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Front Matter: Volume 7601

, "Front Matter: Volume 7601," Proc. SPIE 7601, Terahertz Technology and Applications III, 760101 (19 March 2010); doi: 10.1117/12.862276

SPIE.

Event: SPIE OPTO, 2010, San Francisco, California, United States

PROCEEDINGS OF SPIE

Terahertz Technology and Applications III

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

**27–28 January 2010
San Francisco, California, United States**

Sponsored and Published by
SPIE

Volume 7601

Proceedings of SPIE, 0277-786X, v. 7601

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

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Author(s), "Title of Paper," in *Terahertz Technology and Applications III*, edited by Laurence P. Sadwick, Creidhe M. M. O'Sullivan, Proceedings of SPIE Vol. 7601 (SPIE, Bellingham, WA, 2010) Article CID Number.

ISSN 0277-786X
ISBN 9780819479976

Published by

SPIE

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

The 2010 Terahertz Technology and Applications conference was divided into four sessions reflecting specific categories as follows: Session 1 – THz Imaging, Spectroscopy, and Instrumentation, Session 2 – THz Modeling and Simulation, Sessions 3 – THz Sources, Generation, and Detection, and Session 4 – THz Materials and Configurations.

Session 1 included papers covering terahertz pulsed imaging in quality control, improved terahertz imaging with a sparse synthetic aperture array, terahertz imaging of non-melanoma skin cancers, coherent imaging at 2.4 THz with a CW quantum cascade laser transmitter, wavelet transforms in terahertz spectroscopy of rough surface targets, and a paper on terahertz pulse time-domain holography.

Session 2 included papers on measurement and modeling of rough surface effects on terahertz spectroscopy, modeling of an electrically tunable quantum dot photodetector for terahertz detection, a paper on optical requirements and modeling of coupling devices for future far-infrared space missions, and a new set of simulations for magnetic-field enhancement beyond the skin depth limit.

Session 3 began with a paper on stimulated emission of terahertz radiation from electro-optic dendrimer, optically synchronized dual-channel terahertz signals for high-performance transmitter/receiver system, and included a paper on handheld terahertz systems based on telecom technologies, terahertz photonic transmitters with a high-gain open-ended rampart slot array antenna, and concluded with a paper on extended spectral coverage of BWO combined with frequency multipliers in which BWOs combined with solid state multipliers were able to achieve output power up to about 2.2 THz.

Session 4 began with a paper on terahertz dynamics of ionic liquids from a combined dielectric relaxation, terahertz, and optical Kerr effect study, and included additional papers on electric coupling resonance variation in THz metamaterials, a floating gate double quantum well far-infrared photoconductor, design and performance of reflective ultra-broadband terahertz time-domain spectroscopy with air-biased-coherent-detection, and concluded with a paper on the design of hybrid GaAs waveguide emitters for generation of terahertz radiation based on phase-matched optical rectification process pumped by 1550-nm fiber lasers.

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 three years of the Proceedings of this conference (conferences 6472, 6893 and 7215), 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
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 the last three years' introduction to SPIE Proceedings, volumes 6472, 6893, and 7215 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 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 CO2 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, CO2 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:LiNbO3 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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