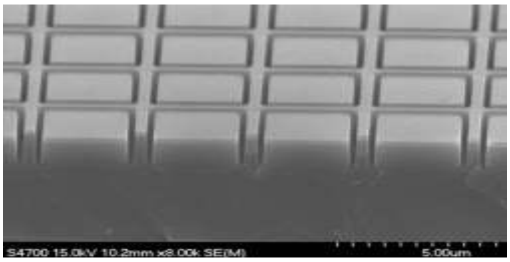

**Figure 5. Electron microscope image of master template**

### Energycollection of Silicon Prototype

Experimental measurements were performed on a prototype consisting of a 1.0 cm2 array of loop nantennas fabricated on a silicon substrate. This rigid substrate prototype served as the precursor to current work on large-scale flexible substrate nantennas.

The IR nantennas were designed to operate as a reflective band pass filter centered at a wavelength of 6.5um. The spectral surface characteristics from 3 to 15um were studied using spectral radiometer and FTIR analysis methods. The prototype was elevated to a temperature of 200ºC and its spectral radiance spectrum was compared to blackbody emission at 200ºC. Maximum contrast is over 90% between emission near 4 μm and emission at resonance [6].

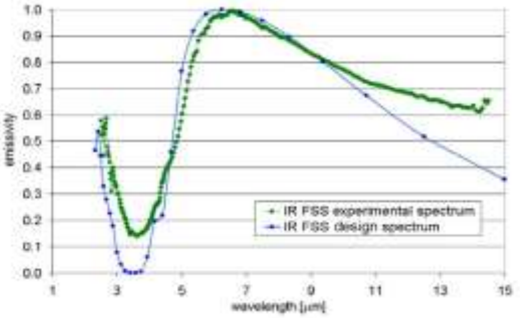

**Figure12.Demonstrated success in energy collection.Validated using a spectral radiometer and a FTIR**

The experimental spectrum closely correlates to the modeled spectrum. Peak resonance was achieved at the 6.5um wavelength.

### Prototype of Nec Devices

Processes have been developed to form nantennas onto polyethylene (PE) in a stamp and repeat process. Roll-to-roll manufacturing process is used. Prototype NEC structures have been fabricated onto flexible substrates. Using this semi-automated process, we have produced a number of 4-inch square coupons that were tied together to form sheets of NEC structures. (See Figures 6a and b) Prior to fully automated roll-to-roll scale up, all tooling and processes are being further developed and optimized using the semi-automated lab equipment. [1]

**Figure6a. Prototype FSS structure on flexible substrate. [1]**

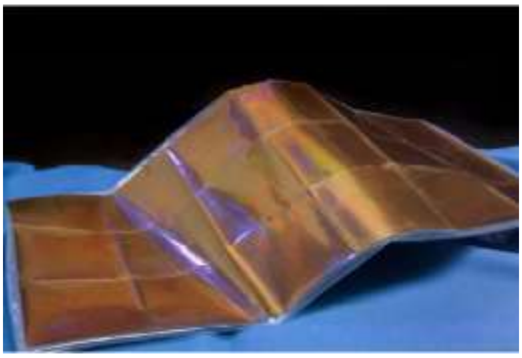

**Figure 6b. Nantenna sheet, stitched together from 18 coupons. [1]**

### Applications

Applications for this technology are very diverse. It can be combined with appropriate rectifying elements & integrated into the ‘skin’ of consumer electronic devices to continuously charge their batteries. It can be used as coating of the roofs of buildings and supplementing the power grid. The NEC devices can be optimized for collection of discrete bands of electromagnetic energy. It can be used for window coatings. It can be used as building insulation. It can be used to heat dissipation in small electronic consumer products, such as, computers. It will collect unwanted energy (residual or incident heat) & thermal radiation which keeps the rooms cool.

### Future Work

Future work will focus on designing the nantenna structure for operation in other wavelengths. Tunnel diode can be replaced by using femtosecond-fast MIM diodes in a traveling-wave (TW) configuration; we obtain a distributed rectifier with improved bandwidth. Due to the ability of integrating the nanostructures into poly materials it is possible that the nantennas can be formed on thin, flexible materials like polyethylene. [1]Double-sided panels could absorb a broad spectrum of energy from the sun during the day, while the other side might be designed to take in the narrow frequency of energy produced from the earth's radiated heat or potentially residual heat from electronic devices.[1] It can be made using the aluminum, copper or Silver.

### Conclusions

Solar power isfreely available & it should use for generation of electricity as our nonrenewable energy sources are going to exhaust. This demonstrates that the individual nantennas can absorb close to 90 percent of the available in-band energy which is better compare to the convention PV. More extensive research needs to be performed on energy conversion methods to derive overall system electricity generation efficiency. The circuits can be made from any of a number of different conducting metals. This is at an intermediate stage and may take years to bring to fruition and into the market.

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