Effect of Insulator Layer on Optical Antenna in IR Energy Harvesting

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***Abstract*—Optical antenna integrated with high speed diode can be considered as an efficient rectification device for converting free space EM waves to DC current. This concept has shown many developments in the field of energy harvesting applications. To realize a diode at THz frequency, an insulator layer is added or sandwiched in between two arms of the metal antenna. In this paper, a four layer stack-up model with Bow-tie Optical antenna has been adopted and further investigated at 28.3 THz for IR energy harvesting application. The effect of addition of the insulator layer on the antenna characteristics has been studied.**

keywords– Bow-tie; rectenna; Metal-Insulator-Metal (MIM);

I. Introduction

To convert free-propagating optical radiation to a localized energy, and vice-versa, an optical antenna is used as an EM energy collector. It can be configured as frequency selective surfaces to efficiently absorb the entire solar spectrum [1]. It has been demonstrated that energy conversion efficiency of rectenna (antenna+rectifier) at frequency 2GHz is about 90 % [2]. Research theory suggests [3], efficiency this high could also be achieved for an optical rectenna using an ideal diode that is, one with ultralow capacitance and resistance, and high non-linearity and asymmetry.

When an antenna is excited into a resonance mode, it induces a cyclic plasma movement of free electrons in the metal antenna. Incident frequency causes this free electrons to move along the metal with same resonant frequency, creating alternating current wave. Electromagnetic modeling of antenna having pointed tip geometry [4] shows that 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 hotspot, where metal-insulator-metal (MIM) diode can be realized.

High frequency diode need to have very low RC time constant. But commercially available electronic diodes are not fast enough to handle the THz frequency switching [5]. So, integrated diode structure is required to rectify IR radiations. The MIM diode consists of a thin barrier dielectric (oxide) layer sandwiched between two metal electrodes with different work functions. The device works when a large enough field causes tunneling of electrons across the barrier layers. This device proved to be a good candidate for high frequency rectification. A difference in work functions between the metal junctions produces nonlinear effects, resulting in high-speed rectification [6].

In this work CST (Computer simulation technology) MW studio is used to simulate the optical antenna design. For this application Frequency Domain (FD) solver is used. Probe E-field values are used to define the convergence criteria for adaptive mesh refinement.

II. System Model

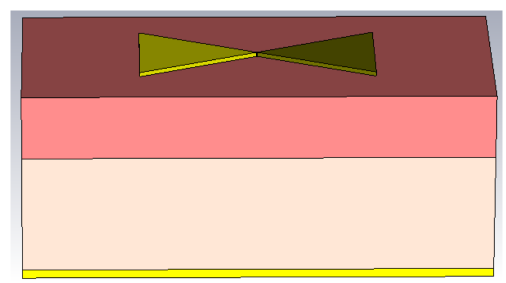

Fig. 1. Device structure

In this work, the structure adopted for IR energy harvesting is a bow-tie dipole employing gold metallization with a gap of 1 nm and it has been realized on a four layer stack up as shown in Figure 1. The first layer is a 3 nm chromium thin film used as an adhesion layer. The second is 1.5 μm silicon dioxide as a matching section, employed to increase the transmission of the incoming THz signal to the silicon substrate. The third layer is a 2.75 μm high resistivity silicon (4 KV-cm) where the high resistivity reduces the substrate losses. Finally, the fourth layer is a 200 nm gold back reflector to enhance coupling to the antenna from the substrate. The simulated structure, shown in Figure 1, is excited through a normally incident plane wave (z-axis) with an electric field intensity of 1 V/m and a linear polarization parallel to the antenna axis (x-axis). The electric field intensity is computed in the middle of the antenna gap where simultaneous optimization of both the length and the bow's angle of a 100 nm thick optical antenna results in a relative intensity enhancement of approximately 54 dB magnitude for a 10 nm gap, as shown in Figure 2. The model chosen for this application is considered as an optimal model from investigating the recent researches in optical rectenna.

Design specification for bow-tie dipole is same as that of RF bow-tie dipole antenna. The geometry of this antenna at 28.3 THz (mid-infrared) frequency is given as length equals to 2.7 μm and 50^0 as a flaring angle [7],[8].

III. Simulations and Results

The simulations are performed in order to observe the relative field enhancement at the tip of both arms of an optical antenna. It is observed that there is considerably high near E-field intensity enhancement when two different metal arms are used. This is needed for introducing asymmetric characteristics of diode. Field probes are used to measure the field enhancement at the tip and the gap of antenna. It can be observed from figure, copper (Cu) has higher field intensity than gold (Au) due to lossy nature of gold metal at high frequency. Based on this observation, a parallel sandwiched rectenna device has been investigated in this work, where very thin insulator layer is sandwiched between bow-tie arms and to realize a THz receiver. Gap between antenna arms is the only possible location where diode can be constructed to rectify highly localized EM field. Table I shows field enhancement for different antenna arms.

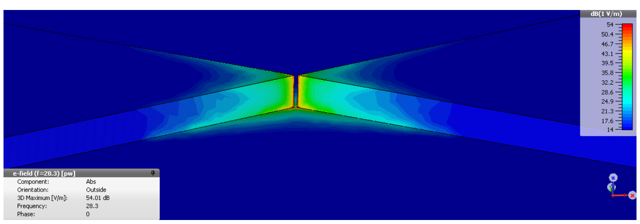

Fig. 2. Relative E-field enhancement

TABLE I
Near-field intensity enhancement for different antenna arms

Antenna arms	Relative intensity enhancement
Au-Au	46 dB
Au-Cu	51.72 dB - 53.47 dB

Diode Design - In this work, antenna characteristics have been revised by adding a thin sheet of Cupric Oxide layer as shown in figure 3 Simulation results shows that antenna characteristics are not altered at all. In fact, there is increase in relative field enhancement when diode section is added. Although perfect matching between antenna and diode is not demonstrated, rise of 6 to 7 dB(1V/m) enhancement has been observed 4.

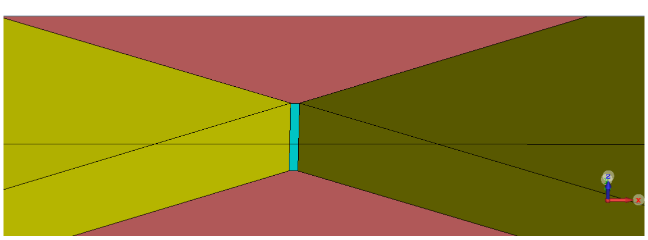

Fig. 3. Device structure with insulator (Diode)

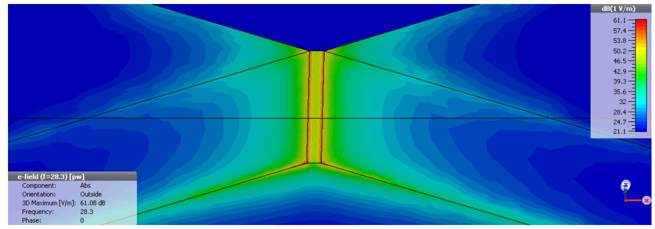

Fig. 4. Near E-field intensity in diode structure

When we add insulator layer, it exhibit features of parallel plate capacitor. As there is large accumulation of charge carries near tip of antenna, E-field will be established between two antenna arms which would force the charge carries to tunnel from on arm to another for a very small period pf time (17.66 psec). The current that will flow from one arm to other through insulator, can be drawn from opposite ends of the antenna.

IV. Conclusion and Future Work

For optical energy harvesting application MIM diode has been proposed as a good candidate for high frequency diode. In this work, an optimal design of IR energy receiving antenna in terms of maximum relative field enhancement has been investigated successfully. The effect of the addition of insulator layer between antenna arms on antenna characteristics has also been demonstrated. Next is to figure out best possible permutations of Metal-Insulator-Metal (MIM) diode that can give maximum conversion efficiency.

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