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High Input Resistance Terahertz Dipole Antenna With an Isolating Photonic Band Gap Layer

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Abstract—A terahertz dipole antenna with a high input resistance is proposed by minimizing the effects of the supporting GaAs substrate using a two dimensional photonic band gap (PBG) layer. In additio, special attentions have been given to the choice of PBG unit cell dimensions so that the photo-mixer is illuminated by the two laser beams with no obstruction. An electromagnetic simulator has been used to optimize the antenna, and its resistance is ~2.7kΩ .

Index Terms—Terahertz antenna, dipole antenna, high input impedance.

I. INTRODUCTION

Numerous studies have been reported that focus on the terahertz applications in communications, radar, imaging, sensors, and so on. [1], [2]. Photomixing system is a well-known approach to generate a continuous wave (CW) THz signal, due to its low cost, compactness and frequency selectivity [3]. As a result, a properly designed antenna is needed to transfer induced photocurrent into a radiated THz wave [4]. However, the coupling between the photomixer is a critical issue since the photomixer yields a significantly high output impedance that is typically in the order of 10kΩ [4]. As a consequence, the pronounced impedance mismatch results in the radiation of a marginal fraction of the generated THz power. Therefore, it is essential to design an extremely high input resistance THz antenna in order to improve the impedance matching. It should be noted that for practical purposes, a typical GaAs substrate thickness of ~300µm is required to provide the required mechanical support and to sustain the thermal flow. Therefore, employing a thin GaAs substrate will not satisfy the aforementioned requirements [5]. This limitation is associated with added complexity of fabricating a GaAs membrane.

Several high input resistance THz antennas have been designed and reported in the literature. For example, an input resistance of ~2.75kΩ has been proposed using a folded dipole that is printed on a 350µm GaAs substrate [6]. Further, a four leaf clover shaped antenna with an input resistance of ~1.6kΩ has been reported [7]. In addition, measured and simulated results have been reported for a THz meander dipole with improved radiation and matching efficiencies [8].

Therefore, a THz antenna design is needed that radiates efficiently in the presence of an electrically thick GaAs substrate. In other words, a special structure is needed to electromagnetically decouple the THz antenna and the thick supporting GaAs substrate. A two dimensional photonic band gap (PBG) layer is a potential structure that can act as an isolating layer between the thick GaAs substrate and a printed dipole antenna to achieve a higher input resistance as well as to minimize THz wave radiation towards the GaAs substrate.

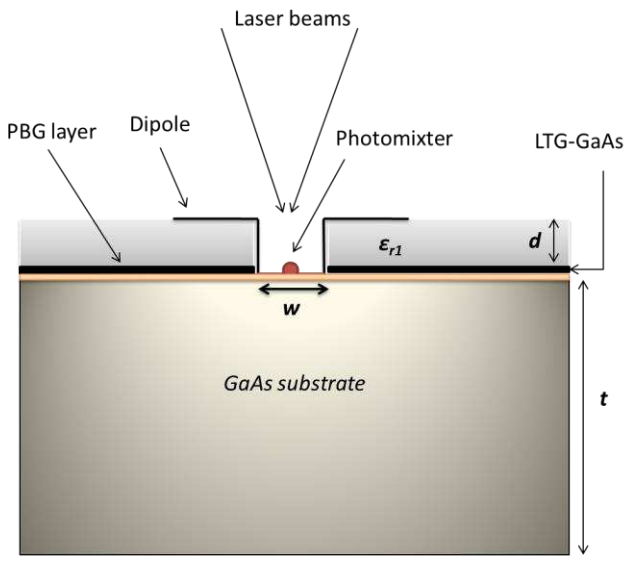

Fig. 1 Schematic of a THz dipole above a thick GaAs substrate with an isolating metallic surface.

II. ANTENNA CONFIGURATION

The structure of the proposed geometry of Fig. 1 illustrates a printed dipole that is mounted on a thin dielectric substrate with relative permittivity ε_{r1}=3.25 and a thickness d=12µm. In addition, a PBG reflection layer has been inserted between the thick GaAs (1800×1800×300)µm3 supporting substrate and the thin dielectric substrate layer. In order to facilitates the laser beams illumination of the photomixer, a central cavity with a size of (6×6)µm2 has been created in the thin dielectric substrate. Besides, the dipole is excited by a photocurrent that is generated from the photomixer and fed through two vertical probes. The length, thickness, and width of the dipole have been chosen as 140µm, 0.35µm and 3µm, respectively.(Was the length 140 or 170 um with the PBG??)

III. RESULTS

As mentioned earlier, a PBG surface has been considered in order to achieve the required electromagnetic decoupling between the dipole and the GaAs substrate. The presented design has been simulated using the Computer simulation Technology (CST) Microwave Studio package [9], where the photomixer has been modelled as a THz discrete port with a typical source impedance of 10kΩ. Due to the presence of the photomixer, the PBG unit cells shown in Fig. 2 have been utilized as they offer an ample circular aperture that is needed to accommodate the photomixer. The PBG unit cell has been designed assuming that it is located at the top of a thin LTG-GaAs layer that is supported by the GaAs substrate. As shown in Fig. 2, a PBG grid of 7×7 unit cells has been used to represent the required reflecting surface. The computed input resistance of the dipole is illustrated in Fig. 3, where it can be seen that incorporating the PBG surface produced an input resistance of ~2.7kΩ compared to a typical value of ~300Ω. The radiation efficiency has been calculated as 39%. It should be noted that the input resistance of a perfectly conducting configuration has been calculated as 6.7kΩ, which offers a matching efficiency of 96% compared to 67% for the copper structure. Therefore, the presence of ohmic losses deteriorates both of the matching and radiation efficiencies. The total efficiency of the antenna has been calculated as ~26%.

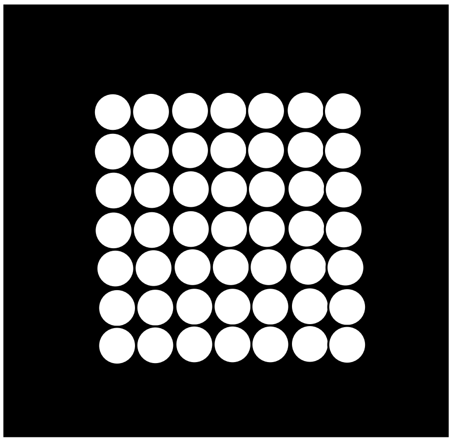

Fig. 2 The reflecting PBG surface with a circluar hole radius of 10µm and a periodicity of 50µm.

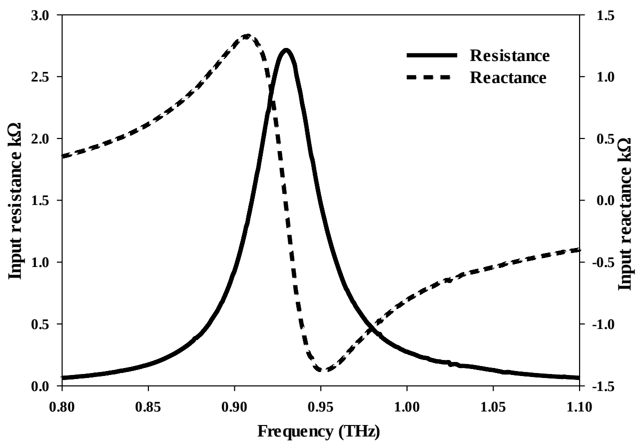

Fig. 3 Input impedance of a copper THz dipole antenna that is isolated from the GaAs substrate using a PBG surface.

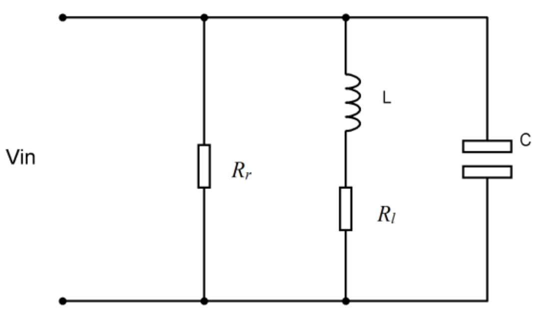

Fig. 4 Equivalent circuit of a lossy parallel resonant antenna

Since this is parallel resonance mode antenna, the impact of ohmic losses can be understood by considering the equivalent circuit shown in Fig. 4, from which an expression for the resonance input resistance can be derived as

$$R_{in} = \frac{X_L^2 R_r}{X_L^2 + R_\ell R_r} \tag{1}$$

where X_L is the inductive reactance at resonance. This equation demonstrates that the presence of ohmic losses reduces the input resistance, which subsequently lowers the matching efficiency. An expression for the radiation efficiency can be derived as

$$\eta_r = \frac{\left(V_{in}^2 / 2R_r \right)}{\left(V_{in}^2 / 2R_{in} \right)} = \frac{R_{in}}{R_r} \tag{2}$$

From equations (1) and (2), it is evident that a small loss resistance of few ohms may have a considerable impact on radiation as well as matching efficiencies. Although a larger radiation resistance is needed to improve the matching efficiency, this will result in a reduced radiation efficiency.

The effectiveness of the achieved decoupling between the radiating element and the supporting GaAs substrate has been investigated by varying the height of the latter. Fig. 5 illustrates the variation in the input resistance at various GaAs substrate heights, where it can be observed that the substrate thickness has a marginal effect on the input resistance. Furthermore, the inclusion of the PBG surface offers a structure that radiates most of the THz power into the upper half space as illustrated in Fig. 6, where it can be noticed that a far field pattern with a broadside directivity of ~7dBi has been achieved. Once more, the GaAs substrate height has minimal effect on the far field pattern. These results demonstrate that a considerable electromagnetic decoupling has been attained between the dipole and the GaAs substrate in the proposed configuration. As a result, the well-known limitations of utilizing an electrically thick GaAs substrate have been eliminated. In addition, the antenna can be simulated and optimized assuming a thickness of 50µm, which accelerates the simulation time and provides a considerable saving in the required computational resources.

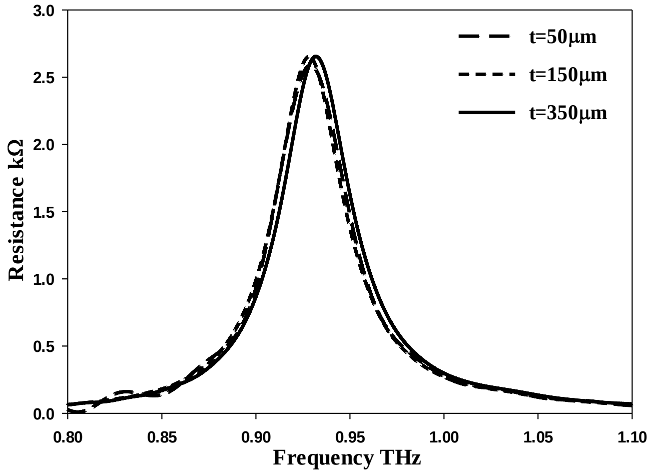

Fig. 5 Input resistance of a THz dipole above PBG reflecting surface as a function of the GaAs substrate thickness.

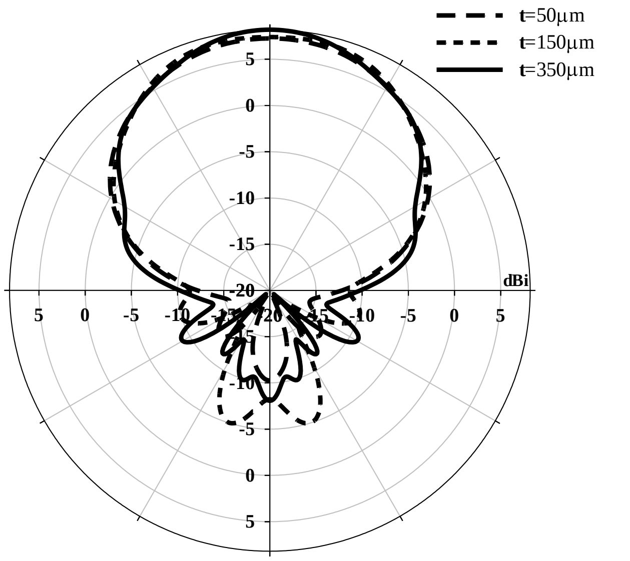

Fig. 6 Far field of a THz antenna isolated from the GaAs substrate using a PBG surface

IV. CONCLUSION

An input resistance of ~2.7kΩ for a THz dipole antenna has been achieved by using a PBG layer to isolate the supporting GaAs substrate. In addition, an upward broadside radiation has been obtained due to the presence of the PBG layer. It worth noticed that the THz antenna input resistance in the absence of an isolating layer has been calculated as ~300Ω. As a result, a huge progress in impedance matching can be attained when the antenna is connected to a photomixer with an impedance of 10kΩ. Besides, the impact of ohmic losses on matching and radiation efficiencies has been discussed. The choice of the PBG dimensions as well as the optimization for the dipole-photomixer connection has been considered carefully. Owing to the existence of the PBG layer, the GaAs substrate is effectively invisible to the THz radiating element. Therefore, antenna performance is independent of the thick substrate.

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