Development of Organic Terahertz Devices

Towards high-performance and compact terahertz sources

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Terahertz waves hold promise in applications such as non-contact, non-invasive sensing and ultra-high-speed wireless communications. To promote their use in society, it will be necessary to reduce the size and increase the performance of terahertz equipment. We are developing organic polymers with excellent properties, as well as devices that use them, in the hope of realizing terahertz sources and detectors that are more compact and have higher performance than ever before.

Background

Terahertz waves are electromagnetic waves with frequencies between those of radio waves and light (0.1 to 10 THz). They are higher in frequency than radio waves, so they are promising for applications in ultra-high-speed wireless communications. They are also highly penetrating of objects, and materials produce characteristic absorption patterns called *fingerprint spectra*, so they are also promising for use in sensing. When using terahertz waves for sensing, the internal structure of an object can be imaged in a non-contact and non-invasive way, information can be obtained about things (materials, biomaterials, etc.) in the immediate surroundings, and materials composing the object can be identified. Such information about objects is difficult to obtain using conventional sensors, and using it in society will enable increases in productivity and efficiency in all kinds of scenarios related to security, health, medicine, the environment, science, industry and agriculture. We will also be able to detect dangers in society quickly.

To accelerate utilization of terahertz waves in society for sensing and wireless communications, it will be important to reduce the size and increase the performance of terahertz equipment (terahertz sources and detectors) (see Figure 1). A number of current terahertz sources generate terahertz waves by changing the wavelength of laser light using non-linear optical materials. However, such wavelength conversions are extremely inefficient, so they require large laser light sources with high output, and the equipment is large. Most current terahertz wave equipment for emission and detection is also limited to lower frequencies (approx. 0.1 to 4 THz), so for *fingerprint spectra*, it has been difficult to obtain many of the absorption peaks in the higher-frequencies, which are useful for identifying materials. To advance the use of terahertz waves in sensing, the bandwidth of terahertz wave emitters and detectors needs to be increased.

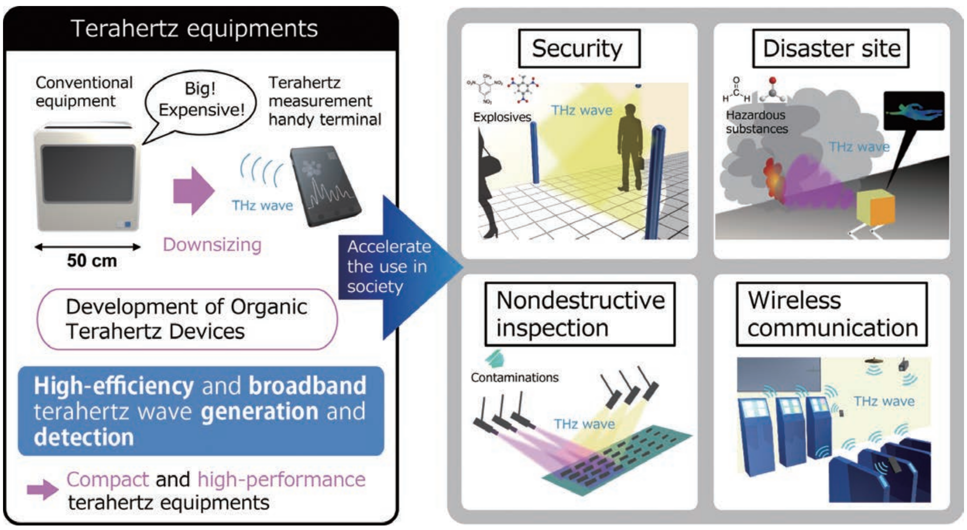

Figure 1 Expansion of the use in society by reducing size and increasing performance of terahertz equipment

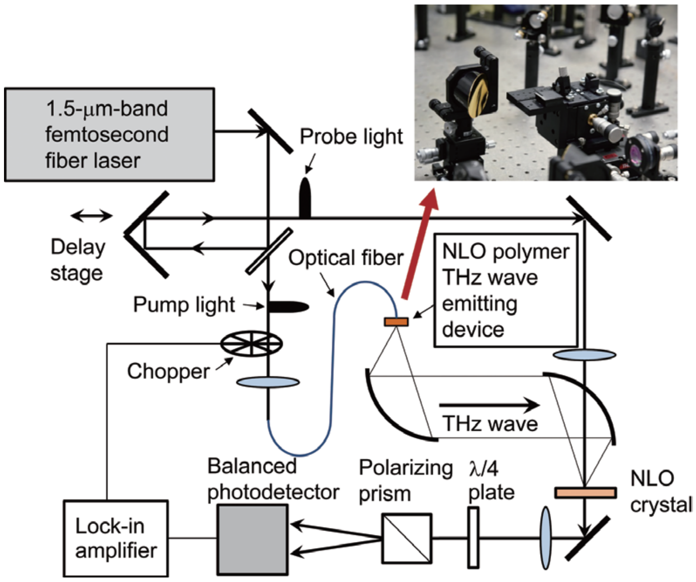

Figure 2 Apparatus for evaluating a non-linear optical polymer terahertz wave emitting device

Terahertz technology using non-linear optical polymers

We have developed non-linear optical polymers and devices that use them in order to greatly increase the efficiency and bandwidth of terahertz wave emitters and detectors.

Compared to inorganic and organic non-linear optical crystal materials that have been used for emission and detection of terahertz waves, such as lithium niobate ($LiNbO_3$), zinc telluride (ZnTe) and DAST, non-linear optical polymers have a large electro-optical coefficient (> 100 pm/V) and their figure of merit (FOM) values for terahertz wave emission, considering the effects of refractive index of the materials, exceed the values for the materials above (see Table).

For inorganic crystal materials such as $LiNbO_3$ and ZnTe, the bandwidth of emitted terahertz waves is narrow because high-frequencies are absorbed due to crystal lattice vibration. For non-linear optical polymers, the absorption coefficient is small over a wide range of the terahertz domain, so emission and detection of terahertz waves over an ultra-broad band (0.1 to 20 THz) is possible.

Non-linear optical polymers can also be used with micro-processing to fabricate waveguide devices, so we can expect to realize devices that yield large increases in terahertz wave emission efficiency through use of optical confinement effects.

Terahertz wave emitting devices using non-linear optical polymers

To realize a compact terahertz source, we are developing a terahertz emitter device using 1.5 μm band laser light that can lase in small semiconductor lasers and fiber lasers and can be used in various optical communication technologies.

Earlier, we successfully generated terahertz waves by taking laser light from a femtosecond titanium-sapphire laser, converting it to laser light of wavelength 1.5 μm using an optical parametric amplifier, and then exposing a non-linear optical polymer to this light. We also built a system to evaluate a terahertz emitter device using an even smaller, low-power 1.5 μm-band erbium-doped fiber laser (Figure 2), and succeeded for the first time in observing terahertz wave emission from a non-linear optical polymer device under weak pump light intensity conditions. To further increase the terahertz wave emission efficiency, we are continuing to develop terahertz wave emitter devices using micro-waveguide structures and conducting experiments using a 1.5 μm-band ultra-short pulse fiber laser able to emit terahertz waves over a very wide bandwidth.

Future prospects

To further improve the performance of terahertz devices, we are developing materials that greatly reduce terahertz wave absorption losses, and by applying the organic-silicon hybrid optical modulator technology that our group is developing, we will develop devices with dramatically increased terahertz wave emission efficiencies. Use of non-linear optical polymers will also make more-sensitive terahertz wave detectors possible. Improved performance of both emission and detection will make it possible to implement compact terahertz equipment not seen before, and this will contribute to a safer, more secure ICT society using terahertz waves.

Table Comparison of non-linear optical materials used for terahertz wave emitters and detectors

	THz frequency range	Refractive index n_o , n_{THz}	EO coefficient r (pm/V)	FOM of THz generation	Micro-fabrication
Nonlinear optical polymer	0.1 - 20 THz	~1.7, ~1.7	> 100	> 8900	Feasible
Lithium niobate ($LiNbO_3$)	0.1 - 2 THz	2.2, 4.96	32	1500	Modestly
Zinc telluride (ZnTe)	0.1 - 4 THz	2.83, 3.16	4	160	
DAST	0.3 - 16 THz	2.13, 2.26	47	5600	