ASEE 2014 Zone I Conference, April 3-5, 2014, University of Bridgeport, Bridgpeort, CT, USA.

Analytical model of Graphene based antenna for energy harvesting applications

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Abstract— **Recent advances in fabrication and characterization of nanomaterials have led to the intelligible applications of such nanomaterials in the next generation flexible electronics and the highly efficient photovoltaic devices. Nanotechnology has been used in thin film photovoltaic devices, and is considered as one of the most promising research area in power harvesting applications. Excellent electron transport properties of Graphene make it an attractive choice for next generation electronics and applications in energy-related areas. In this paper we present design and analytical model of graphene based nanoscale antennas for power harvesting applications. Unlike conventional solar cells that harvest energy in visible light frequencies range, we focus on design of nanoscale antenna to harvesting energy in UV spectrum range frequencies. Thought the irradiance of UV from sun is less than infrared and visible light frequencies, the excess energy of photons in UV frequency is greater than infrared or visible light frequencies and makeup for the lack of irradiance.**

Keywords-component; Nanoantenna; Graphene based antenna; Energy harvesting; Patch antenna; Solar energy, UV frequency (key words)

I. INTRODUCTION

Advances in nanotechnology have led to the development of semiconductor based solar cells, nanoscale antennas for power harvesting applications [1-3] and integration of antennas into solar cells to design low-cost light weights systems [2, 4]. Similarly, Grapheme has emerges as a promising candidate for next generation and post silicon electronics. Graphene based antennas have been explored due to high optical transmittance and conductivity of Graphene [5]. In this paper we present the design and analytical model of Graphene based antenna for power harvesting application. Typically solar cells use the visible light to produce electricity, the photovoltaic and rectification properties of sandwiched material is used to produce electricity. Unlike conventional solar cells that harvest energy in visible light frequencies range, we focus on design of graphene based nanoscale antenna in UV spectrum range frequencies. Since the UV frequency range is much greater than visible light, we consider the quantum mechanical behavior of a driven particle in graphene to calculate current in graphene based nanoscale antennas for power harvesting applications.

Sun is the biggest energy source for mankind, but taping into this huge energy reservoirs remains a challenge. Solar Energy is enormous, the surface of earth receive about $3x10^{24}$ Joules per year [5]. The energy reaches the earth in the form of emitted photons with variant frequencies. Frequencies of these photons represent the wavelength spectrum of sunlight which varies from Radio waves, to Gama waves. Sunlight, in space, contains of about 50% infrared waves, 40% visible light and 10% UV, X and γ. Each wave has their own frequency range and these ranges define the energy of each wave. Energy of a photon with a specified frequency is defined as:

$$E=h.f$$

Where “h” is the Planks constant, “f” is the frequency of the wave and “E” is the energy of photon (Joules). There are many ways to harvest this energy from the Sun. In addition to conventional Solar panels and Solar-water heaters, antennas are emerging as a promising technology for light energy harvesting [6] tools.

Solar plants use different ways to harvest energy from the Sun. Some panels use the heat (infrared photons) and concentrate it on a specific point (boiler) to heat water for the steam turbine in power plants. Such solar cells are using the visible light to produce electricity. Other panels use heat to produce air flow in towers and use wind turbines to produce power.

II. SOLAR PANELS AND ANTENNAS:

Typically solar cell consists of a semiconductor as middle layer, and two conductive layers. They use photo-electric phenomenon to produce electricity [7]. Working at the visible light frequency, these solar cells excite an

978-1-4577-1343-9/12/$26.00

electron and move it to valance shell. Such solar cells employ PN junction in semiconductor and the current flow as electrons flows across the PN junctions. Photovoltaic panels can be connected in series or parallel, to get desired output voltage or current.

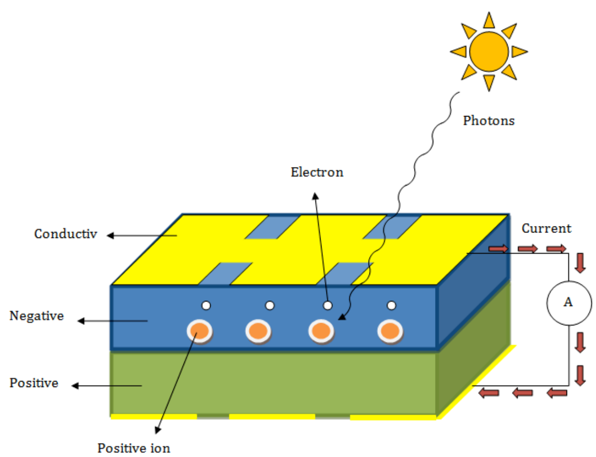

Figure 1: Solar Cells

Contrary to classical Solar cell (Fig 1), antennas based solar cells use faradays law to produce current. They are mostly made of copper, since it has a good conductivity. Their structure is easier than solar cells. Also their theoretical efficiency is greater than solar cells. Antennas, in energy harvesting area, are mostly designed for Infrared waves. Infrared waves have less energy than visible light or UV. Since sunlight mostly contains of infrared waves, the power which is harvested is significant. The amount of UV waves in space is greater than earth. The reason is the ozone layer which is filtering frequencies higher than visible light. In this paper we propose using Graphene to build antennas and gathering the energy from UV waves, in space.

III. WHY UV

Traditional PV solar cells harvest energy from visible and infrared light spectrum. Despite the improvement in semiconductor industry PV solar cells are not efficient, as they do not absorb long and short wavelength lights [2]. While irradiance of UV light is much lower than visible light (Figure 2), power of photons due to higher frequency is much more than visible and infrared frequencies. UV waves have frequency range between 0.75 PHz and 3 PHz. The frequencies above 1.034 PHz are being absorbed by the ozone layer. These photons may cause cancer and they have great amount of energy. Quantum mechanics states that the frequency and energy of a quantum of electromagnetic radiation are proportional. A photon with the frequency higher than the threshold frequency of matter will excite the electron to jump out from atom. The Photons with visible light frequency can excite electrons from atoms of some materials. This process is being used in solar cells to produce electrical current. Since the UV frequency range is much greater than visible light, not only it excites electrons and move them to Valance shell and make the antenna more conductive, but also will give them enough energy to increase this current. As we know from quantum mechanics, if the frequency of photon is more than threshold frequency, we can excite an electron and release it from its atom:

$$K = hf_{ph} - hf_0$$

f_0 is the threshold frequency of matter.

Table 1: Energy of photons and frequencies:

Wave	Frequency range	Energy of a photon (eV)
Infrared	0.3THz – 0.429 PHz	0.001 – 1.772
Visible-Light	0.385PHz – 0.789 PHz	1.591 – 3.265
UV-A	0.75 PHz – 0.952 PHz	3.102 – 3.939
UV-B	0.952 PHz – 1.07 PHz	3.939 – 4.431
UV-C	1.07 PHz – 1.5 PHz	4.431 – 6.203
Vacuum UV	1.5 PHz – 3 PHz	6.203 – 12.407

Table 1 list the energy of photons with different frequencies. The irradiance of sunlight can be plotted in the figure 2 below:

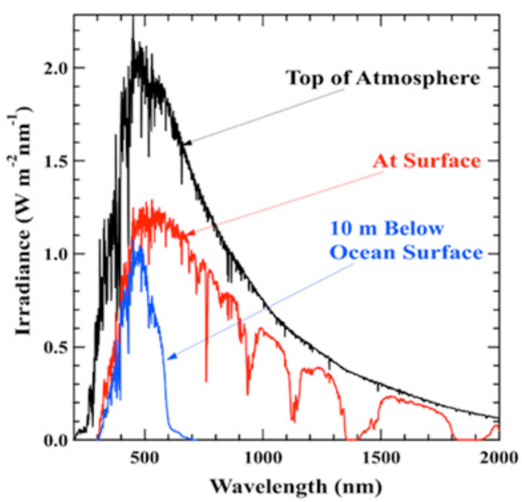

Figure 2: The irradiance of sunlight

Average photon energy (APE) indicates a spectral irradiance distribution. APE express the relationship between photon flux density and irradiance[8]. Photon flux shows the number of photon that hit the unit surface per second. We can find the total energy in each wavelength from energy and flux density. The relation between photon flux and irradiance is as below:

$$H= \Phi \times E=\Phi \times h \times f$$

Where H is the irradiance (W/m^2), Φ is photon flux (number of $photons/sm^2$), E is energy of photon (J), h is Plank constant and f is the frequency (Hz).

We used data from Solar Radiation and Climate Experiment (SORCE) [9, 10] to build the relationship between photon flux and irradiance. Table 2 show energy per photon as well as total energy in UV, UAV and Infrared bands.

Wave		**λ (nm)**	**H (W/m^2)**	**Φ ($Photons/sm^2$)**	**E per Photon (eV)**	**E Total (eV/sm^2)**
Infrared	**Max**	2412.34	0.060679	7.36384E+17	0.51430858	3.78729E+17
	Min	701.56	1.4017	4.94706E+18	1.768469068	8.74872E+18
UVA	**Max**	400.34	1.6641	3.35147E+18	3.099083676	1.03865E+19
	Min	315.02	0.63217	1.00184E+18	3.938439334	3.94569E+18
UVB	**Max**	315.02	0.93217	1.47727E+18	3.938439334	5.81815E+18
	Min	280.5	0.086971	1.22725E+17	4.423127127	5.4283E+17

Table 2 Energy in UV, UAV and Infrared bands

By comparing the total energy of infrared and UVA waves in table, we see that the maximum energy in UVA is greater than infrareds energy.

IV. ELECTRICAL AND CHEMICAL PROPERTIES OF GRAPHENE

Carbon is located in group IV of periodic table, which means Carbon has four valance electrons. Carbon form different allotropes such as graphite, diamond and graphene. In graphene, all the carbon atoms form covalent bonds. It is a monolayer honeycomb lattice structure. Graphene Nanoribbons (GNR) can be formed by cutting graphene sheets in small rectangles. GNR exhibit excellent electrical, optical, mechanical, thermal and quantum-mechanical properties[11, 12]. The practical threshold frequency of graphene is 1 THz. Calculating the k value from quantum mechanics equation, we can see that K is a positive value, which means photons with UV frequency can excite electrons from atoms:

$$K_{graphene} = h(f_p - f_0) = 4.135\times10^{-15}\times(1P - 1T) = 4.1309 \text{ e.V}$$

Thus a graphene based patch antenna shown in figure 3 will exhibit excellent properties and can be used to produce high amount of current.

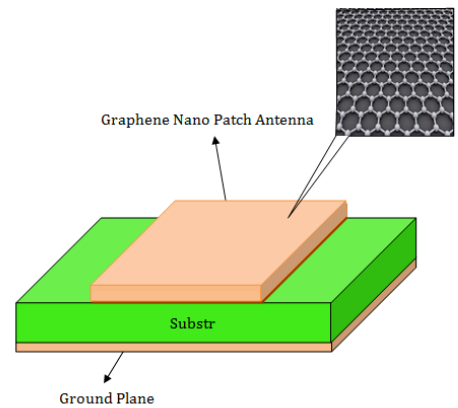

Figure 3: Graphene based patch antenna for power harvesting applications

V. ARRAY NANO PATCH ANTENNAS USING GRAPHENE:

We have proved analytically that graphene based patch antenna can be used to harvest energy from UV spectrum. Due to higher energy of UV photons, the electrons of single layer graphene not only gain this energy, but also the electrons in 2s shell of carbon atoms (first layer) can be excited and move to valance layer. Therefore, the number of electrons in valance layer increase and so the current. Like other nanoantennas [1, 2], we should also design array of antennas with rectifier circuit to convert these high frequency current into useable current. For this, we need a diode that can work in Petahertz frequency. High frequency MIM diodes can be used to build the rectifier kit. These diodes are also made from graphene.

VI. RESULTS

Conventional solar cells have very low efficiency [13], the most expensive solar cells reach up to 30% **efficiency**. Even with the advances in nano-technology, current state of art solar cell technology has little chance to compete with fossil fuels. Scientists are investigating various nano-structures and their designs to harvest energy from various frequencies of light [14]. In this paper we presented design and analytical mode for metal-insulator -metal (MIM) tunneling diode with integrated graphene based patch antenna.

Applications of such antennas are in the field of power harvesting and aerospace industry [15] We calculated and compared the energy of photons in

Infrared, UV and visible light spectrum. We concluded that light weight, highly efficient graphene based nanoscale antennas can be designed to harvest energy from UV light spectrum.

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