PROCEEDINGS OF SPIE

Terahertz Technology and Applications V

Laurence P. Sadwick
Créidhe M. O'Sullivan
Editors

25–26 January 2012
San Francisco, California, United States

Sponsored and Published by
SPIE

Volume 8261

Proceedings of SPIE, 0277-786X, v. 8261

Please use the following format to cite material from this book:
Author(s), "Title of Paper," in *Terahertz Technology and Applications V*, edited by Laurence P. Sadwick, Créidhe M. O'Sullivan, Proceedings of SPIE Vol. 8261 (SPIE, Bellingham, WA, 2012) Article CID Number.

ISSN 0277-786X
ISBN 9780819489043

Published by
SPIE
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445
SPIE.org

Printed in the United States of America.

Publication of record for individual papers is online in the SPIE Digital Library.

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Paper Numbering: Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print and on CD-ROM. Papers are published as they are submitted and meet publication criteria. A unique, consistent, permanent citation identifier (CID) number is assigned to each article at the time of the first publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

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The CID number appears on each page of the manuscript. The complete citation is used on the first page, and an abbreviated version on subsequent pages. Numbers in the index correspond to the last two digits of the six-digit CID number.

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3 THz Modeling and Simulation
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Robert H. Giles, University of Massachusetts Lowell (United States)

Introduction

The 2012 Terahertz Technology and Applications Conference was divided into eight sessions reflecting specific categories as follows: Session 1 – THz Imaging, Spectroscopy, and Instrumentation I, Session 2 – THz Imaging, Spectroscopy, and Instrumentation II, Session 3 – THz Modeling and Simulation, Session 4 – THz Sources, Generation, and Detection I, Session 5 – THz Sources, Generation, and Detection II, Session 6 – THz Materials and Configurations, Session 7 – THz Sources, Generation, and Detection III, and Session 8 – THz Sources, Generation, and Detection IV.

Session 1 included an invited talk by Professor Elliott Brown covering: a critical comparison of GaAs and InGaAs THz photoconductors, and contributed talks on a portable terahertz spectrometer with InP related semiconductor photonic devices, high-speed three-dimensional terahertz tomography using electronically controlled optical sampling, terahertz dynamic scanning reflectometry of soldier protective material, and a talk towards monolithically integrated CMOS cameras for active imaging with 600 GHz radiation

Session 2 included papers on a miniature self-aligned external cavity tunable single frequency laser for THz imaging, an evaluation of terahertz spectra using chemometric methods, and the application of graphene membrane in micro-Golay cell array

Session 3 began with an invited paper by Dr. Dwight Woolard of the Army Research Office on THz lasing in InAs/GaSb broken-gap heterostructure devices and quantum-dot pillar arrays followed by a talk on energy conversion efficiency calculation model for direct-bonding planar-waveguide THz emitters based on optical rectification effects in GaAs, a talk on long-term frequency and amplitude stability of a solid-nitrogen cooled continuous wave THz quantum cascade laser, followed by a talk on the plasmonic response of grating-gated InGaAs/InP HEMT device to terahertz and millimeter wave radiation, and concluding with a talk on new developments in waveguide mode matching techniques for far-infrared astronomy.

Session 4 began with a paper on the spoof plasmon analogue of metal-insulator-metal waveguides, followed by a talk on Wide-range broadband terahertz emission from high chi(2) dendrimer, a talk on thin-film platinum nanowires as sub-wavelength bolometers, and concluding with a talk on terahertz transmission enhancement through GaN quantum wells controlled by a DC voltage. There was also a poster on Aberrations of the large aperture attenuating THz lenses.

Session 5 began with an invited talk on real-world applications of terahertz pulsed technology by Dr. Philip F. Taday of TeraView Ltd., followed by a talk on one-half milliwatt 2.33 THz CW QCL operating at 77K, a talk on backwards wave oscillators combined with solid state frequency multipliers extending the spectral coverage of electronic sources to 2.2 THz, a talk on the upper band operation of active photonic crystal terahertz lasers, real-time THz imaging setup based on QC lasers, and concluding with a talk on exploring performance limits of silicon CMOS FET detectors for THz frequencies.

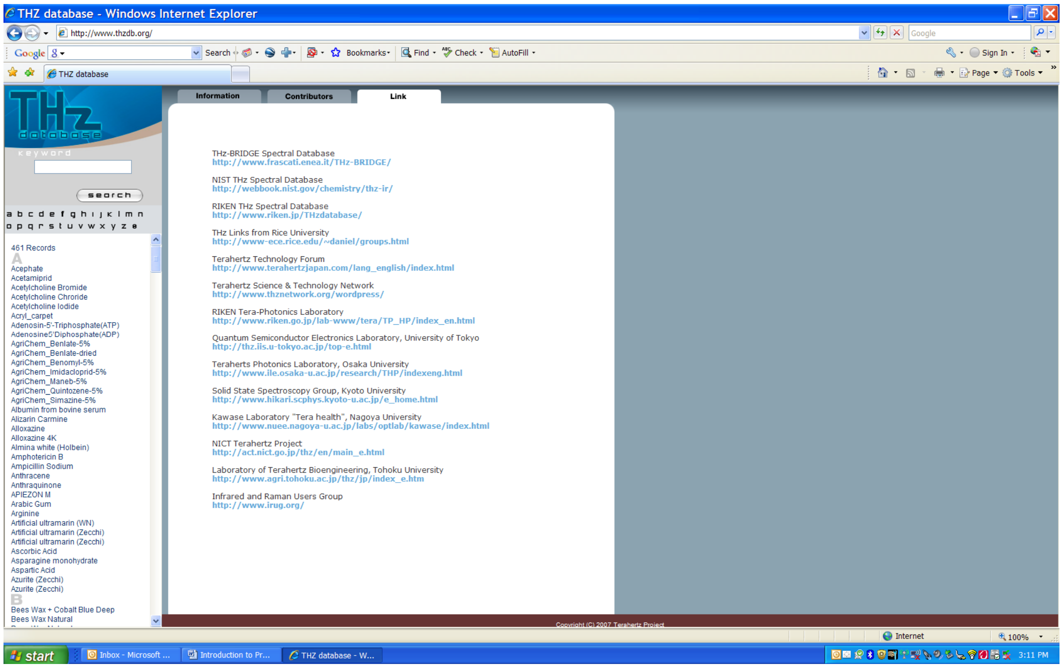
Session 6 began with a talk on the propagation loss optimization in dielectric/metal coated hollow flexible terahertz waveguides, followed by a talk on thin film lithium tantalate (TFLTR) pyroelectric detectors, a talk on metamaterial-based tunable absorber in the infrared regime, and concluding with a talk on changing growth of neurites of sensory ganglions by terahertz radiation.

Session 7 began with an invited talk on advances in biomedical imaging using THz technology with applications to burn wound assessment by Dr. Zachary D. Taylor from the Univ. of California, Los Angeles, the invited talk was followed by a talk on the generation and detection of broadband THz pulses (>10 THz) with organic nonlinear optical crystals OH1 and DSTMS as alternatives to DAST, and concluding with a talk on terahertz generation from quasi-phase matched gallium arsenide using a type II ring cavity optical parametric oscillator.

Session 8 began with a talk on continuous wave terahertz reflection imaging of ex vivo nonmelanoma skin cancers, followed by a talk on THz time-domain spectroscopy in different carbon nanotube and graphene thin-films, and concluding with a talk on the laser driven generation of an intense single-cycle THz field.

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 five years of the Proceedings of this conference (Conferences 6472, 6893, 7215, 7601, and 7938, 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.



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/

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

In the last five years' introduction to SPIE Proceedings, Volumes 6472, 6893, 7215, 7601, and 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, InGaAs (fiber laser pump), Ge photoconducting (PC) switch	* Mode locked Nd:YAG or Ti:sapphire laser	Imaging apparatus produced, 0.1 to 3 THz
	creates short across biased spiral antenna gap	Commercially available, CW uW range, $50K-500K
	* 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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