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Terahertz Technology and Applications II

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Laurence P. Sadwick
Créidhe M. M. O'Sullivan**
Editors

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Introduction

The 2009 Terahertz Technology and Applications Conference was divided into five sessions reflecting specific categories as follows: Session 1 - Terahertz Sources and Detection, Session 2 – Terahertz Metamaterials and Configurations, Sessions 3 and 4 – Terahertz Imaging, Spectroscopy, and Instrumentation I and II, and Session 5 – Simulation and Modeling.

Session 1 included papers covering coherent generation of terahertz radiation by acoustic waves, plasmonic terahertz detectors with monolithic hot electron bolometers (HEBs), terahertz quantum cascade laser integration into micro-machined waveguides, multi-channel detection of ultra-short terahertz pulses, and tunable narrowband terahertz generation by photoconductive beam-forming, followed by an invited paper on recent advances in photonic terahertz technology.

Session 2 and an associated poster session included a paper on terahertz detection by Schottky diode balanced mixers, characterization of sub-wavelength plastic fibers using time-domain spectroscopy, single-mode photonic quasi-crystal fibers, and quasi-optical system design.

Session 3 began with an invited paper dealing with the use of quantum cascade lasers as transmitters and local oscillators in short-range coherent terahertz TX/RX systems, followed by papers on gas sensing, spectroscopy of proteins in solution, fast terahertz cameras, and an invited paper on pulsed imaging for pathology of colon tissue.

Session 4 included papers on terahertz standoff detection, spectroscopy of various skin-cancers, imaging with MOSFET focal plane arrays, followed by an invited paper on nanoelectronic architectures for terahertz-based biological agent detection.

Session 5 included papers on HEB mixer amplifier chains, analysis of quantum cascade laser waveguides, modeling and measurement of dielectric tube waveguides, and optical modeling using Gaussian beam modes.

As in the prior conference with this title last year, these papers represent a cross section of much of the research work that is being pursued in the technically challenging terahertz spectral region.

In the prior two years of the proceedings of this conference (conferences 6472 and 6893), we presented a list of recent technical articles describing significant advances in the terahertz technology. This year, for the interested reader, we point to a rather extensive database on the terahertz absorption characteristics

of a large number of chemicals given on the website www.thzdb.org. That website, in turn, provides links to related terahertz technology database websites as shown in Table 1.

Table 1 List of terahertz technology database websites as found at www.thzdb.org

THz-BRIDGE Spectral Database http://www.frascati.enea.it/THz-BRIDGE/
NIST THz Spectral Database http://webbook.nist.gov/chemistry/thz-ir/
RIKEN THz Spectral Database http://www.riken.jp/THzdatabase/
THz Links from Rice University http://www-ece.rice.edu/~daniel/groups.html
Terahertz Technology Forum http://www.terahertzjapan.com/lang_english/index.html
Terahertz Science & Technology Network http://www.thznetwork.org/wordpress/
RIKEN Tera-Photonics Laboratory http://www.riken.go.jp/lab-www/tera/TP_HP/index_en.html
Quantum Semiconductor Electronics Laboratory, University of Tokyo http://thz.iis.u-tokyo.ac.jp/top-e.html
Terahertz Photonics Laboratory, Osaka University http://www.ile.osaka-u.ac.jp/research/THP/indexeng.html
Solid State Spectroscopy Group, Kyoto University http://www.hikari.scphys.kyoto-u.ac.jp/e_home.html
Kawase Laboratory "Tera health", Nagoya University http://www.nuee.nagoya-u.ac.jp/labs/optlab/kawase/index.html
NICT Terahertz Project http://act.nict.go.jp/thz/en/main_e.html
Laboratory of Terahertz Bioengineering, Tohoku University http://www.agri.tohoku.ac.jp/thz/jp/index_e.htm
Infrared and Raman Users Group http://www.irug.org/

In last two years' introductions to SPIE Proceedings volumes 6472 and 6893, we presented two tables, one summarizing the more common terahertz radiation sources, and the other summarizing the more common terahertz detector types. For the interest of the general reader we again include these tables, with some minor updates from last year. Readers of this volume may send additions to these

tables so that future volumes can continue to provide readers with relevant information on the availability of terahertz sources and detectors. Such suggestions can be sent to klinden@spirecorp.com.

Table 2 Summary of common terahertz sources

THz source type	Details	Characteristics
Synchrotron	* Coherent synchrotron produces very high photon flux, including THz region	E-beam, very broadband source, limited instrument availability, very large size, 20 W pulsed
Free electron laser	* Benchtop design at Univ. Essex, UK Elec beam moves over alternate H-field regions	Tunable over entire THz region, under development 0.1 - 4.8 THz, 0.5 - 5 kW, 1 - 20 us pulses at 1 Hz
Smith-Purcell emitters	* E-beam travels over metal grating surface,	Requires vacuum, has low efficiency
Backward-wave oscillators	* Vacuum tube, requires homog H-field~10 kG "Carcinotron", room temperature, to 1.2 THz	Tunable output possible. Under development and commercially available, 10 mW power level, <1 THz
Mercury lamp	* Water cooled housing, low press. 1E-3 Torr 75-150 W lamp, broad emission	Sciencetech SPS-200,300, low power density Low-cost, used in THz spectroscopy
Optically pumped gas cell laser	* Grating-tuned CO ₂ laser and far-IR gas cell such as methane. Most mature laser.	> 100 mW, 0.3-10 THz, discrete lines, CW/pulsed Commercially avail - Coherent (\$400K - \$1M)
Opt pump GaAs, p-InAs, Si, ZnTe, InGaAs (fiber laser pump), Ge photoconducting (PC) switch	* Mode locked Nd:YAG or Ti:sapphire laser creates short across biased spiral antenna gap * Also As-doped Si, CO ₂ laser pump	Imaging apparatus produced, 0.1 to 3 THz Commercially available, CW uW range, \$50K-500K 6 THz stim emission from As, Liq He temp.
Laser-induced air plasma	* Ti-saph laser induces air plasma	Remote THz generation possible, very low power Possibility of power increase in multiple plasmas
Photomixing of near-IR lasers	* Mixing tunable Ti-sapphire laser and diode laser in LT-grown GaAs photomixer. * GaSe crystal, Nd:YAG/OPO difference freq * Single 835 nm diode laser, external cavity * Diff-freq generation with 2 monolith QCLs	Tens of nW, tunable. Requires antenna pattern Not commercial. GaP gave 480 mW @ 1.3 THz Tunable 58-3540um (5-0.1THz), 209 W pulse 1.5THz 2-freq mix& 4-wave mixing, RT, sub-nW, 0.3-4.2THz 7.6 u & 8.7 u -> 5 THz, 60 nW pulsed output
Electrically pumped Ge in H-field	* Electric field injects electrons, magnetic field splits hole levels for low-E transitions	Requires electric and magnetic fields. Output up to hundres of mW, cryogenic cooling, 1.5 ~ 4 THz
Electrically pumped Si:B or As	* Transitions between impurity levels 100 x 200 um rectangle mesas, biased	31 uW output at 8.1 THz, slightly polarized Cryogenic cooling needed
Electrically pulsed InGaAs RTD	* Harmonically generated by electrical pulses RTD integrated into slot antenna	0.6 uW, 1.02 THz harmonic from InGaAs/AlAs RTD pulsed at 300 Hz
Direct multiplied mm waves	* Multiplied to low-THz region up-multiplied from mm-wave	Low power (uW level), available (VA Diodes) Coherent, heterodyne local oscillators in astronomy
Parametric generators	* Q-switched Nd:YAG pumps MgO:LiNbO ₃ non-linear crystal, Phase matched GaAs, GaP	200 W pulsed power, room temp., 0.1-5 THz tunable some commercially available ~ \$30K
Quantum cascade (QC) laser	* First announced in 2002, semiconductor, AlGaAs/GaAs-based, MBE grown, 1.6 to 4 THz	Operated at mW power, and up to 164K pulsed THz not commercially available, require cryo-cooling
Josephson junction cascades	Research stage	0.4-0.85 THz, microwatts
Transistor	* InGaAs channel PHEMT with 35 nm gate * InGaAs with 12.5 nm gate, 0.845 THz	1.2 THz, development at Northrop Grumman Univ. Ill (Dec 2006)
Grating-bicoupled plasmon-FET	* GaAs based double interdigitated grating	with 1.5um laser illum., Tohoku/Hokkaido Univ.

Table 3 Summary of common terahertz radiation detectors

THz detector type	Details	Characteristics
Si bolometer	* Most sensitive (10 pW Hz ^{1/2}) THz detector at liquid He temp., slow response time	Responsivity 2E9V/W, NEP=1E-17 W/Hz ^{1/2} , 100 mK Requires liquid He dewar, commercially avail.
Superconducting hot elec bolom	* Highest sensitivity Fast (1 us) response time	Requires cooling to 0.3 K, NEP=1E-17 W/Hz ^{1/2} Commercially available, expensive, bulky
Pyroelectric detectors	* Slow response t, 220 nW sensitiv at 24 Hz Requires pulsed signals or mechanical chopper	Room temp operation, commercially available, Low cost, imagers available ~ \$10K
Schottky diodes	* ~ 1 THz cutoff frequency Fast response, but low THz sensitivity	Commercially available ((VA Diodes) with corner ref. Room temp operation, good for mixers
PC dipole antennas	* signal gen across biased spiral antenna gap Short pulsed detection only	Analogous to optically pumped THz PC switch but in detection mode. Commercially available
Antenna coupled inter-subband	* 4-terminal phototransistor, 1.6 THz	Under development UCSB
III-V HEMT & Si FET to 300K	* HEMT with 250 nm gate plasma wave-based detection	20 K, 50 mV/W at 420 GHz, still in development Univ research, Si NEP to 1E-10 W/Hz ^{1/2} at 300 K
Quantum dot photon detector	* Demo-photon counting terahertz microscopy imaging, requires 0.3 K temp, research only	Under development, 1E-19 W = 100 photons/sec, Tokyo Univ.

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