Photoconductive Antenna for Terahertz Generation

Titto Anujan
Assistant Professor
Department of Electronics and Communication
Trinity College of Engineering

***Abstract*—Terahertz photoconductive antennas are most common device for the generation and detection of terahertz waves and are very different from conventional RF/microwave antennas. LTG-GaAs has been the most widely used material for the photoconductive emitter and detector. This paper presents a computational procedure to design and simulate a photoconductive antenna for continuous wave terahertz emission. The simulated results show that the radiated power is sensitive to the dimension of the substrate. Most of the radiated power is radiated towards the substrate side rather than the free space and a thin substrate is preferred to maximize the radiated power and control the radiation direction**

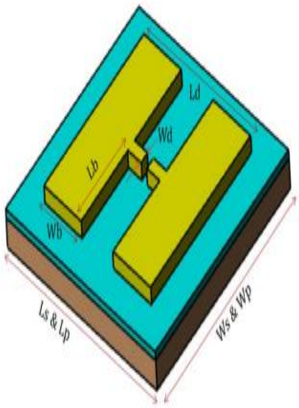
Keywords- LTG- GaAs, photoconductive antenna, Terahertz, CST microwave studio

I. INTRODUCTION

Terahertz (THz)[3] waves are located between the microwave and infrared regions and have frequencies in the range 0.1–10 THz. THz waves penetrate non-conducting materials as microwaves do, produce high-resolution images as does light, and are strongly attenuated in water, unlike any other spectrum of electromagnetic waves. These interesting properties make THz waves attractive in imaging, spectroscopy, and communication technologies. For example, it is possible to use them to see through the internal structure of opaque objects, analyze a molecular-level mechanism, and transmit radio signals from space. They can also provide much higher data transmission rates than existing microwave or millimeter systems for short-range communication.

II. ANTENNA STRUCTURE AND SIMULATION

Photoconductive antennas (PCA)[1] are biased terahertz emitters used to generate broadband terahertz pulses as well as narrowband continuous terahertz signals. It can provide relatively large output average power and bandwidth as high as 10THz. The bandwidth of the generated signal is limited by the antenna's frequency response and the carrier life time of the photoconductive material. The material used for the fabrication of PCA is required to have 1) Ultra short carrier life time, 2) High carrier mobility and 3) Large dark current sensitivity. The most commonly used material for PCA fabrication in 800 nm ranges is Low Temperature Grown GaAs (LTG-GaAs)[2] and Low Temperature Grown InGaAs for 1550 nm operation.



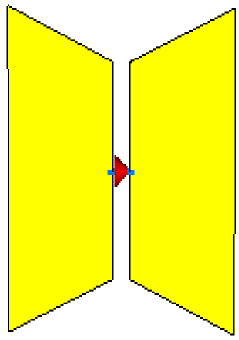


Fig1.Structure of coplanar strip line and Bow type antenna.

LTG GaAs is grown on a semi-insulating GaAs substrate, by standard molecular-beam epitaxy at temperatures around 200°C, with As over-pressure. LTG-GaAs material grown under these conditions is known to contain a nonstoichiometric excess of roughly 1% arsenic. Such a deviation of stoichiometry would result in very short carrier lifetime of around 1ps but poor carrier mobility. enhance the electrical properties the material is annealed at a temperature above 500°C in the arsenic flux that causes the excess arsenic atoms to rearrange primarily in the gallium sites. The annealing maintains the short lifetime but improves the carrier mobilities to > 100 cm2 / V-s. This also improves the dark current resistivity and breakdown field significantly. It consist of two metal electrode made of gold deposited on the GaAs layer. The parameters of the LTG-GaAs material and electrode are same as those in Table 2. The absorbing boundary conditions are applied to the simulation domain. For the designed structure, the minimum and maximum frequency are 0.1 THz and 1 THz respectively, also the beat frequency is 0.5 THz and the applied bias voltage between the electrodes is 20 V. Transient solver method can be used for numerical simulation of the antenna structure. By using this solver we can determine the radiation pattern, return loss and voltage standing wave ratio of various dipole antenna. Table 3 shows the directivity, minimum and maximum return loss, and minimum and maximum voltage standing wave ratio of various dipole antennas.

TABLE 1: LTG-GaAs physical parameters

Description	Notation	Value
Work temperature	T_0	300K
Absorption coefficient	α	1000 cm^{-1}
Electron saturation velocity	v_{sn}	4 10^4m/s
Hole saturation velocity	v_{sp}	1 10^4m/s
Low field electron lifetime	τ_n	0.1 ps
Low field hole lifetime	τ_p	0.4 ps
Low field electron mobility	μ_{n0}	400 cm^2/Vs
Low field hole mobility	μ_{p0}	100 cm^2/Vs
Surface recombination velocity	$s_{n,p}$	5000 m/s

TABLE 2: Physical parameters of photoconductive antenna

Experimental Analysis

Parameters	Substrate(LT-GaAs)	Electrode(Gold)
Epsilon/Electric conductivity	12.94	4.561e+007
Mue	1.0	1.0
Rho (kg/m^3)	5320.0	19320
Thermal conductivity (W/K/m)	54	314
Heat Capacity (kJ/K/kg)	0.33	0.13
Diffusivity (m^2/s)	3.07587e-005	0.00012502
Youngs Modulus (kN/mm^2)	85	78
Poisson Ratio	0.31	0.42
Thermal Expansion(1e-6/k)	5.8	14

TABLE 3: Design parameters of dipole antenna

A. Far field radiation pattern.

Far field radiation pattern is the power radiated from an antenna per unit solid angle which is nothing but the radiation intensity. Figures 2&3 shows the change of the radiation pattern of coplanar strip line and bow type antenna for electrode gap of 2 µm and 100 µm. Cst Microwave studio has the capability to calculate and plot a 3D far field radiation pattern also.

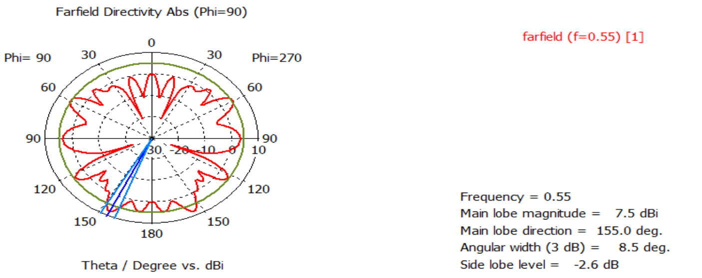


Fig2.Radiation pattern of coplanar stripline with 2 µm Electrode gap

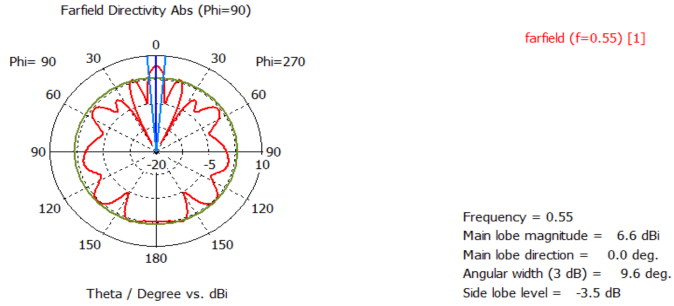


Fig3.Radiation pattern of Bow type with 100 µm Electrode gap

B. Return Loss

Return loss[4] is a parameter which indicates the amount of power that is lost and does not return as a reflection. A graph of S11 of an antenna Vs frequency is called its return loss curve. From the plot it can be determine that whether the antenna is single band or multi band. The reflection coefficient S11 magnitude in dB for the specified antennas are shown in Figures 4&5. The maximum return loss within the simulated frequency range can be calculated by using transient solver.

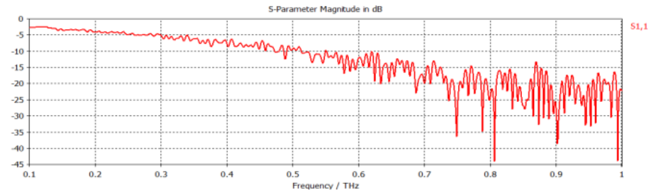


Fig4:S_{11} parameter for coplanar stripline with 2 µm electrode gap

Sl.No	Type	Substrate Dimension (µm)	Substrate Thickness (µm)	Electrode Width (µm)	Gap b/w Electrodes (µm)	Freq (THz)
1	Coplanar stripline Dipole	4000x4000	2	0.5	2	0.1 to 1
2	Bow	2000x2000	2	0.06	100	0.1 to 1

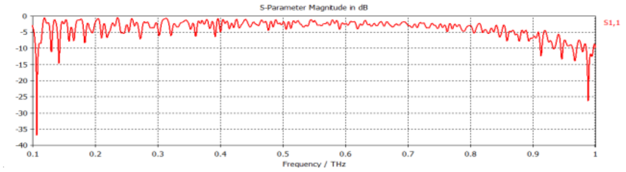


Fig5.S_{11} parameter for Bow type with 100 µm Electrode gap

C.VSWR

VSWR is a measure of how efficiently radio-frequency power is transmitted from a power source ,through a transmission line to an antenna. The VSWR is always a real and positive number for antenna. Low VSWR means power is being delivered to the antenna and not being reflected. Figure6&7 shows VSWR for dipole and bow type antenna.

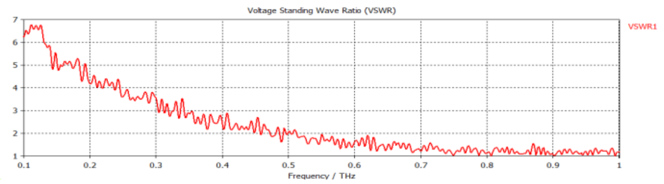


Fig6.VSWR of coplanar stripline with 2 µm Electrode gap.

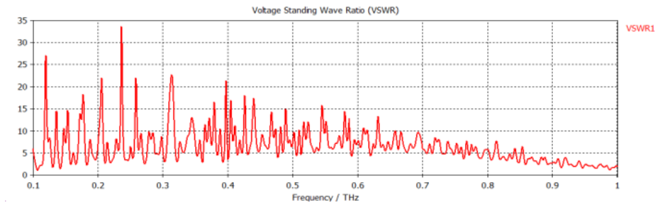


Fig7.VSWR of Bow type with 100 µm Electrode gap.

TABLE 4: The overall performance of dipole antenna is as follows

Sl. No	**Type**	**Gap b/w Electrodes (µm)**	**Min. Return loss in dB**	**Max. Return loss in dB**	**Min. VSWR**	**Max. VSWR**	**Directivity in dB**
1	Coplanar stripline Dipole	2	44.03	2.59	1.01	6.75	7.52
2	Bow	100	-36.76	-0.51	1.02	33.51	7.79

D. CST Microwave studio

CST microwave studio is a fully featured software package for electromagnetic analysis and design in the high frequency range. The key feature of CST microwave studio is the Method on Demand approach which give the choice of simulator or mesh type that is best suited to similar of particular problem. It simplifies the process of creating the structure by providing a powerful graphical solid modelling [5] front end which is based on ACIS modelling kerner.

III. CONCLUSION

The design of two types of antennas for terahertz wave generation and detection has been completed using CST microwave studio software. The simulation gave results good enough to satisfy our requirements to fabricate it on hardware which can be used wherever needed. Based on the results simulated above, it is clearly shown that the coplanar stripline dipole antenna with two micrometer electrode gap has better performance than the bow type antenna with an electrode gap of 100 micrometer. The investigation has been limited mostly to theoretical studies and simulations due to lack of fabrication facilities. Detailed experimental studies can be taken up at a later stage to fabricate the antenna. Before going for fabrication we can optimize the parameters of antenna using one of the soft computing techniques known as Transient solver.

IV. ACKNOWLEDGMENT

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