C. R. Physique 11 (2010) 411–412

Contents lists available at ScienceDirect

Comptes Rendus Physique

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Terahertz electronic and optoelectronic components and systems

Foreword

Modern relationships between Japan and France started on the 9th of October 1858 by the signature in Edo (the former name of Tokyo) of a treaty of Peace, Friendship and Trading. The 150th anniversary of this treaty was celebrated in 2008, through many official events including art exhibitions, workshops on the culture and civilization of both countries, and so on. In the academic and scientific domain, many common conferences were organized, and collaboration programs were launched. There is in fact a long tradition of partnership between Japan and France in higher education, science, and technology. For example, the first arsenal in Yokosuka was built in 1864 by the French Engineer F.L. Verny, who also established at that time in Japan an engineering school as well as a naval architecture school, and supervised the construction of lighthouses, like the ones in Kanonzaki and in Jogashima. As well, another French engineer, P. Brunat, started the first modern factory of silk material in Tomioka in 1872. Last, but not least, one can mention E. Bertin who was leading the construction of the first modern Japanese battle fleet in 1886, by rebuilding the arsenal in Yokosuka and creating those in Kure and Sasebo. Today, the scientific and technologic exchanges between the two countries are numerous. Concerning academic research, collaboration agreements have been signed between the French National Research Center (CNRS) and the Japan Society for the Promotion of Science (JSPS). Common research laboratories exist, located in both countries, like those devoted to Mechatronics at the University of Tokyo and to Robotics at the University of Toulouse.

Among all the anniversary events, a team of French scientists working in the field of Terahertz (THz) Electronics and Optoelectronics visited, in June 2008, several major THz Japanese laboratories, in Sendai, Tokyo, Sapporo, Kyoto and Osaka. Then, a team of Japanese scientists visited their French colleagues in Montpellier, Paris, Lille, Dunkerque and Chambéry during a trip in September 2008. Several of them are participating to the works of the French international research network (GDR-E) funded by CNRS, dedicated to “Semiconductor sources and detectors of THz frequencies”. Also a joint project on telecommunications with THz carrier frequency, funded commonly by the French Research Founding Agency (ANR) and the JSPS, has just been launched. To enlighten the close contacts between Japanese and French researchers in this research field, it was proposed to edit a special issue of the proceedings of the French Academy of Sciences, namely Comptes Rendus Physique, devoted to THz Electronics and Optoelectronics in Japan and France. This issue follows a first issue of Comptes Rendus Physique published in 2008 with international contributions on THz phenomena and devices. As compared to this first issue, the French contributions to the second issue are more focused on devices, while the Japanese contributions embrace a wider survey.

Let us define, for a non-specialist reader, what is called the THz frequency range of the electromagnetic spectrum. The THz range, also called the Far Infrared (FIR), spreads typically from 0.1 to 30 THz, i.e. from 3 mm down to 10 μm in terms of wavelength. This band is located in between the infrared and microwaves bands. Even if mm-wavelength waves have been produced and nicely used by J. Bose (see D.T. Emerson, “The work of Jagadis Chandra Bose: 100 years of mm-wave research”, IEEE MTT-S International Microwave Symposium Digest, Volume 2, pp. 553–556 (1997)) as early as 1897 and later in 1910 by H. Rubens (E.D. Palik, “History of far-infrared research. I. The Rubens era”, JOSA 67, pp. 857–865 (1977)), this frequency domain has been studied extensively only since the last 20–30 years, thanks to the progress of high frequency electronic devices and to new techniques, like the now well-established THz optoelectronics, and also because numerous applications in daily life and in industry are foreseen. Nevertheless, a strong research effort is still required to transfer the research results from laboratories to the industry, mostly because efficient sources and detectors are still missing.

This issue includes several papers on nanotransistors for the emission and detection of THz electromagnetic waves. The first one, written by Prof. M. Dyakonov from the University of Montpellier, who together with M. Shur proposed the original idea of THz plasma oscillations in transistors as early as 1992, describes the basic physical principles of such THz plasma transistors. It is followed by a contribution of Prof. T. Otsuji from Tohoku University in Sendai and his co-workers in Sendai, Sapporo, Aizu and Montpellier, who present their work on such devices and on more generally on 2D-electron gas devices, with nice technological improvements. Additional results on graphene are very promising. The last paper on nanotransistors, by Dr. W. Knap from Montpellier University and colleagues from Grenoble, Lille and Cardiff, demonstrates experimentally the operation of the devices in emission and reception, with significant examples in THz imagery, and gives rules for improving the device efficiency. The next paper by Profs. K. Ikushima and S. Komiyama, from, respectively, the Tokyo University of

1631-0705/$ – see front matter
doi:10.1016/j.crhy.2010.09.003

A&T and the University of Tokyo, presents another smart nanotechnology device, i.e. the semi-conductor quantum-dot THz-photon detector, which exhibits an amazing sensitivity allowing a few THz photons detection. This detector is used by the authors in a scanning THz microscope, with which cyclotron radiation from semi-conductor quantum Hall effect devices is detected and studied.

The three next papers treat the difficult question of THz sources. Dr. H. Minamade and Prof. H. Ito, from RIKEN and the Tohoku University in Sendai, have built an efficient tunable parametric oscillator. With its unique detector based on up-frequency conversion, the system permits a fine mapping of semiconductor wafers and of the humidity level in biological tissues. Tunable photomixing of laser beams may also be achieved in ultrafast semiconductor photoswitches. In this case, the emitting power in free space may greatly been enhanced with an optimized horn antenna, as described in the paper by A. Beck and coworkers at IEMN Lille. The paper by Dr. A. Maestrini from the Observatory of Paris and colleagues from Pasadena, Oxford and Marcoussis, deals with frequency multipliers and Schottky mixers that are used in ultra-sensitive heterodyne detection for observation in astrophysics, space and atmosphere sciences. These devices work up at to 2.5 THz and matrices of detectors are already foreseen for everyday applications.

The last section of this special issue is close to applications. The first paper by Dr. N. Oda from NEC Corporation describes a THz video camera, whose sensor is a 320×240 matrix of micro-bolometers working at room temperature. Beside applications for security, the camera is also very useful for imagery in biology, and nice results of label-free detection of chemical reactions are reported. The second paper by Prof. K. Kawase and coworkers from Nagoya University and RIKEN Sendai concerns promising real-life applications of THz imaging, including tomography, non-destructive inspection, thickness measurement of thin films. The last paper by Drs. K. Fukunaga and I. Hosako explain how THz spectroscopy and imaging techniques are used to perform a non-invasive inspection of art-works. The technique is nicely illustrated by a study of a masterpiece by Italian painter Giotto, namely “The Polittico di Badia”, whose inspection was performed at Galleria degli Uffizi, in Firenze, Italy.

This survey of THz research in Japan and France is not exhaustive because of the limited size of the journal. Many other teams in both countries produce outstanding results. Nevertheless, we hope that this issue confirms both the quality and the vitality of THz research in Japan and France, and also the promising potentiality of THz electronics and optoelectronics, not only in fundamental research, but also in technology to solve many problems encountered by the society and the people.

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