1 Terahertz Technology Striding Toward Further Progress

IZUTSU Masayuki

Terahertz technology is attracting a great deal of attention these days. While the use of radio waves and light waves is prevalent throughout society, terahertz waves — electromagnetic waves in the transition range between radio waves and light waves — are situated within a relatively unexplored frequency range. This has begun to change: the recent rapid development of terahertz technology has highlighted the terahertz band as a frequency range with new possibilities that set this band apart from those of light or radio waves. As a result, today's researchers and engineers are researching a diverse field of potential applications. Specifically, the use of terahertz waves is expected to lead to new sensing and communication applications that would be difficult to implement using conventional technologies.

Terahertz waves are electromagnetic waves in the frequency range centering around 1 THz (at a free-space wavelength of approximately 300 μm). Some references define these waves as falling within the frequency range of 0.3 THz (300 GHz) to 3 THz (i.e., a wavelength range from 1 mm to 100 μm). Other sources define a slightly wider frequency range, from 0.1 THz (100 GHz) to 10 THz (for a wavelength range from 3 mm to 30 μm). Under either definition, these waves fall within the boundary region between radio waves and light waves. Radio waves are known to be generated by the accelerated motion of electric charges, while light waves are generated by transitions between different quantized energy levels. While the main source of radio wave noise is thermal noise, noise in light waves is dominated by quantum noise independent of temperature. The ratio of quantum noise to thermal noise is given by $h\nu/(kT)$. Here, ν is the frequency of the electromagnetic wave, T is the absolute temperature, h is Planck's constant, and k is the Boltzmann constant. The frequency, ν, that satisfies $h\nu = kT$ at T = 273 K (0 ˚C) is 5.6 THz (the wavelength is 53 μm). In other words, the magnitudes of quantum noise and thermal noise are approximately the same in the frequency band around 5 to 6 THz in the temperature range in which human beings feel comfortable.

Terahertz waves are now attracting a great deal of attention, with corresponding progress in research and development, thanks to the development of new-generation technologies and measurement methods. A wide variety of applications are coming into consideration as a result. Diverse absorption bands for various substances are present in the terahertz range — indicating, for example, the rotational states of molecules, and terahertz spectroscopy is expected to allow identification of trace amounts of chemical substances that cannot be identified using conventional technologies. It may also be possible to take advantage of reflection and transmission characteristics that differ significantly from those found in other wavelength ranges, for a number of different substances. On the other hand, diverse absorption bands can limit propagation distance to several tens of meters in air, if the frequency band is selected appropriately. This property offers potential use in highly secure, confidential short-distance communications. Despite the foregoing, we are only starting to accumulate data on the spectroscopic characteristics of various substances and media in the terahertz band. If we are to develop useful applications in the terahertz band, it will be essential to accumulate data and investigate these propagation characteristics.

The National Institute of Information and Communications Technology (NICT) has conducted consistent research and development relating to the generation and detection of terahertz waves, with a long history of related research. We succeeded in terahertz pulse signal generation using femtosecond light pulses, time resolved spectroscopy using terahertz pulses, array devices for detection in the terahertz to far-infrared range using unique semiconductor materials, and more recently, developed a terahertz quantum cascade laser. We have also begun collecting data on the spectroscopic characteristics of various materials.

This special issue describes some of NICT's current research and development in this area. It summarizes results obtained in the past and also discusses future research and development of terahertz technologies. We hope that this special issue will help add momentum to further efforts to develop terahertz technologies.

***IZUTSU Masayuki**, Dr. Eng.*
Distinguished Researcher
Optoelectronics