Form 1

2019 Report Form for Collaboration with Research Center for Biomedical Engineering

Year/month/date	
Number	

Date/Month/Year
date: 28/03/2020

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 (No. 2032) （英）Non-invasive and non-destructive terahertz imaging for diagnostics and bio-medical applications (No. 2032)
Research Area	1. Biomaterials 2. Bioengineering 3. Functional molecules ◯,4. Chemistry/Electrical Engineering/Mechanical Engineering/Materials Science
Research Period	From: Date/month/Year 14/05/2019 To: Date/month/Year 31/03/2020

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 R.	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.)

Purpose

Electromagnetic waves have a high potential for diagnostics, understanding and treatment of illnesses, e.g. elevated skin temperature measured by infrared (IR) cameras is an indicator of infection. Using visible, IR, and terahertz (THz) waves has given a new understanding of patient's dry skin (1), of healing processes after plasma treatment of wounds (2), and new insights into sweat ducts properties (3). A prerequisite for non-invasive imaging of skin are cameras enabling systematic medical studies with high statistical value. Our research tackles the *challenge* to correlate spectral fingerprints in the visible, IR, and THz region of heterogeneous complex biocompatible materials, cells, tissue, and skin. Our *strategy* is to measure additional modalities by providing the imaging technologies for discoveries. Our *research* concentrates on the development of the required technology and THz spectral fingerprints/resonances.

Results

During project No. 2032 at the Research Center of Biomedical Engineering and the MOU between KIT and Shizuoka University, the technology has progressed by identifying suitable materials (4). We studied a long meander-line, titanium thermistor to obtain higher responsivity by the larger resistance (5). This meander line with 0.1-µm width and 90-µm length is at the core of the THz detector pixel (Fig. 1). A single pixel usable at 10times higher (500 Hz) than typical camera framerates of 50 Hz and illuminated with a few nW at 1 THz showed about 1000times lower noise level. We achieved a noise-equivalent power (NEP) value of 6.7 pW in a 1 Hz bandwidth (5). Simulation suggests response times suitable for framerates even beyond 5000 Hz. A multi-spectral camera concept for imaging and high throughput applications with detector antennas, resonant at 3 different THz frequencies (pixel arrangement symbolized by color), was presented (6) at the 4th International Symposium Biomedical Engineering (ISBE), see Fig. 2.

Figures

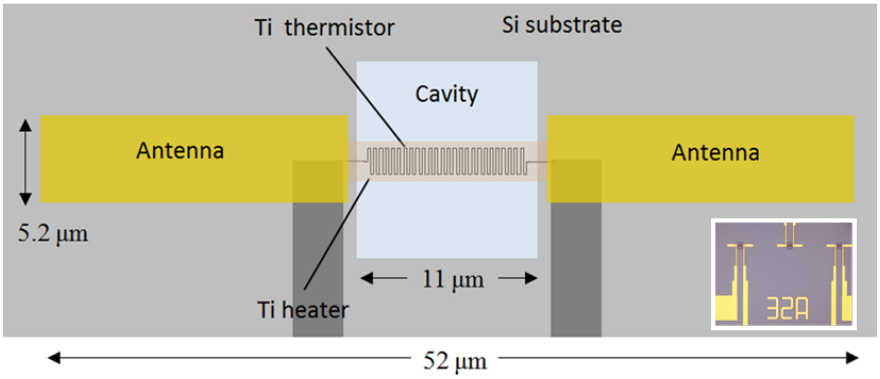

Fig. 1. Antenna-coupled bolometer with a meander thermistor. Inset (right): photo of 3 pixel.

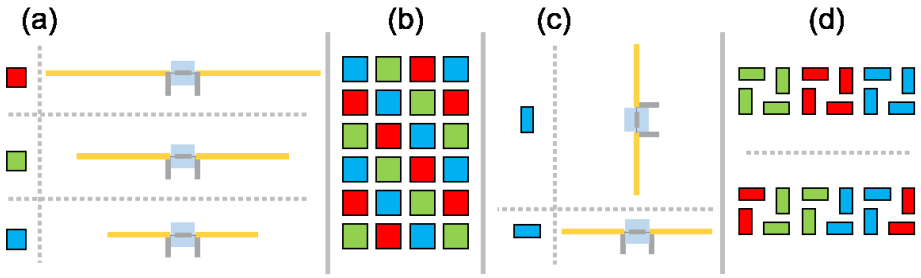

Fig. 2: (a) Detector antennas, resonant for 3 different THz frequencies (symbolized by 3 colored squares/pixel), (b) artists' view and concept of multi-spectral/color camera pixel arrangement, (c) positioning for polarization-sensitive measurements (symbolized by colored rectangles), (d) artists' view and concepts of multi-spectral and polarization-sensitive camera.

References (project members underlined)

(1) M. Mischo, L.B. Kobyletzki, E. Bründermann, et al., "Similar appearance, different mechanisms: xerosis in HIV, atopic dermatitis and ageing," Experimental dermatology 23(6), 446-448 (2014). DOI: https://doi.org/10.1111/exd.12425.

(2) K. Kartaschew, M. Mischo, S. Baldus, E. Bründermann, et al., "Unraveling the interactions between cold atmospheric plasma and skin-components with vibrational microspectroscopy," Biointerphases 10, 029516 (2015). DOI: https://doi.org/10.1116/1.4919610.

(3) S. R. Tripathi, et al., "Morphology of human sweat ducts observed by optical coherence tomography and their frequency of resonance in the terahertz frequency region," Scientific Reports 5, Article number: 9071 (2015). DOI: https://doi.org/10.1038/srep09071.

(4) N. Hiromoto, A. Banerjee, D. Elamaran, M. Aoki, C. Apriono, H. Satoh, E. Bruendermann, E. T. Rahardjo, H. Inokawa, "Room-Temperature Terahertz Antenna-Coupled Microbolometers with Titanium Thermistor and Heater." Proc. 16th Int. Conf. on Quality in Research (QIR): Int. Symp. Electr. and Comput. Eng., Padang, RI, July 22-24 (2019). DOI: https://doi.org/10.1109/QIR.2019.8898200.

(5) N. Hiromoto, A. Banerjee, D. Elamaran, M. Aoki, C. Apriono, H. Satoh, E. Bruendermann, E. T. Rahardjo, H. Inokawa, "High Responsivity and Low NEP of Room-Temperature Terahertz Antenna-Coupled Microbolometers with Meander Titanium Thermistor." 44th Int. Conf. Infrared, Millimeter, and Terahertz Waves, Paris, Sep. 1-6 (2019). DOI: https://doi.org/10.1109/IRMMW-THz.2019.8874346.

(6) E. Bruendermann, S. R. Tripathi, N. Hiromoto, H. Inokawa, "Non-invasive and non-destructive terahertz imaging for diagnostics and bio-medical applications," 4th Int. Symp. Biomed. Eng. (ISBE), Hamamatsu, Nov. 14-15, ISBE2019, ID: #094, Poster P2-28 (2019).

List of Publications Related to the Collaboration Research

1. Hiromoto, N.; Banerjee, A.; Elamaran, D.; Aoki, M.; Apriono, C.; Satoh, H.; Bruendermann, E.; Rahardjo, E. T.; Inokawa, H. 2019. "Room-Temperature Terahertz Antenna-Coupled Microbolometers with Titanium Thermistor and Heater." Proceedings of the 16th International Conference on Quality in Research (QIR): International Symposium on Electrical and Computer Engineering, Padang, RI, July 22-24, 2019, IEEE, DOI: https://doi.org/10.1109/QIR.2019.8898200.

2. Hiromoto, N.; Banerjee, A.; Elamaran, D.; Aoki, M.; Apriono, C.; Satoh, H.; Bründermann, E.; Rahardjo, E. T.; Inokawa, H.. 2019. "High Responsivity and Low NEP of Room-Temperature Terahertz Antenna-Coupled Microbolometers with Meander Titanium Thermistor." IRMMW-THz 2019: 44th International Conference on Infrared, Millimeter, and Terahertz Waves, Paris, 1-6 September 2019, IEEE, DOI: https://doi.org/10.1109/IRMMW-THz.2019.8874346.

3. Bruendermann, E.; Tripathi, S. R.; Hiromoto, N.; Inokawa, H., "Toward non invasive diagnostics and imaging of human skin disentangling xerosis of HIV and atopic dermatitis patients and due to ageing, of physicochemical changes in skin due to plasma treatment, and of human sweat ducts with technologies in the terahertz region and beyond," Part of the "Annual meeting 2019" report for the "Collaborative Research in Biomedical Research" project No. 2032 with Research Institute of Electronics (RIE) of Shizuoka University, Hamamatsu Campus, Japan. Published in KITopen, https://publikationen.bibliothek.kit.edu/1000117744, Open Access.

List of Presentations (Conference, Meeting, etc)

1. Hiromoto, N.; Banerjee, A.; Elamaran, D.; Aoki, M.; Apriono, C.; Satoh, H.; Bruendermann, E.; Rahardjo, E. T.; Inokawa, H. 2019. "Room-Temperature Terahertz Antenna-Coupled Microbolometers with Titanium Thermistor and Heater." Proceedings of the 16th International Conference on Quality in Research (QIR): International Symposium on Electrical and Computer Engineering, Padang, RI, July 22-24, 2019, IEEE, DOI: https://doi.org/10.1109/QIR.2019.8898200.

2. Hiromoto, N.; Banerjee, A.; Elamaran, D.; Aoki, M.; Apriono, C.; Satoh, H.; Bründermann, E.; Rahardjo, E. T.; Inokawa, H.. 2019. "High Responsivity and Low NEP of Room-Temperature Terahertz Antenna-Coupled Microbolometers with Meander Titanium Thermistor." IRMMW-THz 2019: 44th International Conference on Infrared, Millimeter, and Terahertz Waves, Paris, 1-6 September 2019, IEEE, DOI: https://doi.org/10.1109/IRMMW-THz.2019.8874346.

3. Bruendermann, E.; Tripathi, S. R.; Hiromoto, N.; Inokawa, H., "Non-invasive and non-destructive terahertz imaging for diagnostics and bio-medical applications," The 4th Int. Symp. Biomed. Eng. (ISBE), Hamamatsu, Nov. 14-15, ISBE2019, ID: #094, Poster P2-28 (2019). The 4th International Symposium on Biomedical Engineering (ISBE2019) sponsored by Ministry of Education, Culture, Sports, Science and Technology [MEXT], Japan in Hamamatsu, Japan.

List of Awards

April 2019: Erik Bründermann elected as Honorable Guest Professor of Shizuoka University, Graduate School of Science and Technology, Hamamatsu, Shizuoka, Japan.

Registration of research-theme continuation for next year Prior consent from the collaboration partner in the Research Center is necessary.	Yes	No

Research plan for the next year (from April 1, 2020 to March 31, 2021), if the collaboration research is continued.

We plan to advance the technologies on THz array and camera technologies further and stable conditions for THz light sources to foster systematic studies and statistics for medical researches. High THz source power and sensitive cameras allows multi-modal, multi-dimensional data for systematic medical imaging with high statistical value. The research is required to enable the systematic study of heterogeneous materials such as complex aqueous solutions with biomolecules relevant to medicine, biocompatible materials, cells and tissue. We also study the techniques for observing fingerprints of biological matter in the terahertz spectral region mostly terra incognita in which high potential for discoveries is expected. This work shall be conducted in the framework of the 5-year Memorandum of Understanding (MOU) signed between Karlsruhe Institute of Technology (KIT), Germany, and Shizuoka University (SU), Japan, on November 24th, 2015, and as Cooperative Research of the Research Institute of Electronics for the Research Center of Biomedical Engineering. Preparations for extending the MOU by another 5 years are under way at KIT and SU.