Form 1

2017 Report Form for Collaboration with Research Center for Biomedical Engineering

Year/month/date	
Number	2031

Date /Month/Year
date: 19/03/2018

To Chairman, Board of Directors, Research Center for Biomedical Engineering

Applicant

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Report Form for Collaboration Research

Research Theme	(和)生体医歯検査応用のための非侵襲・非破壊テラヘルツイメージング技術の研究 (英)Non-invasive and non-destructive terahertz imaging for diagnostics and bio-medical applications
Research Area	1. Biomaterials 2. Bioengineering 3. Functional molecules ④. Chemistry/Electrical Engineering/Mechanical Engineering/Materials Science
Research Period	From: Date/month/Year 17/04/2017 To: Date/month/Year 31/03/2018

Applicant Organization			
Name	Department	Title	Role
Bründermann, Erik	Karlsruhe Institute of Technology (KIT), Institute for Beam Physics and Technology (IBPT)	Head of Department, Dr.	Project leader
Hiromoto, Norihisa	Shizuoka University, Graduate School of science and technology	Professor, Dr.	Collaborator (Measurement)
Tripathi, Saroj	Shizuoka University, Faculty of Engineering	Associate Professor, Dr.	Collaborator (Analysis)

Collaboration Partners in the Research Center	静岡大学電子工学研究所　ナノシステム集積化分野　教授 猪川　洋 Research Institute of Electronics, Shizuoka University Professor Dr. Inokawa, Hiroshi

Research Results (Including Purpose, Results, Figures, etc.)

At KIT several THz sources and detection systems were prepared, which enable the testing of THz pixel detectors and arrays developed at Shizuoka University. N. Hiromoto also visited KIT in the framework of the MOU between KIT and SU from September 9th to 16th in 2017 to review available sources and for research discussions. Besides accelerator-based THz sources such as coherent synchrotron radiation (CSR) from the Karlsruhe Research Accelerator (KARA, Fig. 1) with an operator-defined time-structure (Fig. 2), emission spectrum (Fig. 3) and beam profile (Fig. 4), there are laser-based THz sources such as THz time-domain systems (Fig. 5). One further example is the use of a $LiNbO_3$ prism to generate high power THz pulses in the frequency range around 0.3 to 0.5 THz. The beam profile of this THz source was detected by a commercial about 100,000 pixel pyroelectric camera (see Yan *et al.* and Schlott *et al.*). The THz sources can serve as test systems for RIE's detectors. Recent technology advances (see Caselle *et al.*) allow very high data rates, for example, produced by a sampling system such as the Karlsruhe Pulse Taking Ultra-fast Readout Electronics (KAPTURE). The sampled data is processed in real-time by a heterogeneous FPGA and GPU architecture operating up to 6.5 GB/s continuously. Such a technology opens the path to a read-out system for very large arrays with a high number of pixels and, at the same time, large effective number of bits (ENOB) to measure a wide dynamic range of the employed pixel detector. E. Bruendermann and collaborators of SU had a meeting to discuss on the research results and the future plans at SU in March 22nd to 26th, 2018.

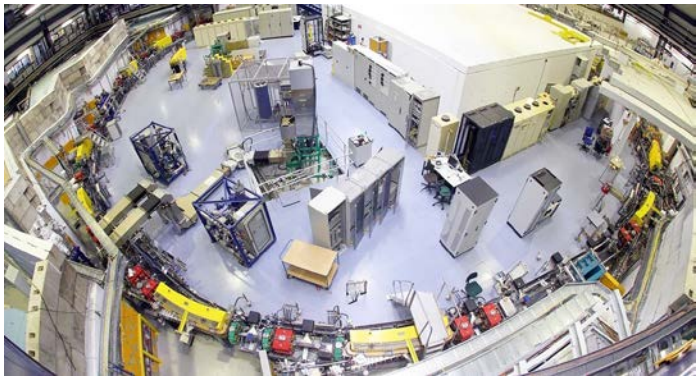

Fig.1: Karlsruhe Research Accelerator (KARA) at KIT

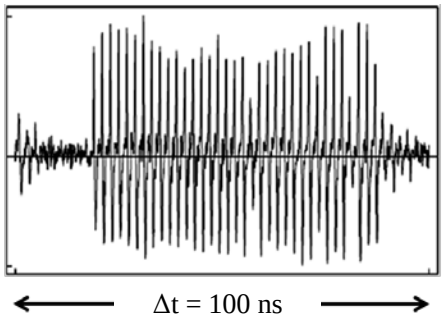

Fig.2: Example of time structure of THz CSR

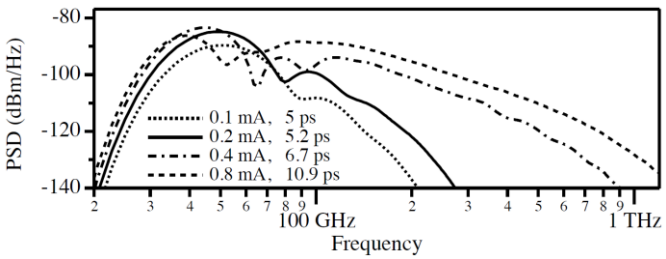

Fig. 3: Calculation of THz CSR spectrum (from Steinmann *et al.*, arXiv:1710.09568)

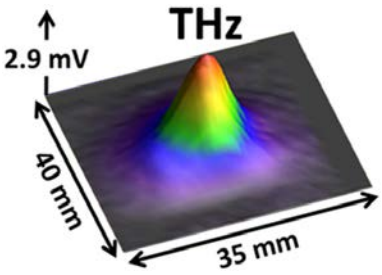

Fig. 4: Example measurement of the spatial beam profile in a distance of several meters from the electron storage ring KARA

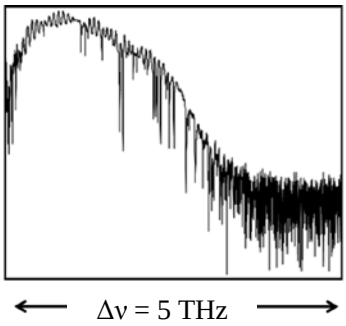

Fig. 5: Typical frequency coverage of a THz time-domain spectrometer source

List of Publications Related to the Collaboration Research

(1) M. Caselle, L.E. Ardila Perez, M. Balzer, A. Kopmann, L. Rota, M. Weber, M. Brosi, J. Steinmann, E. Bründermann, and A.-S. Müller, “KAPTURE-2. A picosecond sampling system for individual THz pulses with high repetition rate,” JINST 12 C01040 (2017). DOI: 10.1088/1748-0221/12/01/C01040

(2) J.L. Steinmann, M. Brosi, E. Bründermann, M. Caselle, B. Kehrer, L. Rota, P. Schönfeldt, M. Schuh, M. Siegel, M. Weber, A.-S. Müller, “Continuous bunch-by-bunch spectroscopic investigation of the micro-bunching instability”, arXiv preprint, arXiv:1710.09568 (26 Oct. 2017)

(3) A. Banerjee, H. Satoh, A. Tiwari, Catur A., Eko T. R., N. Hiromoto and H. Inokawa, “Width dependence of platium and titanium thermistor characteristics for application in room-temperature antenna-coupled terahertz microbolometer,” Jpn. J. Appl. Phys. 56, 04CC07 (23 Mar. 2017).

List of Presentations (Conference, Meeting, etc)

(1) M. Yan, E. Bründermann, S. Funkner, A.-S. Müller, M.J. Nasse, G. Niehues, R. Ruprecht, M. Schedler, T. Schmelzer, M. Schuh, M. Schwarz, B. Smit, M.M. Dehler, N. Hiller, R. Ischebeck, V. Schlott, T. Feurer, M. Hayati, “Design of a Time-resolved Electron Diagnostics Using THz Fields Excited in a Split Ring Resonator at FLUTE,” Proc. Int. Beam Instrumentation Conf.: Barcelona, 11-15 Sep 2016, TUPG56 (published Feb 2017)

(2) V. Schlott, M. Dehler, R. Ischebeck, M. Moser, T. Feurer, M. Hayati, Z. Ollmann, R. Tarkeshian, E. Bründermann, S. Funkner, A.-S. Müller, M.J. Nasse, G. Niehues, R. Ruprecht, T. Schmelzer, M. Schuh, M. Schwarz, M. Yan, “Status of the THz Streaking Experiment with Split Ring Resonators at FLUTE”, Proc. Int. Beam Instrumentation Conf., Grand Rapids, 20-24 Aug 2017, TUPCC16.

(3) M. Caselle, L.E. Ardila Perez, M. Balzer, A. Kopmann, L. Rota, M. Weber, M. Brosi, J. Steinmann, E. Bründermann, A.-S. Müller, KAPTURE-2. A picosecond sampling system for individual THz pulses with high repetition rate, JINST 12, C01040 (2017). DOI: 10.1088/1748-0221/12/01/C01040, also held as a presentation at the Topical Workshop on Electronics for Particle Physics (TWEPP)

(4) J.L. Steinmann, E. Blomley, M. Brosi, E. Bründermann, M. Caselle, B. Kehrer, L. Rota, P. Schönfeldt, M. Schuh, M. Siegel, M. Weber, A.-S. Müller, Anke-Susanne, 4-Channel Single Shot and Turn-by-Turn Spectral Measurements of Bursting CSR, Proceedings of the International Particle Accelerator Conference (IPAC’17), Copenhagen, DK, 14-19 May 2017, pp. 231-234 (2017)

(5) A. Banerjee, H. Satoh, Y. Sharma, A. Tiwari, N. Hiromoto, and H. Inokawa, “Optimization of Narrow Width Effect on Titanium Thermistor in Uncooled Antenna-Coupled Terahertz Microbolometer,” 2017 International Conference on Solid-State Devices and Materials (SSDM 2017),(Sendai International Center, Sendai, Japan), (Sept. 2017).

(6) A. Banerjee, H. Satoh, Y. Sharma, A. Tiwari, N. Hiromoto, and H. Inokawa, “Optimization of Platinum and Titanium Thermistor in Uncooled Antenna-Coupled Terahertz Microbolometer Fabrication,” International Conference organized by Department of Physics and Nanotechnology (ICONN 2017), (SRM University, Chennai, India), (11 Aug. 2017).

(7) N. Hiromoto, A. Banerjee, H. Satoh, H. Inokawa, M. Aoki, E. Bründermann, “Development of THz

antenna-coupled bolometers with a meander-line thermistor," The 27th JSIR Symposium 2018 (Osaka City Univ., Osaka, Japan), 2017-IR-09 (Oct. 2017). (in Japanese)

(8) N. Hiromoto, A. Banerjee, M. Aoki, H. Satoh, H. Inokawa, "Study on THz antenna-coupled bolometers with minutes meander structures," The 78th JSAP Autumn Meeting, 2017(Fukuoka Convention Center, Fukuoka), 8a-A405-10 (Sep. 2017). (in Japanese)

List of Awards

During the period of the collaborative research, E. Bründermann received on May 17, 2017 a JSPS BRIDGE award in part due to a support letter by Prof. N. Hiromoto. E. Bründermann commenced the award on March 14, 2018 in Japan and attended research meetings in the visit to Shizuoka University, Hamamatsu Campus, within the period from March 21 to 27, 2018.

Research plan for the next year (from April 1, 2018 to March 31, 2019), if the collaboration research is continued. Prior consent from the collaboration partner in the Research Center is necessary.

The applicant desires to continue the collaboration research.

Research objective: long-term with intention to develop and explore new methods and technologies for diagnostics. Main goal is real-time terahertz (THz) imaging with extreme-performance multi-pixel, while exploring the potential from video-mode towards ultrafast imaging. The proposed research is to develop new detection and imaging technologies at the Research Institute of Electronics (RIE) at Shizuoka University and employ them at the accelerator and laser facilities at the Karlsruhe Institute of Technology (KIT) for diagnostics and in biomedical applications at Shizuoka University and affiliates. The project leader (PL) will collaborate on the detection method using THz antenna-coupled bolometers, which have the potential for multi-pixel arrays and spectral imaging applications.

About the PL: The PL heads the department of Accelerator Research at KIT to explore new accelerator and detector technologies for application-driven research towards life sciences and medicine. He is involved in research at FLUTE (Ferninfrarot Linac- Und Test Experiment), a linear accelerator-based test experiment at KIT, which will commence operation in the near future. The experiment shall provide stable and reproducible operation and will allow tuning of frequency, pulse duration and THz intensity over a very wide range. Emission stability will enable the systematic study of heterogeneous materials such as complex aqueous solutions with biomolecules relevant to medicine, biocompatible materials, cells and tissue. A further required key-element for this research will be efficient, well-defined detectors for THz radiation currently in development by the RIE. The PL is part of a 3-year project on plasma accelerator development and project leader for the KIT contribution, funded since 2017 as a future topic by the strategic initiative fund of the Helmholtz Association's president. Plasma accelerators promise a size reduction of conventional accelerators by several orders of magnitude, so that these accelerators could enable widespread use in science, industry, and medicine.

MOU: The intended research will be considered to commence in the framework of the signed MOU between Karlsruhe Institute of Technology (KIT), Germany, and Shizuoka University, Japan (final signature was on Nov. 24th, 2015 to foster exchange of personnel and students, see further information on KIT website in section on International Affairs: "Cooperating with Japan", http://www.intl.kit.edu/ischolar/8214.php).

Environment for biomedical applications: The future biomedical applications can rely on the long-standing collaboration of the PL with Shizuoka University, affiliates and partners in biology and medicine, which are documented by peer-reviewed publications. KIT provides an ideal environment for such future collaborative research activities. For example, KIT hosts the European Zebrafish Resource Center (www.ezrc.kit.edu), which provides over 2000 plasmids. KIT also contributes to the Helmholtz Repository of Bioparts (HeRBi) with model systems for biomedical research and a stock collection containing several thousand mutations. In addition, the European Molecular Biology Laboratory (EMBL) is located nearby, in Heidelberg, and is Europe's flagship laboratory for basic research in molecular biology. The cooperation between Heidelberg University and KIT at Karlsruhe is governed by the "Heidelberg-Karlsruhe Research Partnership" (HEiKA).

Research plan: develop and explore new methods and technologies for diagnostics to allow real-time terahertz

(THz) imaging with extreme-performance multi-pixel, while exploring the potential from video-mode towards ultrafast imaging. New detection and imaging technologies are in development at RIE at Shizuoka University. Tests are envisioned at the accelerator and laser facilities at KIT. For comparison and accurate power measurements, a 64x64 pixel commercial camera sensitive up to 0.7 THz, a commercial pyroelectric camera, and PTB-calibrated THz power meters are available at KIT.