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Editors

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Introduction

The 2014 Terahertz, RF, Millimeter, and Submillimeter-Wave Technology and Applications VI Conference was divided into eleven sessions reflecting specific categories as follows: Session 1 Terahertz Sources I, Session 2 Terahertz Sources II, Session 3 Terahertz Sources III, Session 4 New Developments in THz, RF, Millimeter-Waves, and Sub-Milimeter Waves I, Session 5 Spectroscopy I, Session 6 Spectroscopy II, Session 7 Detectors, Session 8 New Developments in THz, RF, Millimeter-Waves, and Sub-Millimeter Waves II, Session 9 Terahertz, RF, Millimeter-Wave, and Sub-Millimeter-Wave Passive Components, Session 10 RF, Sub-Millimeter-Wave, and Millimeter-Wave Sources, and Session 11 New Developments in THz, RF, Millimeter-Waves, and Sub-Millimeter Waves III and a poster session.

Session 1 began with an invited talk presented by Dr. Matthieu Martin from Professor Elliott Brown's research group on ErAs:GaAs extrinsic photoconductivity: a new alternative for 1550-nm-driven THz sources followed by a talk on Plasmonic photoconductive terahertz optoelectronics presented by Professor Mona Jarrahi, with additional talks on Narrowband continuous-wave terahertz generation and imaging, and Nonlinear optical resonators for tunable THz emission.

Session 2 began with an invited talk by Dr. Kyung Hyun Park on Photonic devices for tunable continuous-wave terahertz generation and detection followed by a talk on Silicon gradient index lens for THz pulse extraction with additional talks on A cost-effective terahertz continuous-wave system based on a compact dual-mode laser diode, Non-contact thickness, with the final talk of the session on conductivity measurement using a continuous-wave terahertz spectrometer based on a 1.3 μm dual-mode laser.

Session 3 began with a talk on Non-contact probes for THz-integrated devices based on fiber-coupled photomixers, followed by talks that included Terahertz emission in organic crystals pumped by conventional laser wavelength, Generation of broadband THz pulses (1-14 THz) with organic crystal DSTMS pumped by compact fs fiber lasers and Direct observation of terahertz photoluminescence from multi-layer epitaxial graphene on SiC under excitation by a mid-IR quantum cascade laser concluding with a talk on Confinement loss scaling law analysis in tube lattice fibers for terahertz applications.

Session 4 began with an invited talk on Optical design for translation of THz medical imaging technology by Dr. Zachary Taylor followed by talks on High-speed and broadband RF spectrum analyzer based on spectral hole burning in rare-earth-ion doped crystal, 10,000-fold field-enhancement for millimeter-wave transmission through one-nanometer gaps, and ending the session with a talk on Terahertz polarization imaging for colon cancer detection.

Session 5 began with a talk on Terahertz plasmonic waveguide sensing based on metal rod array structures followed by talks on Doping profile recognition in silicon using terahertz time-domain spectroscopy, Widening the span of GHz spacing optical frequency comb by increasing the pulse-shortening rate in RHML fiber lasers and concluding with a talk on Innovative evaluation methods for terahertz-spectra by combining different chemometric tools

Session 6 began with a talk on the Design and engineering of organic molecules for customizable Terahertz tags, Terahertz spectroscopy of concrete for evaluating the critical hydration level, Compact and reconfigurable fiber-based terahertz spectrometer at 1550 nm, and concluding with Terahertz selective and reversible volatile vapor detection using micro-porous polymer structure.

Session 7 began with a talk on Broadband monopole optical nano-antennas followed by talks that included Ultrabroadband phased-array radio frequency (RF) receivers based on optical techniques, Nb_5N_6 microbolometer array for a compact THz imaging system, and concluded with a talk on High-performance room-temperature THz nanodetectors with a narrowband antenna.

Session 8 began with a talk on Active metasurfaces, followed by talks on Nonreciprocity and gyromagnetically-induced transparency of metasurfaces, RF-photonic wideband measurements of energetic pulses on NIF enhanced by compressive sensing algorithms, Terahertz applications: trends and challenges, RF-wave generation using external cavity laser diodes frequency-stabilized to single optical cavity by using orthogonal polarized modes, and concluded with a talk on Vertical transitions between transmission lines and waveguides in multilayer liquid crystal polymer (LCP) substrates.

Session 9 began with a talk on Comparison analysis of microwave photonic filter using SOI microring and microdisk resonators, followed by talks on Techniques for the modelling of QUBIC: a next-generation quasi-optical bolometric interferometer for cosmology, Dual-frequency laser harmonic phase locking: Ultra-narrow line width of an optically carried signal at 300 GHz and concluded with a talk on Dual-frequency characterization of bending loss in hollow flexible terahertz waveguides.

Session 10 began with a talk on A widely tunable narrow linewidth RF source utilizing an integrated heterogeneous photonic module, followed by talks on A wide bandwidth analog front-end circuit for 60-GHz wireless communication receiver, Photonic generation of continuously-tunable microwave signals exploiting two tunable external-cavity lasers based on a polymer Bragg grating, Continuously-tunable microwave photonic filter based on a multiwavelength fiber laser incorporating polarization-differential time delay and nonlinear polarization rotation and concluded with a talk on On the metrological performances of optoelectronic oscillators based on whispering gallery mode resonators.

Session 11 began with a talk on Graphene-based optical modulator realized in metamaterial split-ring resonators operating in the THz frequency range, and continued with a talk on Polymeric waveguide components for THz quantum cascade laser outcoupling, Enhanced transmission and beam confinement using bullseye plasmonic lenses at THz frequencies, and concluded with a talk on An optically-controlled microwave phase stabilizer based on polarization interference technique using semiconductor optical amplifier.

There were also a number of excellent poster presentations at this conference.

As in prior Terahertz Technology and Applications Conferences, 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 seven years of the Proceedings of this conference (Conferences 6472, 6893 7215, 7601, 7938, and 8621, 8624, respectively), we (including Dr. Kurt Linden) presented a list of recent technical articles describing significant advances in the terahertz technology. This year, for the interested reader, we also include a list that points to a rather extensive and growing 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

Teraherts 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 the last five years' introduction to SPIE Proceedings, Volumes 6472, 6893, 7215, 7601, 7938, respectively, two tables were included, 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 without updates other than to note that recent advancements in vacuum electronics BWOs coupled with solid state multipliers have now produced usable power above 2 THz and that devices such as quantum cascade lasers continue to make improvements that encroach upon established high power sources such as carbon dioxide lasers. Due to such advancements, any values listed in Tables 2 and 3 are likely to be bested by new records in a very short time period; however the sources and detectors listed in Tables 2 and 3 still comprise the majority of those used in the THz regime. Readers of this volume may send additions and enhancements 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 sadwick@innosystech.com.

Table 2. Summary of common terahertz sources

THz source type	Details	Characteristics
Synchrotron	* Coherent synchrotron produces very high	E-beam, very broadband source, limited instrument
	photon flux, including THz region	availability, very large size, 20 W pulsed
Free electron laser	* Benchtop design at Univ. Essex, UK	Tunable over entire THz region, under development
	Elec beam moves over alternate H-field regions	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	Tunable output possible. Under development and
	"Carcinotron", room temperature, to 1.2 Thz	commercially available, 10 mW power level, <1 THz
Mercury lamp	* Water cooled housing, low press. 1E-3 Torr	Sciencetech SPS-200,300, low power density
	75-150 W lamp, broad emission	Low-cost, used in THz spectroscopy
Optically pumped gas cell laser	* Grating-tuned CO2 laser and far-IR gas	> 100 mW, 0.3-10 THz, discrete lines, CW/pulsed
	cell such as methane. Most mature laser.	Commercially avail - Coherent ($400K - $1M)
Opt pump GaAs, p-InAs, Si, ZnTe,	* Mode locked Nd:YAG or Ti:sapphire laser	Imaging apparatus produced, 0.1 to 3 THz
InGaAs (fiber laser pump), Ge	creates short across biased spiral antenna gap	Commercially available, CW uW range, $50K-500K
photoconducting (PC) switch	* Also As-doped Si, CO2 laser pump	6 THz stim emission from As, Liq He temp.
Laser-induced air plasma	* Ti-saph laser induces air plasma	Remote THz generatiion possible, very low power
		Possibility of power increase in multiple plasmas
Photomixing of near-IR lasers	* Mixing tunable Ti-sapphire laser and diode	Tens of nW, tunable. Requires antenna pattern
	laser in LT-grown GaAs photomixer.	Not commercial. GaP gave 480 mW @ 1.3 THz
	* GaSe crystal, Nd:YAG/OPO difference freq	Tunable 58-3540um (5-0.1THz),209 W pulse 1.5THz
	* Single 835 nm diode laser, external cavity	2-freq mix& 4-wave mixing, RT, sub-nW,0.3-4.2THz
	* Diff-freq generation with 2 monolith QCLs	7.6 u & 8.7 u -> 5 THz, 60 nW puled output
Electrically pumped Ge in H-field	* Electric field injects electrons, magnetic	Requires electric and magnetic fields Output up to
	field splits hole levels for low-E transitions	hundres of mW, cryogenic cooling, 1.5 ~ 4 THz
Electrically pumped Si:B or As	* Transitions between impurity levels	31 uW output at 8.1 THz, slightly polarized
	100 x 200 um rectangle mesas, biased	Cryogenic cooling needed
Electrically pulsed InGaAs RTD	* Harmonically generated by electrical pulses	0.6 uW, 1.02 THz harmonic from InGaAs/AlAs RTD
	RTD integrated into slot antenna	pulsed at 300 Hz
Direct multiplied mm waves	* Multiplied to low-THz region	Low power (uW level), available (VA Diodes)
	up-multiplied from mm-wave	Coherent, heterodyne local oscillators in astronomy
Parametric generators	* Q-switched Nd:YAG pumps MgO:LiNbO3	200 W pulsed power, room temp., 0.1-5 THz tunable
	non-linear crystal, Phase matched GaAs, GaP	some commercially available ~ $30K
Quantum cascade (QC) laser	* First announced in 2002, semiconductor,	Operated at mW power, and up to 164K pulsed
	AlGaAs/GaAs-based, MBE grown, 1.6 to 4 THz	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	1.2 THz, development at Northrop Grumman
	* InGaAs with 12.5 nm gate, 0.845 THz	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 Hz1/2) THz detector	Responsivity 2E9V/W,NEP=1E-17 WHz1/2,100 mK
	at liquid He temp., slow response time	Requires liquid He dewar, commercially avail.
Superconducting hot elec bolom	* Highest sensitivity	Requires cooling to 0.3 K, NEP=1E-17 WHz1/2
	Fast (1 us) response time	Commercially available, expensive, bulky
Pyroelectric detectors	* Slow response t, 220 nW sensitiv at 24 Hz	Room temp operation, commercially available,
	Requires pulsed signals or mechanical chopper	Low cost, imagers available ~ $10K
Schottky diodes	* ~ 1 THz cutoff frequency	Commercially available ((VA Diodes) with corner ref.
	Fast response, but low THz sensitivity	Room temp operation, good for mixers
PC dipole antennas	* signal gen across biased spiral antenna gap	Analogous to optically pumped THz PC switch but
	Short pulsed detection only	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	20 K, 50 mV/W at 420 GHz, still in development
	plasma wave-based detection	Univ research, Si NEP to 1E-10 W/Hz1/2 at 300 K
Quantum dot photon detector	* Demo-photon counting terahertz microscopy	Under development, 1E-19 W = 100 photons/sec,
	imaging, requires 0.3 K temp, research only	Tokyo Univ.

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