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This is to certify that the thesis entitled ***"Study of Graphene-based Metasurface Structures for Terahertz Frequency Applications"*** being submitted by **Sambit Kumar Ghosh (Roll No-17091021)** to the Indian Institute of Technology (Banaras Hindu University) Varanasi, for the award of the Degree of Doctor of Philosophy in the Department of Electronics Engineering is a record of bonafide research work carried out absolutely by him under our supervision and guidance. The thesis has reached the standard; fulfilling the requirements of the regulations relating to the nature of the degree. The results embodied in this thesis have not been submitted to any other university or institute for the award of any degree or diploma.

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I, Sambit Kumar Ghosh, certify that the work embodied in this thesis is my own bonafide work and carried out by me under the supervision of Dr. Somak Bhattacharyya and co-supervision of Dr. Santanu Das from "25/07/2017" to "30/06/2022", at the Department of Electronics Engineering, Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, *etc*., reported in journals, books, magazines, reports, dissertations, theses, *etc*., or available at websites and have not included them in this thesis and have not cited as my own work.

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Acknowledgment

This dissertation is the culmination of my Ph.D. experience, which was like climbing a mountain step by step while encountering encouragement, struggle, bitterness, frustration, and faith. It gives me immense pleasure to take this opportunity to offer my heartfelt appreciation to everyone who contributed to this thesis and assisted me along this incredible journey toward my Ph.D.

I would like to take the opportunity to convey my heartfelt appreciation to **Dr. Somak Bhattacharyya**, my Ph.D. supervisor and **Dr. Santanu Das**, my Ph.D. co-supervisor for accepting me as a student without hesitation and exposing me to a fascinating and exciting field of research. They have always been patient and encouraging while discussing new ideas, guiding me in the right direction. This research would not have been possible without their assistance.

I am extremely grateful to my research performance evaluation committee (RPEC) members Dr. Smrity Dwivedi of the Department of Electronics Engineering and Prof. Sandip Chatterjee of the Department of Physics whose suggestions and critical comments during my semester progress presentations really helped me to shape my thesis. I also thank Dr. M. Thottappan, and other faculty members for their kind cooperation and encouragement during this journey.

I must acknowledge Prof. K.P. Singh, Prof P. K Jain, Prof. S.P. Singh, Prof. R.U. Khan, Dr. Amit Singh, and Prof. M. K. Meshram for teaching interesting and informative subjects during my coursework period. That study done in the initial days of my Ph.D. helped a lot in refreshing the basics of electronics, which helped a lot in my research work.

My special thanks to my seniors Dr. Anshu Sharan Singh, Dr. Rajan Agrahari, Dr. Vineet Singh, Dr. Siva Venkateshwara Rao V., Dr. A. P. Singh, Dr. Vikram Kumar, Dr. Arjun Kumar,

Dr. Akash, Dr. Prabhakar Tripathi, Dr. R. K. Singh, Dr. M. A. Ansari, Dr. Sudhir Bhaskar for their friendly attitude and academic support.

I am very much thankful to my seniors and colleagues research scholars of the CRMT laboratory for their help and efforts to make the lab an enthusiastic place for research. My thanks go to Dr. Soumojit Shee, Mr. S. G. Yadav, Mr. V. V. Reddy, Mr. Nisheeth Upadhyay, Mr. V. Veera Babu, Mr. G. Venkatesh, Mr. Hemant Kumar, Mrs. Kirtika Singh, Miss Pratibha Verma, Mr. Sougata Chatterjee, Mrs. Madhavi Chandra, Mr. Vishal. I would like to share special thanks to my all-time partners Mr. Nilotpal, Mr. Diptiranjan Samantaray, Mr. Abhinav Pratap Singh, Mr. Sanjeevmani Yadav, Mr. Arun Kumar Saurabh, and Mr. Rishibrind Upadhyay with whom I have shared many a tensed moment as well as joyful moments with them and they always cared well for me.

My thanks and sincere appreciations also go to all staff members of the CRMT laboratory, especially to Mr. Rajesh Kr. Rai and Mr. Sanjay Kr. Vishwakarma for their kind co-operation.

No words of appreciation could express my gratitude for my family, who have always been with me although they were miles away from me. My special thanks to my elder brothers Dr. Suman Ghosh, Dr. Amit Kumar Ghosh and my sister-in-law Mrs. Chandana Guha, Mrs. Swagata Mazumdar who always considered my research as a top priority and tried his best to make my life comfortable.

No words of appreciation could express my gratitude for my parents Shri. Rajkumar Ghosh and Mrs. Chandana Ghosh who always encouraged me to follow my dreams and have always advised me to be a good human being first. Whatever I am today is because of their unconditional love, care, guidance, encouragement, and moral support. To put in one line, they sacrifice their own lives to make our life.

Last per not least, I owe a debt of gratitude to Lord Vishwanath to sail the journey and make this possible by being with me all the time.

I seek pardon to those whose names unintentionally I have missed inspite of their immense support. I would like to thank all those who directly or indirectly helped me to bring this thesis to fruition.

Sambit Kr. Ghosh 30/06/202

Thank you

Sambit Kumar Ghosh

This thesis is dedicated to my Parents

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LIST OF ABBREVIATIONS

Abbreviation	Full Form
EM	Electromagnetic
THz	Terahertz
TE	Transverse Electric
TM	Transverse Magnetic
CST	Computer Simulation Technology
ADS	Advanced Design Systems
MS	Metasurface
MTM	Metamaterial
1D	One-Dimensional
2D	Two-Dimensional
3D	Three-Dimensional
EMC	Electromagnetic Compatibility
EBG	Electromagnetic Band Gap
FSS	Frequency Selective Surface
HIS	High Impedance Surface
PEC	Perfect Electric Conductor
PMC	Perfect Magnetic Conductor
SPPs	Surface Plasmon Polaritons
SPR	Surface Plasmon Resonances
LSPPs	Localized Surface Plasmon Polaritons

Abbreviation	Full Form
DUT	Device Under Test
DMD	Dielectric-Metal-Dielectric
MDM	Metal-Dielectric-Metal
GSPs	Graphene Surface Plasmon Polaritons
FP	Fabry-Perot
CP	Circular Polarization
LP	Linear Polarization
PCR	Polarization Conversion Ratio
RCS	Radar Cross Section
Abs	Absorptivity
RLCPC	Reflective-type LP to CP Conversion
TTLCPC	Transmittive-type LP to CP Conversion
DFD	Dual Functional Device
NIR	Near Infrared
MIR	Mid Infrared
FIR	Far Infrared
LHCP	Left-Handed Circular Polarization
RHCP	Right-Handed Circular Polarization
AR	Axial Ratio
FARBW	Fractional Axial Ratio Bandwidth
CVD	Chemical Vapour Deposition
FABW	Fractional Absorption Bandwidth
FTBW	Fractional Transmission Bandwidth
PTC	Peak Transmission Coefficient

Abbreviation	Full Form
FBO	Frequency Band of Operation
PSBGL	Periodically Slotted Bottom Gold Layer
FP-LWA	Fabry perot-leaky wave antenna
FIT	Finite Integration Technique

LIST OF SYMBOLS

Symbol	Details
σ_g	Surface conductivity of graphene
μ	Chemical Potential of graphene
k_B	Boltzmann's constant
e	Charge of an electron
E_f	Fermi energy of graphene
ω	Angular frequency of the photon
T	Room temperature (300 K)
Γ	Scattering rate of the Dirac electrons
T	Relaxation time
h	Plank's constant
$\hbar$	Reduced Plank's constant
$f_d(\varepsilon)$	Fermi dirac distribution function
$\hbar\omega$	Energy of a photon
v_f	Fermi velocity of the electrons
t_g	Thickness of the graphene layer
E_o	DC electrostatic bias
V_g	DC gate voltage
C_{ox}	Gate capacitance
n_s	Concentration of the charge carriers
E_{bd}	Breakdown voltage of the dielectric substrate

Symbol	Details
ε_r	Effective permittivity
J	Surface conductivity of graphene
E	Electric field component
σ_{intra}	Intraband conductivity
σ_{inter}	Interband conductivity
eV	Electron-volt
N	Inclusive movement of the free electrons
P	Polarization density of the electrons
f_p	Plasma frequency
q_{spp}	Wave vector of the SPP mode
k_j	SPP wavenumber
ξ	Static electric field
ϕ	Polarization angle
θ	Angle of Incidence
ε_{eff}	Effective permittivity
μ_{eff}	Effective permeability
δ_g	Skin depth of graphene
D_n	Normalized component of the displacement vector
β	Wave propagation constant
ω_p	Plasma frequency
T_μ	Chemical potentials of the top layer graphene layer
B_μ	Chemical potentials of the top layer graphene layer

Symbol	Details
β^{p}	Phase constant of the surface plasmon mode
β^{LM}	Phase constant of the leaky plasmon mode
k_{LM}	Wavenumber corresponding to the leaky plasmon mode
α_{LM}	Attenuation constant of the leaky plasmon mode
σ_{R}	Resistive conductivity of graphene surface
σ_{J}	Reactive surface conductivity of graphene surface
η_{o}	Characteristic impedance of the vacuum
λ_g	Guided wavelength
Z_o	Free space impedance