9 Prospect for Research and Development of Terahertz Technology in Future

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1 Introduction

Recent years have seen a marked increase in expectations of terahertz-wave applications[1]-[3]. These waves have been studied for years, yet applications have remained relatively unexplored; any applications that have been developed have been limited to the fields of radio astronomy and analytical science. In the mid-1980s, terahertz generation based on ultra-short pulses and time-domain spectroscopy (TDS) came into development, representing a breakthrough in analytical science. In the mid-1990s, prospects for imaging applications began to emerge. Since then, terahertz technology has rapidly developed in the areas of sensing and imaging. This research and development in turn has spurred a variety of studies on terahertz waves. Since 2000, a wide range of research has taken place, including the development of terahertz sources such as a high-power light-terahertz-wave converter based on non-linear optical effects and a terahertz quantum cascade laser. Terahertz waves are also studied in application research ranging from noninvasive testing to bioanalysis and security technologies. Against the backdrop of these global activities, the National Institute of Information and Communications Technology (NICT) began verification experiments on terahertz TDS in the early 1990s. In the middle of the same decade, NICT discovered terahertz-wave generation from superconductors and became capable of conducting original studies. Since approximately 2000, terahertz research has had its principal locus of activity in Europe. In 2004, the "Terahertz Technology Trend Report" was compiled under the auspices of the Japan Ministry of Internal Affairs and Communications, and this survey generated significant movement in terahertz-related research in Japan. The survey clarified that the comprehensive promotion of terahertz waves, terahertz photonics, and terahertz electronics will lead to not only basic uses in analytical science but to an eye-opening range of other applications: terahertz telecommunications, safety, and security technologies, as well as inspection applications related to biotechnology, bioengineering, medical treatment, and pharmaceuticals, to cite a few. A worldwide trend is now underway. NICT has been playing a central role within Japan in the creation of the field of terahertz studies, and is expected to emerge as a world leader in the field.

2 Challenges in terahertz technology

The telecommunications and sensing fields will clearly benefit from the possibilities created by terahertz technology. Moreover, the resultant technologies may be combined in the future to create an even greater number of new applications. The most important role of NICT in this future environment will lie in the development of the terahertz telecommunication field, and in particular, in wireless terahertz communications. Currently, the development of sensing technologies and the exploration of associated applications are widely underway, in a range of major international research projects. Nevertheless, a crowded field should not dissuade Japan from entering with the aim to lead, terahertz telecommunications are expected to open large markets and are essential to industrial development in Japan. Yet at this moment, it is difficult for private companies to conduct research and development from a long-term perspective. As a result, NICT has a responsibility to move research forward, as part of an overall national policy.

In addition to telecommunications, research and development in nascent sensing technologies is also important. In particular, we must address security and safety applications for purposes of the national interest. RIKEN and other organizations have been developing inspection systems to detect hazardous substances and illegal drugs in the mail without having to open letters and packages, with excellent results. NICT has now also begun research and development of gas-detection and lifesaving systems in cases of fire through collaboration with and among industry, academia, and government. NICT has thus naturally assumed the responsibility of critical research and development. The application of terahertz waves to safety and security covers a wide range of societal applications, from food safety to measures against disasters and terrorism. To spur research and development throughout such a wide range, we must establish an overarching terahertz research and development network specifically aimed at safety and security applications. Given all of the foregoing considerations, I fully expect NICT to form the main core of the so-called "THz Network of Excellence".

NICT also has an important role to play in accelerating the development of the fundamental technologies that support these two significant movements in telecommunications and sensing. The major research and development issues focus on a number of component technologies: (1) development of terahertz sources, (2) development of terahertz detectors and cameras, (3) system development, (4) standardization technology, and (5) software. Terahertz sources include those based on light-terahertz-wave conversion, electronic device sources, and terahertz quantum cascade lasers. In Japan, the development of terahertz sources has yielded significant achievements thanks in part to the support of the SCOPE program, including resonant tunneling diodes, secondary plasmon devices, and terahertz generation from diverse electronic materials. Further development of terahertz sources will be essential, including the application of nonlinear effects such as difference frequency mixing, Cerenkov radiation, and parametric radiation. In terms of these potential sources, Japan had lagged significantly in the development of quantum cascade lasers. This delay is attributable to the advanced nanotechnology-based semiconductor material fabrication techniques required to develop these devices, techniques that have proved difficult to tackle for individual researchers. In response, NICT is developing quantum cascade lasers, already having achieved a position of global leadership with its GaAs-based lasers. NICT is also launching original research and development in the pursuit of additional devices, including a GaSb-based laser. Needless to say, I have high hopes for these development efforts.

In terms of research and development of terahertz detectors and cameras, we must admit that Japan is trailing significantly, as the United States has led the way in the associated fundamental technologies as a national defense priority, with DARPA leading the way. In this context, the NEC Group has joined in development of terahertz cameras for the terahertz disaster system promoted by the Ministry of Internal Affairs and Communications, and I hope that these efforts will soon enable Japan to catch up in this field. Additionally, a group led by NICT's own Wan Zhen is at the global forefront of development of a superconducting terahertz detector. While such a detector will be particularly useful in radio astronomy, the establishment of further applications for this device will be essential.

Moreover, NICT has made significant contributions to system development by leading the development of terahertz TDS in JAPAN. These efforts began in Japan approximately ten years later than the inception of similar efforts in other countries. However, the techniques developed at NICT have been transferred to the private sector and promptly commercialized — specifically in the form of a terahertz spectrometer leading to international recognition of Japan's achievements embodied in this device. In the future, we will develop this technology even further, by making full use of Japan's outstanding optical technologies (such as the femtosecond fiber laser). In addition, the current development of techniques for detecting hazardous gases in disasters promises to provide added momentum to system development research.

The major topics that NICT must address include the establishment of a system of standardization and research on EMC. To accelerate industrial applications of these "unexplored" electromagnetic waves, we must develop these targeted technologies in addition to basic research and development. In particular, the Ministry of Internal Affairs and Communications should specifically address the issue of standardization of frequency and power of electronic waves.

Alongside the technological development discussed above, databases must be constructed for industrial applications. Given the unexplored nature of this range of the electromagnetic spectrum, we need to accumulate a great deal of measurement data and to establish a technique of standardization for such data measurement. Fukunaga et al. of NICT have already begun construction of just such a database. I hope that they will be able to gain the cooperation of a number of interested parties to facilitate the further development and eventual release of this database.

3 Conclusions

In the future development of the field of terahertz research, NICT will play an extremely important role. Extensive research and development in collaboration with and among industry, academia, and the government are obviously essential. I also hope that NICT will solve the problems that must be addressed as part of national policy, including the construction of the THz Network of Excellence, databases, communication standards, and other standards. Opening the door to undeveloped terahertz telecommunications will lead to an expanding business environment that will determine the future of Japan. I intend to take part, to the best of my ability, in the establishment of such a network, one that will create knowledge and generate innovative technologies.

References

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THz Devices