Chapter 6

Conclusions and Future Scope

6.1. Major Conclusion

The objective of this thesis was to study the metasurfaces for the THz domain. We have studied that the initially evolved theory of absorption in a metasurface absorber based on single-layer effective model had some discrepancy as well as limitations. In view of this we have investigated in chapter 2 the metasurface absorber structure based on three layered model which model the dielectric layer as a metallic cavity bounded between top and bottom metallic plates. The total reflection from the whole structure is equal to the multiplication of reflection from each layer. The absorption in the structure is due to the occurrence of Fabry-Perot resonance inside the dielectric cavity. For the first time, we have validated the multiple reflection phenomenon in the light of time domain analysis and found that for both normal and oblique incidence the simulated and analytical results are in good agreement to each other, as discussed in chapter 2. In chapter 3, we extended this work to model the multiple reflection phenomenon in the light of electric and magnetic field. For this we considered the TE polarized wave; however the model is equally valid for the TM polarized incidence as well. From the electric and magnetic field equations, it is evident that the wave propagates in x direction while undergoing multiple reflection between the top and bottom metallic plate which leads to standing wave formation in z direction. The reason for the parallel and antiparallel surface current has been studied from the electric field variation inside the dielectric layer.

Multifunctionality has been a long-lasting pursuit for the electronic system, specifically if the functions are mutually exclusive from one another. Additionally, apart from offering multifunctionality, if the device is bidirectional too, then it makes the whole system directionally efficient also. For the design of absorbers, the most common configuration comprises of a three-layered structure, where the dielectric layer is sandwiched between the top layer of the metasurface (consisting of periodically arranged sub-wavelength metallic pattern) and bottom metallic plate. Any such structure consisting of metallic pattern (metasurface) on one of its layers and metallic plate on the other is also termed as single-sided metasurface structure. The top metasurface layer is responsible for determining the frequency of resonance, whereas the bottom metallic plate suppresses any transmission from the structure. However, on the cost of two major limitations,

1) The presence of metallic plate at the bottom makes the device unfunctional.

2) The metallic plate at the bottom makes the device direction sensitive (unidirectional) also.

Acknowledging the limitation of single-sided metasurface design, we have presented a complete mathematical and structural study of dual-sided metasurface structures in chapter 4. It is found that a dual sided metasurface structure always resonate at two frequencies where at low resonant frequency the structure behaves like a band pass filter whereas at high resonance frequency the structure works like an absorber. This ambiguity in the response at the two frequencies has been explained based on wave-structure interaction. The two main factors which plays a crucial role in the analysis of wave-structure interaction are the size of the structure and wavelength of the incident electromagnetic wave. Firstly, at low resonance, when the resonating wavelength is large, the structure's thickness (h) is very small compared to the resonating wavelength. For such a small thickness (compared to the resonating wavelength), the wave cannot distinguish different layers of the structure and therefore acknowledge the whole structure as a single entity having an effective impedance value. Under this condition, the EM wave cannot identify the presence of complementary metallic patterns at the top and bottom metasurface layers. As a result, the wave incident on metasurface 1(2) gets transmitted out from metasurface 2(1) without getting affected by the two metasurface layers. Consequently, the structure exhibits a high transmission coefficient value at low resonance frequency.

In contrast, when the frequency of resonance increases i.e., when the resonating wavelength is small, the thickness of the structure becomes more comparable to the resonating wavelength. The incident EM wave can now distinguish the three different layers of the structure and thereby acknowledges the presence of complementary set of metallic patterns at the top and bottom metallic layer, resulting a low transmission coefficient value at high resonance frequencies. Further, we have investigated the variation in the resonance with respect to variation in the impedance through an equivalent circuit model of the dual-sided metasurface structure and found that due to the variation in the impedances the structure offers different resonance for variation in the direction of incidence. The study has been further validated by designing a bidirectional rasorber. A complete mathematical and structural study of such structures can open up a broad avenue for the research and development of metasurface based multifunctional or bidirectional optoelectronic devices.

In chapter 5, we have studied metasurface based cross polarization converter for the application in far infrared region. The structure is transmissive in nature which rotates the polarization of the transmitted wave orthogonally. The structure is three layered where the top and bottom layer consist of metallic patches which are horizontally and vertically aligned. The idea is to achieve cross polarization conversion of waves. The chiral structure in the middle layer offers anisotropy, which is required for the cross-polarization conversion. The polarization conversion has also been realized using the Brewster’s angle concept which states that when the light is incident on a dielectric interface at Brewster’s angle (also known as the polarization angle), then it allows light with a particular polarization to perfectly transmit leaving the other polarization completely reflected.

6.2. Suggestions for future research

The metasurface based devices in terahertz frequency domain is finding its suitability in various applications such as solar harvesting, thermal imaging, sensors, spatial light modulators. It is difficult to employ a naturally occurring material due to the natural breakpoint of electric and magnetic resonances at such frequencies. Also, realization of certain applications in microwave frequency range by means of active or passive elements in the design is not feasible at such high frequencies. Artificially engineered structures also known as metamaterial are able to harness desirable properties in the terahertz region. The following avenues are suggested for further research:

1. The meta cavity model based on multiple reflection phenomenon presented in this work can be explored further for the design of metasurface based devices for short distance communication.

2. The design of bidirectional metasurface absorbers can increase the light capturing capability of a device and hence this study can be explored further for the design of bifacial solar absorbers.

3. Coding metasurface concept can be implemented in a dual-sided metasurface structure, where by programming different coding sequences, a single digital metamaterial has the ability to manipulate EM waves in different manners, thereby realizing ‘directional insensitive programmable metamaterials which can be used for the communication application as well as computational imaging applications.