Introduction to Millimeter-Wave, Infrared and Terahertz Technologies

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Abstract In this preparatory chapter, brief introductions to the state-of-the-art millimeter-wave (mm-wave), infrared (IR) and terahertz (THz) technologies are given. Short descriptions of prospective applications of mm-wave, IR and THz signals have also been included in this chapter. A chapter-wise overview of the entire book has been incorporated at the end of this introductory chapter.

1 Introduction

The subject matter of this book covers three major frequency bands of the electromagnetic spectrum, such as millimeter-wave (mm-wave), infrared (IR) and terahertz (THz) spectrums. The mm-wave spectrum begins at 30 GHz and it is extended up to 300 GHz; the wavelength range of 1–10 mm falls within this spectrum. On the other hand, the IR spectrum starts from 0.3 THz and ends roughly at 430 THz. As a whole, the IR spectrum is a very wide frequency regime (wavelength range is 0.7–1000 μm). The IR spectrum is conventionally divided into three separate sub-spectrums, such as (i) near-IR spectrum having the wavelength range of 2.5–25 μm (i.e. frequency range of 120–428.57 THz), (ii) mid-IR spectrum having the wavelength range of 0.7–2.5 μm (i.e. frequency range of 12–120 THz), and (iii) far-IR spectrum having the wavelength range of 25–1000 μm (i.e. frequency range of 0.3–12 THz). These sub-spectrums like near-, mid- and far-IR regions are named with respect to their

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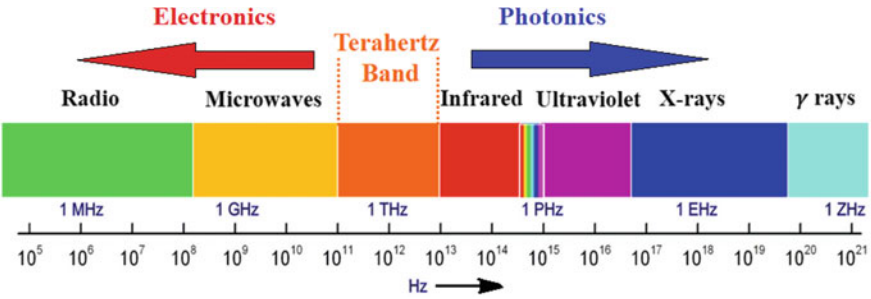

Fig. 1 Electromagnetic spectrum showing the position of the THz band [1]

close proximity to the visible spectrum of light (i.e. 0.39–0.7 μm). Now, the THz region is the portion of the electromagnetic spectrum (0.3–10 THz), which begins at the end of the mm-wave spectrum and extends up to far-IR regime. The left side of the THz spectrum belongs to the world of ‘Electronics’ and the world of ‘Photonics’ starts from the right edge of this spectrum. Figure 1 depicts an elaborate illustration of the electromagnetic spectrum [1]. In Fig. 1, the entire broad frequency band 1–300 GHz is denoted as microwaves; however, the spectrum 1–30 GHz is specifically known as microwaves and the spectrum 30–300 GHz is known as mm-waves.

The mm-wave spectrum is highly demanding for future wireless communication technologies [2]. Presence of three low absorption window frequencies, such as 94, 140 and 220 GHz (Fig. 2) makes it a highly attractive spectrum for wideband, long-haul wireless communication applications. In order to support ultra-high data rates, 5th generation (5G) technology is currently utilizing the mm-wave band of 24–86 GHz. Less costly mm-wave links may also replace comparatively costlier fibre optic links between mobile base stations. In future, mm-wave spectrum will be utilized in ultra high definition (UHD) video transmission, IEEE 802.11ad WiGig technology, next generation satellite communication links, wideband and high definition and high fidelity video and audio transmission in virtual reality devices, etc. However, despite having several advantages of this spectrum, one major hurdle is still obstructing the rapid progress of this technology. Considerable amount of atmospheric absorption of the mm-wave frequencies, especially in fog, dust particles, clouds, etc. is limiting the mm-wave communication range.

The IR spectrum is already in use in several existing technologies. Infrared heating technologies are used in safe heat therapy methods of natural health care and physiotherapy, cooking, industrial manufacturing processes, etc. Infrared imaging technology is very popular in military applications like passive night vision goggles, astronomy, etc. Most popular application of this spectrum is the use of it in high speed, wideband, short or medium or long range fibre optic communication technology. This technology utilizes three low absorption window wavelengths, such as (i) 1st window centred at 0.85 μm, (ii) 2nd window centred at 1.35 μm and (iii) 3rd window centred at 1.55 μm; Fig. 3 shows the positions of those windows [3].

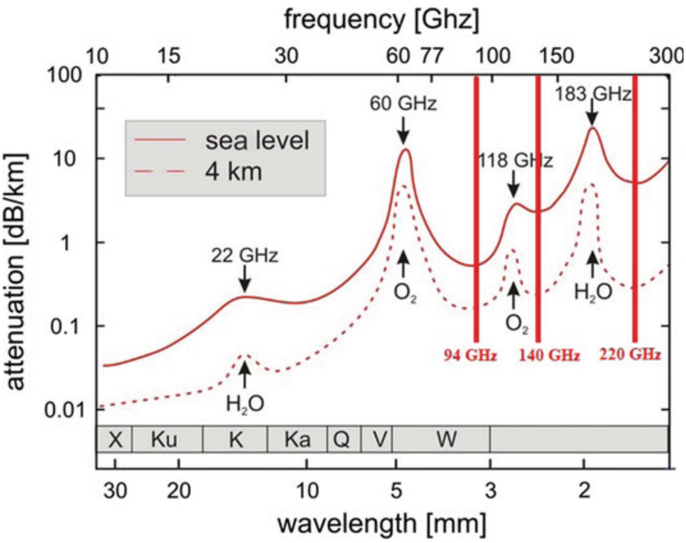

Fig. 2 Atmospheric absorption versus frequency/wavelength plot at sea level and at 4000 m altitude [2]

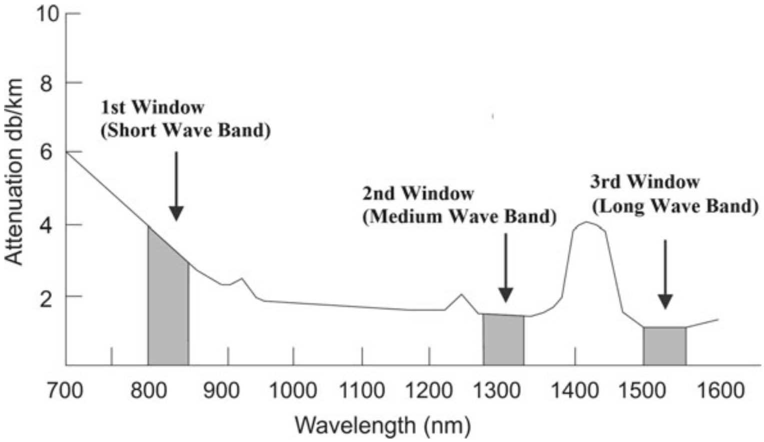

Fig. 3 Attenuation versus optical wavelength plot in glass; three optical transmission windows are shown in this plot [3]

The THz spectrum or THz band is also known as ‘THz-gap’, since it is the most technologically unexplored portion of the electromagnetic spectrum. As mentioned earlier, the ‘THz-gap is an almost untouched frequency band (0.3–10 THz) lying between well explored mm-wave and IR spectrums. Higher data rate can be achieved in THz communication systems as compared to their equivalent mm-wave counterparts. On the other hand, better penetration capability of THz waves as compared to IR frequencies makes the THz band superior to the IR spectrum in some specific applications. Currently, the THz spectrum has massive requirements in various scientific, security, medical and astronomical sectors. Some examples are bio-sensing, bio-imaging, remote sensing, spectroscopy, industrial quality inspection, medical and pharmaceutical sectors, food diagnostics, astronomy, etc. [4–24]. Significantly, the lower energy of THz photons makes those more convenient as compared to the high energy X-ray photons for remote inspection of some highly delicate substances like historical artefacts, historical structures, historical paintings, etc. [25].

2 Brief Overview of the Book

The scope of this book includes a significantly long portion of the electromagnetic spectrum, starting from the mm-waves (i.e. 30 GHz) and extended up to the end of the near-IR spectrum (i.e. 450 THz). Most significant aspect of this portion of the electromagnetic spectrum is that it includes a frequency regime where the gradual transition from electronics to photonics occurs; this frequency regime is nothing but the THz frequency spectrum. This book provides a detailed analysis, description and discussion of some recently developed technologies under this extended frequency spectrum. Especially, the emphasis is given on the state-of-the-art and upcoming research going on at various parts of the globe on THz science and technology [26–36]. This book can be considered as a textbook for undergraduate, post graduate, doctoral students and also for scientists due to the ultra-broad coverage of it.

Chapter-wise organization of the entire book is provided in this section. Sensitivity analysis of Ku-band substrate integrated waveguide has been presented in Chap. 2 for photonic circuit integration. The possibilities of realizing Gallium Nitride integrated power module for terahertz wave generation are discussed in Chap. 3. Design methodologies of SiSnC/Si heterostructure electro-optic modulator (EOM) for optical signal processing applications have been included in Chap. 4. Design and optimization techniques of graphene nanoribbon tunnel field effect transistors (TFETs) for low power digital applications are described in Chap. 5. Chapter 6 describes a very interesting topic of optoelectronics, i.e. birhythmic behaviour in dual loop optielectronic oscillators. Performance analysis of optical arithmetic circuits using artificial neural networks has been presented in Chap. 7. Chapter 8 demonstrates the design and modelling of an infrared sensor-based object detection circuit for computer vision applications. A comparative analysis on bandwidth management techniques in 6th generation mobile communication has been presented in Chap. 9. Noise performance of millimeter-wave impact avalanche transist time (IMPATT) oscillators has been summarized in Chap. 10. Chapter 11 deals with a brief introduction of high frequency passive circuits. Impact of negative bottom gate voltage for improvement of RF/analog performance in asymmetric junctionless dual material double gate MOSFET has been discussed in detail in Chap. 12. Chapter 13 presents a DC and RF analysis of gate all round tunneling field-effect transistor (GAA-TFET) based on graphene nanoribbon (GNR). Generalized distribution functions in heavily doped nano materials have been studied at terahertz frequency and the results are summarized in Chap. 14. Chapter 15 deals with the influence of THz frequency on the gate capacitance in two-dimensional quantum-well field effect transistors (QWFETs). Chapter 16 reveals an alternative scheme of quantum optical superfast tristate controlled-NOT gate using frequency encoding principle of light with semiconductor optical amplifier. Finally, the Chap. 16 deals with the detailed discussion regarding the use of frequency encoding principle for implementing nano-photonic ultrafast tristate Pauli X gate.

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