Intermediate Report

Project ANR / JST Joint Research Program

"WITH"

"WIreless communication using TeraHertz plasmonic-nano ICT devices"

Japan-France initiative on innovative plasmonic nano-device technologies for ultra-broadband ubiquitous wireless communications using terahertz waves

This report was compiled for the ANR-JST Joint workshop which was held in Kobe, Japan in March 2012. This report summarised WITH group research activity of first half research period.
本報告書は、2012 年 3 月に神戸で開催された領域内中間ワークショップのために編纂されました。研究グループの研究期間前半の活動内容をまとめたものです。

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A IDENTIFICATION

Project acronym	"WITH"
Project title	"WIreless communication using TeraHertz plasmonic-nano ICT devices" Japan-France initiative on innovative plasmonic nano-device technologies for ultra-broadband ubiquitous wireless communications using terahertz waves
Project coordinator (French side) (company/organization)	Dr. Wojciech KNAP (L2C, Université. Montpellier)
Project coordinator (Japanese side) (company/organization)	Prof. Dr. Taiichi OTSUJI (RIEC, Tohoku University)
Project start date Project end date	Japan side Official start: 13/05/2010 Official end: 31/03/2014 (original: 31/03/2013) France side Official start: 01/12/2010 Note: acte attributif (available funding): 20/04/2011 Official end: 01/12/2013
Competitiveness cluster labels and contacts (French side) (cluster, name and e-mail of contact)	1. Université Montpellier 2 (MP) Wojciech Knap 2. IEMN (IM) Jean-François Lampin 3. Université de Savoie (SV) Jean-Louis Coutaz
Project website if applicable	

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Date of writing	Jan. 15th, 2012
Period covered by activity report	2010/05/13 – 2011/12/31

B DELIVERABLES AND MILESTONES.

No.	Designation	Nature*	Date of supply			Partners (underline the responsible partner)
			Initially planned	Re-scheduled	Deliv-ered	
T1	**FR-initiative PW high responsivity coherent detectors**	**milestone**	06/11	09/11	09/11	MP, IM, SV, TU
T1.1	Theory and modelling (TH/MOD) of the PW detectors	report	03/11	-	03/11	MP, TU
T1.2	Design (DSN) of the PW detectors	data	12/10	03/11	03/11	MP, TU
T1.3	Fabrication (FAB) of the plasma Wave Detectors	prototype	03/11	06/11	05/11	IM, TU
T1.4	Design (DSN) and integration (INTEG) of the test/characterization system	data	03/11	07/11	06/11	SV, RK, MP, TU
T1.5	Test/analysis (TEST/ANL) of the PW detectors	data report	06/11	09/11	09/11	MP, TU, SV, RK
T1.6	Improvement of the PW detectors	data report			(08/13)	MP, IM, SV
T2	**JP-initiative PW coherent photomixing sources**	**milestone**	09/11	03/12	(03/12)	TU, RK, MP
T2.1	Theory and modelling (TH/MOD) of the Coherent Photomixing Source	report	03/11	-	03/11	TU, MP
T2.2	Design (DSN) of the Coherent PW Photomixing Source	data	12/10	03/11	03/11	TU, MP
T2.3	Fabrication (FAB) of the Coherent	prototype	03/11	09/11	06/11	TU

No.	Designation	Nature*	Date of supply			Partners (underline the responsible partner)
			Initially planned	Re-scheduled	Deliv-ered	
	PW Photomixing Source					
T2.4	Design (DSN) and integration (INTEG) of the test/characterization system	data	06/11	-	06/11	RK, TU, MP
T2.5	Test/analysis (TEST/ANL) of the Coherent PW Photomixing Source	data report	09/11	03/12	(03/12)	TU, RK, MP
T3	**FR-initiative UTC-PD coherent high power photomixing sources**	**milestone**	06/11	03/12	(03/12)	IM, OU, RK, MP
T3.1	Theory and modelling (TH/MOD) of the UTC-PD	report	03/11	06/11	06/11	IM, OU
T3.2	Design (DSN) of the UTC-PD	data	12/10	03/11	03/11	IM, OU
T3.3	Fabrication (FAB) of the UTC-PD	Prototype	12/10	06/11	06/11	IM
T3.4	Integration (INTEG) of the UTC-PD	data	03/11	09/11	09/11	IM, OU
T3.5	Test/analysis (TEST/ANL) of the UTC-PD	data report	06/11	03/12	(03/12)	IM, OU, RK, MP
T3.6	Improvement of the UTC-PD	data report			(10/13)	IM, MP, SV
T4	**JP-initiative PW high speed modulators - dual-grating devices**	**milestone**	12/11	06/12	(06/12)	TU, RK, OU, MP, SV
T4.1	Theory and modelling (TH/MOD) of the PW high speed modulators	report	03/11	-	03/11	TU, MP
T4.2	Design (DSN) of the PW high speed modulators	data	03/11	-	03/11	TU, MP
T4.3	Fabrication (FAB) of the PW High Speed Modulators	prototype	06/11	09/11	09/11	TU
T4.4	Design (DSN) and integration (INTEG) of the test/characterization system	data	12/11	09/11	(03/12)	RK, OU, TU, SV, MP
T4.5	Test/analysis (TEST/ANL) of the PW high speed modulators	data report	12/11	06/12	(06/12)	TU, RK, SV, MP
T5	**FR-initiative Wireless communication receiver prototype based on PW detectors**	**milestone**	09/11	12/11	12/11	IM, MP
T5.1	Theory and Modelling (TH/MOD) of the PW-detector based receiver prototype	report	03/11	12/11	12/11	IM, MP
T5.2	Design (DSN) of the PW-detector based receiver prototype	data	03/11	12/11	02/12	IM, MP
T5.3	Fabrication (FAB) and integration of the PW-detector based receiver prototype	prototype	06/11	03/12	(03/12)	IM
T5.4	Test/analysis (TEST/ANL) of the PW-detector based receiver prototype	data report	09/11	06/12	(06/12)	IM, MP
T5.5	Improvement and characterization of the receiver prototype	data report			(10/13)	IM, MP, SV
T6	**JP-initiative Wireless communication transmitter prototype based on PW/UTC-PD coherent sources and PW modulators**	**milestone**	06/12	09/12	(09/12)	OU, TU, IM
T6.1	Theory and modelling (TH/MOD) of the transmitter prototype system based on the PW/UTC-PD coherent sources and PW modulators	report	06/11	-	06/11	OU, TU
T6.2	Design (DSN) of the transmitter prototype system Based on the PW/UTC-PD coherent sources and PW modulators	data	06/11	09/11	09/11	OU, TU, IM
T6.3	Fabrication (FAB) and integration (INTEG) of the transmitter prototype system Based on the PW/UTC-PD coherent sources and PW modulators	prototype	09/11	06/12	(06/12)	OU, TU, IM
T6.4	Test/analysis (TEST/ANL) of the communication prototype system based on the PW/UTC-PD coherent sources and PW modulators	data report	06/12	09/12	(09/12)	OU, TU
T7	**JP-FR co-initiative Wireless communication prototype test**	**milestone**	03/13	-	(03/13)	OU, IM, TU, MP, SV, RK

No.	Designation	Nature*	Date of supply			Partners (underline the responsible partner)
			Initially planned	Re-scheduled	Deliv-ered	
	with data rate of over 40 Gbit/s					
T7.1	Integration (INTEG) of the transmitter/receiver prototype systems	prototype	03/13	12/12	(12/12)	OU, IM, TU, MP, SV, RK
T7.2	Test/Analysis (TEST/ANL) of the Communication Prototype/system with 40-Gbit/s-class Data Rate	data report	03/13	-	(03/13)	OU, IM, TU, MP, SV, RK
T7.3	Reconstruction and characterization of the prototype/system	data report			(11/13)	IM, MP, SV, OU, TU, RK

C PROGRESS REPORT

C.1 INITIAL OBJECTIVES OF THE PROJECT

This program is devoted to stimulate the Japanese-French initiative on innovative plasmonic nano-device technologies for ultra-broadband ubiquitous wireless communications using "terahertz (THz)" waves. Showing the feasibility and making the first prototype for world-record beyond-40-Gbit/s class ultra-broadband wireless communication which works in an unexplored frequency band ranging from 400 to 900 GHz is one of the main goals of the present project. In order to reach the necessary device performance, we propose two parallel strategies that will be compared before building the prototypes: 1) breaking through the speed limit on conventional carrier transit-type electron devices, by introducing two-dimensional plasma nanotransistors to simultaneously realize i) frequency-tunable, room-temperature operating coherent monochromatic THz sources, ii) fast, coherent detection/down-conversion of coded THz carrier waves, and iii) 10-100-Gbit/s intensity modulators for THz carrier signals and 2) improvement of the most promising pure-electronic devices, i.e. uni-traveling carrier photodiodes (UTC-PDs) as an alternative THz source.

C.2 WORK PERFORMED AND RESULTS ACHIEVED IN THE FIRST HALF PERIOD

The progress in Japan Teams of JST-ANR WITH project concerns (i) development of plasma-wave (PW) key devices (detectors, sources, and modulators) headed by Tohoku Univ. Group (TU), (ii) building up a 20-40-Gbit/s class wireless transmission setup and transmission experiment using the setup headed by Osaka University Group (OU), and (iii) building up and characterization of 400-600-GHz class test systems headed by Riken Group (RK).

TU developed a new type of highly efficient PW transistor structure featured by an asymmetric dual-grating gate (A-DGG) in collaboration with CNRS-Montpellier Group (MP), Riken Group (RK) and other collaborators in Russia and Spain. The structure can work for all the key devices of detectors, sources, and modulators and drastically improve the plasmon excitation efficiency. Based on the collaborative design work by TU and MP, TU fabricated the test device using InAlAs/InGaAs/InP material systems. RK helped TU characterize the fabricated device at room temperature by providing a broadband coherent terahertz parametric oscillator source of their original, verifying a record responsivity 2.2 KW/V at 1 THz. The devices were then transferred to MP by three Japanese students of TU whom MP hosted for four weeks in Montpellier to investigate photoresponse of the new type A-DGG transistors. Montpellier Group (MP) took an initiative for experimental work of the device characterization. Clear resonant-mode detection operation was verified at cryogenic temperature, testifying its unique operation principle due to its complex A-DGG structure. Architecture of these transistors is protected by a

common patent. The A-DGG transistor was post-processed to implement a vertical high Q cavity structure that should work for injection-locked THz oscillation as a PW source and currently under characterization.

OU built up a dedicated 300-400-GHz wireless transmission test system using state-of-the-art traditional-type photonic device technologies in the transmitter as the 1st step to the final goal of THz wireless communication using plasmonic nano-devices. The transmitter and receiver consist of a UTC-PD, an alternative source of the PW one, and a Schottky barrier diode (SBD), an alternative detector of the PW one, respectively. So far >20-Gbit/s, 500-mm error-free transmission was succeeded in at a 300-GHz carrier frequency in the simplest ASK (Amplitude-Shift Keying) format, which is a world record in the 300-GHz band wireless link. The system could be upgraded to 40-Gbit/s transmission using PW sources/detectors/modulators, which will be the next step. Development on high-gain arrayed antenna and arrayed photodides was also progressed.

RK built up 400-600-GHz class measurement systems for testing PW devices. An injection-seeded THz parametric generator (is-TPG) as the sub-THz pulse source and various types of detectors like DLATGS and PM as the sub-THz detector were implemented and calibrated to ready for use. For 600-GHz characterization, a heterodyne detection system was newly built to precisely characterize the generation/modulation signal properties from the transmitter test bed to be constructed by OU and TU.

The progress in France teams of JST-ANR WITH project concerns mainly first experiments both in sub-THz and THz wireless links. While waiting for the first InGaAs FETs, two sub-THz experiments were conducted. First, a UTC-PD 300-GHz emitter signal was successfully detected using a Plasma Wave Silicon MOSFETs (IM-UM collaboration). Two well-defined communication bands were determined (135 GHz & 270 GHz) related to resonant antenna effects of the receiver. Also, a simplest data and sound transmission was realized over 1 m using a VDI (Virginia Diode Inc.) electronic source at 300 GHz (UM), thus showing that sub-THz wireless communication using Plasma Wave Detectors is possible. These results were presented at TeraNano & GDRI Osaka 2011 Conference. In the THz range, a clock-transmission spectrally-resolved experiment scheme was implemented at 654 GHz in order to characterize components bandwidth up to 20–40 GHz.

The team from U. Savoie, Chambery (SV), prepared time-domain experiments for characterizing the temporal and thus the spectral response of plasma wave detectors over a large frequency range. Experiments were not conclusive because the THz radiation induced signal was hidden by noise. These experiments allowed however identification of the noise sources and define the architecture of new low-noise experimental set-up and devices. A characterization set-up based on semiconductor surface assisted THz emission showing a noise level of 25 $nV/Hz^{0.5}$ has been developed.

Montpellier team (MP) has shown how one can predict/calculate the plasma detector signal from the transfer characteristics and established the role of the load resistances and the capacitances of the read out circuit in signal recovery. It was also shown that by cooling the detector to cryogenic temperatures one can improve the detector performances by more than one order of magnitude. MP has also shown in collaboration with OU group, the detection of a 8 GHz modulation frequency carried by 0.3-THz wave, using a GaAs based plasma wave detector and a uni-travelling-carrier photodiode as a source.

Lille team (IM) made an important progress in antennas simulation and masks design of the future InGaAs based detectors. One of the major achievements on France-Japan international collaborative research is the development of ultrahigh-sensitive broadband plasma-wave detectors featured by a newly-invented asymmetric dual-grating gate (A-DGG) structure.

C.3 WORK FORECAST IN THE SECOND HALF PERIOD

As is described in C.2, we Japan and France collaborative teams worked for (i) development of the PW-based key devices of detectors, sources and modulators as well as UTC-PD photomixer sources and (ii) development of high-speed wireless communication front-end hardware systems operating at carrier frequencies beyond 300 GHz. The followings are the work forecast in the next second half period.

(i) Development of the key devices

So far the PW detectors have been successfully fabricated demonstrating excellent performance based on an excellent France-Japan collaboration. The next step is to improve the response speed to make 40-Gbit/s real-time data acquisition. The high-impedance output of the PW detector should be transferred into 50-ohm matched interface via a monolithically integrated transimpedance amplifier. The PW photomixer source test chip has been fabricated and now under characterization. InP-based heterostructure material systems and high-Q vertical cavity structures are newly implemented features which are expected to bring the injection-locked coherent oscillation for the first time, which is a major subject in the second half period at TU and RK. Regarding the PW modulators, the fabricated test chips are now under characterization. Confirmation of the high-speed and high-extinction modulation for 600-900 GHz radiation is the major objective in the second half period at TU and RK. Regarding the UTC-PD photomixer sources, as an alternative source, their operating frequency bandwidth and output power will be improved so that they can be introduced into the 600-GHz carrier transmitter test bed, which is a major subject at IM, SV, and OU.

(ii) Development of the wireless communication test bed prototype systems

In order to maximize the achievement of this project while minimising the risk under the allowable three-year term limit, the followings are the strategy and workforce in the next second half period.

1. Carrier frequency is to be set in an unexplored range from 400 to 900 GHz
2. Development of the test bed at both the JPN and FRN sides will be under complementary/ co-lateral collaboration
3. Test bed at FRN side: wireless communication receiver prototype based on
   - plasmon HEMT detector (FRN initiative)
   - IM is in charge of the test bed construction and its system test/characterization.
   - MP is responsible for implementation/arrangement of the PW detector modules.
   - Experiment at 20 - 40 Gbit/s with 300 and 650 GHz carriers (FRN initiative).
4. Test bed at JPN side: wireless communication transmitter prototype based on PW/UTC-PD coherent sources and PW modulators
   - TU provides PW photomixer and modulator (JPN initiative)
   - MP supplies PW detectors (FRN supplied)
   - OU prepares a traditional photonic-based transmitter frontend using UTC-PDs (provided by IM) and optical modulators as an alternative for risk-task management (JPN initiative, FRN supplied)
   - Experiment at 30 - 40 Gbit/s with 600-900 GHz carrier (JPN initiative)
5. Unify the above two systems to maximize the performance/scheduled as the final milestone
   - To integrate FRN and JPN device technologies.
   - JP-FR co-initiative wireless communication prototype test to demonstrate the record beyond 40-Gbit/s transmission

C.4 DIFFICULTIES ENCOUNTERED AND SOLUTIONS

TU and RK were damaged by the East-Japan Quake disaster in March 2011. RK was relatively less damaged but TU was severely damaged. Thanks to the financial support by JST and MEXT, Japan, damaged measurement instruments could be renewed but about 6 months were lost for the recovery. Now most of the facility in TU has been recovered and now TU team made an extensive effort to recover the delay of the WITH project schedule. We hope that we still have big chance to achieve the original goal of this project within the three-year framework.

French partners were mostly delayed by administrative procedures. As funding was not available before the attributing-act delivery, itself delayed by the consortium agreement signature, funding was not available before April 20, 2011 (i.e., 3 month after the already-postponed project official start).

C.5 SIGNIFICANT EVENTS AND RESULTS

1. WITH Kick-Off Meeting at Japan side
Date: 2010/07/09-10, Venue: Akiu, Sendai, Japan, number of attendees: 11
Summary: This was a first-time meeting to kick off this WITH project at Japan side. The main objective was to review and share the original WITH project objectives/methods/milestones/goals.

2. Site visit of PO, Prof. Yonezawa to Sendai site of PI, Prof. Otsuji
Date: 2010/10/05, Venue: Otsuji Laboratory, Research Inst. of Electrical Communication, Tohoku University, Sendai, number of attendees: 5 (including Prof. Asada at Tokyo Tech., the Advisory Board Member, and Mr. T. Hasegawa, JST Officer)
Summary: Prof. Yonezawa, the PO of this JST-ANR program, Prof. M. Asada, the advisory board member of this JST-ANR WITH project, and a JST officer visited the Tohoku Univ. site of Prof. Otsuji, the PI of this WITH project. The main objective was to check the facility and research environment with which this JST-ANR WITH big project can be surely performed.

3. France-Japan WITH Kick-Off Meeting
Date: 2010/09/28-29, Venue: France National Observatory in Paris, number of attendees: 25
Summary: This was a first-time meeting to kick off this WITH project all together with French and Japanese researchers. The main objective was to review and share the original WITH project objectives/methods/milestones/goals. Technical discussion based on the presentations by principal investigators/collaborators was another further important result.

4. International Workshop of the GDRI Semi-conductors Sources and Detectors of THz Radiation and cooperated 2nd WITH Meeting
Date: 2011/03/29-04/02, Venue, Tignes, France, number of attendees: 80
Summary: European-oriented international research alliance on terahertz science and technology called GDRI: Groupement de Recherche International organized an international workshop. Most of the WITH project members involved in the GDRI alliance. The workshop was held to present the latest achievements and progresses on the THz research field which is close related to this WITH project. The collocated WITH Meeting was planned to join all the WITH French and Japanese members to check the present status and to discuss the subjects. Unfortunately due to the East-Japan Quake and Tsunami Disaster most of the Japanese members could not attend. So it became a kind of France-side meeting.

5. 3rd France-Japan WITH Meeting
Date: 2011/11/26, Venue: Nakanoshima Center Building, Osaka University, number of attendees: 18
Summary: This was the 3rd technical meeting. The main objective was to present the current progress and status of each team in France and Japan and to share the idea of achievements, milestones, difficulties, and any needs for update of planning.

C.6 WORK SPECIFIC TO THE COMPANIES (WHERE APPLICABLE)

Tohoku University

Company	Tohoku University
Author (name + e-mail address)	Taiichi OTSUJI, Email:

TU developed a new type of highly efficient PW transistor structure featured by an asymmetric dual-grating gate (A-DGG) in collaboration with CNRS-Montpellier Group (MP) and other collaborators in Russia and Spain. The structure can work for all the key devices of detectors, sources, and modulators and drastically improve the plasmon excitation efficiency. Based on the collaborative design work by TU and MP, TU fabricated the test device using InAlAs/InGaAs/InP material systems. RK helped TU characterize the fabricated device at room temperature by providing a broadband coherent terahertz parametric oscillator source of their original, verifying a record responsivity 2.2 KW/V at 1 THz. The devices were then transferred to MP by three Japanese students of TU whom MP hosted for two weeks in Montpellier to investigate photoresponse of new type A-DGG transistors. Montpellier Group (MP) took an initiative for experimental work of the device characterization. Clear resonant-mode detection operation was verified at cryogenic temperature, testifying its unique operation principle due to its complex A-DGG structure. Architecture of these transistors is protected by a common patent. The A-DGG transistor was post-processed to implement a vertical high Q cavity structure that should work for injection-locked THz oscillation as a PW source and currently under characterization.

OSAKA University

Company	Osaka University
Author (name + e-mail address)	Tadao NAGATSUMA, Email:

OU built up a dedicated 300-400-GHz wireless transmission test system using state-of-the-art traditional-type photonic device technologies in the transmitter as the 1st step to the final goal of THz wireless communication using plasmonic nano-devices. The transmitter and receiver consist of a UTC-PD, an alternative source of the PW one, and a Schottky barrier diode (SBD), an alternative detector of the PW one, respectively. So far >20-Gbit/s, 500-mm error-free transmission was succeeded in at a 300-GHz carrier frequency in the simplest ASK format. The system is expected to be upgraded to 40-Gbit/s transmission using PW sources/detectors/modulators, which will be the next step. In particular, it was experimentally confirmed that the performance of preamplifier for detectors would be the most important to increase the bit rate. Development on high-gain arrayed antenna and photodiode arrays was also progressed in order to increase the transmission distance.

RIKEN

Company	RIKEN
Author (name + e-mail address)	Chiko OTANI, Email:

RK built up 400-600-GHz class measurement systems for testing PW devices. An injection-seeded THz parametric generator (is-TPG) as the sub-THz pulse source and various types of detectors like DLATGS and PM as the sub-THz detector were implemented and calibrated to ready for use. For 600-GHz characterization, a heterodyne detection system was newly built to precisely characterize the generation/modulation signal properties from the transmitter test bed to be constructed by OU and TU.

High-output-power injection-seeded THz-wave parametric generator (is-TPG) is developed for calibration of THz-wave detector. The generated output of THz-wave radiation from the is-TPG attained to around 100-W peak power. Typically, the sensitivity of THz-wave detector performing at room temperature is poor. Then, higher output in THz-wave source is required. The results of over 100-W THz-wave source provide THz radiation can be directly detected by commercial power-meter or detectors with calibration. Consequently, we have been establishing the traceable calibration procedure of any THz detector using this source. In practice, the output from is-TPG was measured using the calibrated pyro-electric detector (SPI-A-65THz) provided by Spectrum detector Inc. As result, we obtained the peak power around 140-W at 1.8 THz. The result is roughly consistent with that obtained with our calibrated Si bolometer within a factor of ~2. Cross calibration with Erickson's power-meter, DLATGS and LT (Molectron) pyroelectric detectors were also checked and they are all consistent with each other within a factor of ~2. The methodology and the limitation of the calibrational work were also examined. RK took initiative for characterizing the TU-designed and fabricated A-DGG HEMT plasma-wave detector devices by introducing their original TPG terahertz tunable light source and proved the record sensitivity of 2.2 KW/V at 1 THz at room temperature.

Université. Montpellier

Company	Université de Montpellier
Author (name + e-mail address)	Wojciech KNAP, Email:

MP realized first experiments on sub-THz wireless communication with the use of Plasma Wave Detectors. Data and sound were successfully transmitted over 1 m using available Si MOSFETs. A THz spectrally-resolved bench was also realized in order to transmit clock signals at frequency up to 20–40 GHz carried at 650 GHz, thus allowing for bandwidth characterization of source/modulator/detector.

MP has also shown how one can predict/calculate the plasma detector signal from the transfer characteristics and established the role of the load resistances and the capacitances of the read modulator/detector. It was also shown that by cooling the detector to cryogenic temperatures one can improve the detector performances by more than one order of magnitude.

MP has also shown in collaboration with OU group, the detection of a 8 GHz modulation frequency carried by 0.3-THz wave, using a GaAs based plasma wave detector and a uni-travelling-carrier photodiode as a source.

MP has also measured a non-resonant detection signal at 300 GHz in standard GaAs/InP HEMTs as well as in asymmetric DGG structures as a function of different parameters (Vg, L, azimuthal angle), and has shown the real time imaging capabilities of the A-DGG structures at room temperature. MP has also performed emission experiments analysed by Fourier transform

spectroscopy using DGG structures at 300 K. A resonance around 2.1 THz and a threshold-like behaviour as a function of applied drain voltage have been observed.
Finally, MP also developed an analytical model describing plasma frequencies in gated semiconductor slabs, showing that no plasma modes with frequency higher than the 3D plasma frequency could be sustained. Small-signal response and noise spectra of InGaAs HEMTs was also calculated using hydrodynamic and Monte Carlo models, and did show evidence of plasma-waves. Resonant terahertz emission optically excited in InGaAs HEMT channels were also simulated.

CNRS-Grenoble INP-Université de Savoie

Company	CNRS-Grenoble INP-Université de Savoie
Author (name + e-mail address)	Jean-Louis COUTAZ, Email:

The team from U. Savoie, Chambery (SV) prepared experiments in view of testing the temporal and spectral responses of plasma wave detectors. Such a characterization is based on time-domain spectroscopy (TDS). As plasma wave transistors are energy detectors, they integrate the incoming TDS THz pulse and thus their time-response can only be achieved by performing autocorrelation measurements in a THz interferometric set up. This set up has been built and evaluated with commercial THz photoswitch emitters and detectors (supplied by GigaOptics and Teravil): it exhibits a 3-THz bandwidth, with a 60-dB dynamics. First characterization of plasma wave transistors was not conclusive because the THz radiation induced signal was hidden by noise. These experiments allowed however identification the noise sources and define the architecture of new low-noise experimental set-up and devices. Also, it is planned to study other THz energy detectors (Schottky diode supplied by IEMN-Lille and room temperature microbolometers supplied by CEA-LETI) in order to compare their respective performances with the plasma transistor ones. For testing detectors that are strongly sensitive to parasitic signals emitted by the photoswitch emitter an alternative way of generating broadband THz pulse without electrical parasitic signals has been developed. Here the generation process is based on semiconductor surface assisted THz generation and the complete set-up tested with shielded HEMT PW detectors has shown a total noise level of 25 $nV.Hz^{0.5}$. Further improvement of the average THz emitted and detected power is under achievement.

IEMN: Institut d'Electronique de Micro-électronique et de Nanotechnologie

Company	IEMN: Institut d'Electronique de Microélectronique et de Nanotechnologie
Author (name + e-mail address)	Jean-Francois LAMPIN, Email:

IEMN-Lille team (IM) made a millimeter-wave wireless transmission experiment using a UTC-PD emitter and mixer integrated with a horn antenna. Two well defined communication bands were determined at ~135 GHz and ~270 GHz related to resonant antenna effects in the receiver response. The experiment clearly demonstrated that sub-THz wireless communication with the use of Plasma Wave Detectors is possible. The results are presented during TeraNano & GDRI Osaka 2011 Conference. IM has also made the demonstration of bonding of photoconductors on silicon substrates with excellent results, the next step is demonstrate the same approach with

UTC-PD. IM also made an important progress in antennas simulation and masks design of the future InGaAs based detectors. Concerning task 5, slot ring antenna has been optimized with electromagnetic software to design the proper supply voltage circuit, as the antenna acts as the DC access of gate voltage to perform the control of the resonant frequency of the detector. We used MIM capacitance to isolate RF and DC signals and air-bridge technology. Moreover a matching circuit was designed between the antenna and the plasma detector, and coplanar waveguide access was introduced to support the 40Gbit/sec communication rate. Detector were fabricated (figure 1) with high yield process (90%). In the near future, these detectors should be inserted in specific package to perform the THz characterization.

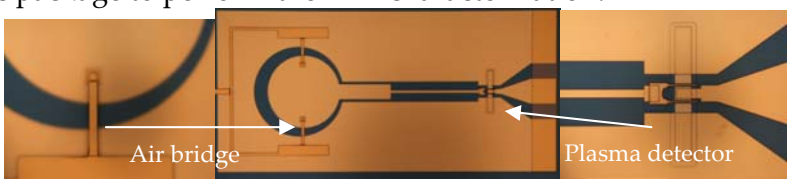

Figure 1 Fabricated plasma wave detector with mtching slot ring antenna

C.7 CONSORTIUM MEETINGS (COLLABORATIVE PROJECTS)

Date	Place	Partners present	Subject of the meeting
2010/07/09-10	Akiu, Sendai, Japan	**TU**: T. Otsuji, A. Satou, S. Boubanga Tombet, **RK**: C. Otani, M. Yamashita, Y. Yamada, H. Ito, H. Minamide, **OU**: T. Nagatsuma, M. Tonouchi, **JST**: T. Hasegawa	**WITH Kick-Off Meeting at Japan side** This was a first-time meeting to kick off this WITH project at Japan side. The main objective was to review and share the original WITH project objectives/methods/milestones/goals.
2010/09/28-29	France National Observatory in Paris	**TU**: T. Otsuji, A. Satou, S. Boubanga Tombet, A. Moutaouakil, T. Watanabe, **OU**: T. Nagatsuma, M. Tonouchi, **RK**: C. Otani, **JST**: T Hasegawa **MP**: W. Knap, D. Coquillat, N. Dyakonova, **SV**: J.-L. Coutaz, B. Patin **IM**: S. Bollaert, Y. Rollens, D. Guillaume	**France-Japan WITH Kick-Off Meeting** The main objective was to review and share the original WITH project objectives/methods/milestones/goals. Technical discussion based on the presentations by principal investigators/collaborators was another further important result.
2011/04/01-02	Tignes, France	**MP**: W. Knap, D. Coquillat, F. Teppe, J. Torres, P. Nouvel **SV**: J.-L. Coutaz, E. Herault, M. Kuppam, J.-F. Roux **IM**: J.-F. Lampin **TU**: S. Boubanga Tombet	**2nd France-Japan WITH Meeting** Collocated to the Int. GDR-I THz Workshop. The meeting was planned to join all the WITH French and Japanese members to check the present status and to discuss the subjects. Unfortunately due to the East-Japan Quake and Tsunami Disaster most of the Japanese members could not attend. So it was limited to the European partners of the GDR-I.
2011/11/26	Nakanoshi	**TU**: T. Otsuji, A. Satou	**3rd France-Japan WITH Meeting**

Date	Place	Partners present	Subject of the meeting
	ma, Osaka, Japan	**OU**: T. Nagatsuma, M. Tonouchi, **RK**: C. Otani, H. Minamide, H. Ito, M. Yamashita, A. Dobroiu **JST**: C. Inamura **MP**: W. Knap, D. Coquillat, Muriel Bernard, **SV**: J.-L. Coutaz, **IM**: J.-F. Lampin	The main objective was to present the current progress and status of each team in France and Japan and to share the idea of achievements, milestones, difficulties, and any needs for update of planning.

C.8 FREE COMMENTS

Comments from the French/Japanese coordinators (PIs)

French coordinator: W. Knap
The administrative and natural disaster delays have consequence mainly on technological development of plasma wave sources and modulators. To show successful data transmission at 40-Gb/s (that is the main objective) the project should concentrate on development plasma wave detectors. The improved UTC-PD sources should be considered as the main candidates for sources in the final communication prototypes.

Japanese coordinator: T. Otsuji
Thanks to the France team's development on alternative sources by using UTC-PDs we Japan team could take a risk to pursue the original goal of development of PW sources and modulators. Although East-Japan quake disaster caused about 6-months stop of the research activity (particularly in TU) we still have an optimistic prospect to be able to supply our PW sources/modulators to the final stage of the test-bed integration and wireless transmission experiments. One unfortunate thing is the delay of the starting time at France side. According to this delay Japan side has extended the research duration till 2013 FSY, one year longer than the original, but no additional financial support will be provided at this moment. So effectively we Japan side cannot continue (and have to terminate) the research work after (within) the original term of 2012 JPN-FSY (31/03/2013) due to the limited budgetary situation. We would very much appreciate it if JST could financially support the extended duration of 2013 FSY. Also we would very much appreciate it if JST/ANR could support the post-WITH collaborative work by a kind of follow-on program.

Comments from the other cooperate researchers

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Question(s) posed to the ANR/JST

- Considering the delays can we limit the demonstration of the communication systems to the UTC-PD sources and plasma wave detectors? Or shall we consider getting more time to develop the plasma wave based source and modulator components? (by W. Knap)

- I do not think that ANR/JST will have concrete plan to provide any continual financial support

after this WITH project in their existing frameworks. We should once terminate our project within the project term with results of our best-effort. We both Japan and France members are very proud of our scientific achievement in this WITH project. I would very much appreciate it if ANR/JST could consider this situation and give us any practical solution. (by T. Otsuji)

D PROJECT VALORIZATION AND IMPACT SINCE BEGINNING

D.1 PUBLICATIONS AND COMMUNICATIONS

<**Joint**> Multinational Joint Papers, etc

List of the Multinational publications (resulting from jointly conducted work)		
International	**Peer-reviewed journals**	1. V.V. Popov, D.V. Fateev, T. Otsuji, Y.M. Meziani, D. Coquillat, W. Knap, "Plasmonic terahertz detection by a double-grating-gate field-effect transistor structure with an asymmetric unit cell," **Appl. Phys. Lett.**, Vol. 99, Iss. 24, pp. 243504-1-4, 2011. 2. T. Otsuji, T. Watanabe, A. El Moutaouakil, H. Karasawa, T. Komori, A. Satou, T. Suemitsu, M. Suemitsu, E. Sano, W. Knap, and V. Ryzhii, "Emission of terahertz radiation from two-dimensional electron systems in semiconductor nano- and hetero-structures," **J. Infrared Milli. Terahertz. Waves**, Vol. 32, No. 5, pp. 629-645, 2011. 3. W. Knap, S. Nadar, H. Videlier, S. Boubanga-Tombet, D. Coquillat, N. Dyakonova, F. Teppe, K. Karpierz, J. Łusakowski, M. Sakowicz, I. Kasalynas, D. Seliuta, G. Valusis, T. Otsuji, Y. Meziani, A. El Fatimy, S. Vandenbrouk, K. Madjour, D. Théron, C. Gaquière, "Field Effect Transistors for Terahertz Detection and Emission," **J. Infrared Milli. Terahertz Waves**, Vol. 32, No. 5, pp. 618-628, 2010. 4. A. El Moutaouakil , T. Suemitsu, T. Otsuji, H. Videlier, S.e-A.n Boubanga-Tombet, D. Coquillat, and W. Knap, "Device loading effect on nonresonant detection of terahertz radiation in dual grating gate plasmon-resonant structure using InGaP/InGaAs/GaAs material systems," **Phys. Stat. Solidi.**, Vol. 8, No. 2, pp. 346–348, 2011. 5. T. Otsuji, "Terahertz emission, detection and modulation using two-dimensional plasmons in high-electron-mobility transistors featured by a dual-grating-gate structure," **PIERS Online**, Vol. 7, No. 1, pp. 1-6, 2011. 6. S. Boubanga-Tombet, F. Teppe, J. Torres, A. El Moutaouakil, D. Coquillat, N. Dyakonova, C. Consejo, P. Arcade, P. Nouvel, H. Marinchio, T. Laurent, C. Palermo, A. Penarier, T. Otsuji, L. Varani, and W. Knap, "Room temperature coherent and voltage tunable terahertz emission from nanometer-sized field effect transistors," **Appl. Phys. Lett.**, Vol. 97, Iss. 26, 262108 (3 pages), 2010. 7. T. Otsuji, H. Karasawa, T. Watanabe, T. Suemitsu, M. Suemitsu, E. Sano, W. Knap, and V. Ryzhii, "Emission of terahertz radiation from two-dimensional electron systems in semiconductor nano-heterostructures," **Comptes Rendus Physique**, Vol. 11, Iss. 7-8, pp. 421-432, 2010.
	Books or chapters in books	(none)
	Communications (conferences)	1. T. Watanabe, S. Boubanba Tombet, Y. Tanimoto, Yuy.e Wang, H. Minamide, H. Ito, D. Fateev, V. Popov, D. Coquillat, W. Knap, and T. Otsuji, "Ultrahigh sensitive plasmonic terahertz detector based on an asymmetric dual-grating gate HEMT structure," ISDRS 2011: International Semiconductor Device Research Symposium, Univ. Meryland, MD, USA, Dec. 7-9, 2011. 2. V. V. Popov, D. V. Fateev, T. Otsuji, Y. M.Meziani, D. Coquillat, W. Knap, "Plasmonic Terahertz Ratchet Effect in a Periodically Gated 2D Electron System," International TeraNano &GDRI Workshop, Osaka, Nov. 2011. (invited) 3. T. Otsuji, T. Watanabe, K. Akagawa, Y. Tanimoto,T. Suemitsu, V. Ryzhii, D. Coquillat, W. Knap, "New semiconductor materials and devices for terahertz imaging and sensing," IEEE SENSORS Conference, A1L-C-1196, Limerick, Ireland, Oct. 28-31, 2011. (invited) 4. J. Torres, F. Teppe, P. Nouvel, S. Boubanga-Tombet, A. El Moutaouaki, D. Coquillat, N. Dyakonova, C. Palermo, W. Knap, L. Varani, T. Ostuji, E. Starikov, P. Shiktorov, V. Gružinskis, Y. Roelens, A. Shchepetov, S. Bollaert, "Terahertz emission from optically excited plasma ocsillation in HEMTs," EDISON17: 17th International Conference on Electron Dynamics in

		Semiconductors, Optoelectronics and Nanostructures, M2.4, Santa Barbara, Aug. 7-12, 2011. 5. S.A. Boubanga Tombet, T. Otsuji, and W. Knap, "Coherent and tunable terahertz emission from nano-metric field effect transistor at room temperature," CLEO: Conference on Lasers and Electro-Optics, CMW4, Baltimore, ML, USA, May 1-7, 2011. 6. T. Watanabe, K. Akagawa, Y. Tanimoto, D. Coquillat, W. M. Knap, and T. Otsuji, "Terahertz imaging with InP high-electron-mobility transistors," SPIE Defense, Security & Sensing, Proc. SPIE, Vol. 8023, iss. 8023-25, Orlando, FL, USA, April 24-27, 2011. 7. A. El Moutaouakil, D. Coquillat, W. Knap, T. Suemitsu, and T. Otsuji, "Gate fingers and device loading effect on terhartz detection from dual grating gate plasmon-resonant structure using InGaP/InGaAs/GaAs material systems," PIERS: Progress in Electromagnetics Research Symposium, 3P2-8, Marrakesh, Morroco, March 20-23, 2011. (invited) 8. Y. M. Meziani, E. Velazquez; E. Diez, N. Dyakonova, W. Knap. A. El Moutaouakil, K. Fobelets, T. Otsuji, "Detection of terahertz radiation from strained silicon modulation field effect transistor," PIERS: Progress in Electromagnetics Research Symposium, 3P2-4, Marrakesh, Morroco, March 20-23, 2011. (invited) 9. S Boubanga-Tombet, F. Teppe, J. Torres, W.Knap and T. Otsuji, "Coherent and tunable terahertz emission from nano-metric field effect transistor at room temperature," OTST: Int. Conf. on Optical Terahertz Science and Technology, MF41, Santa Barbara, CA, USA, March 13-17, 2011. 10. V.V. Popov, D.V. Fateev, T. Otsuji, Y.M. Meziani, D. Coquillat, and W. Knap, "Plasmonic detection of terahertz radiation in a double-grating-gate transistor structure with an asymmetric unit cell," Proc. International Symposium on Nanophysics and Nanoelectronics, pp. 121-122, Avtomobilist resort, Nizhny Novgorod, Russia, March 14-18, 2011. 11. S. Boubanga Tombet, F. Teppe, W. Knap, and T. Otsuji, "Terahertz detection by field effect transistors: from non-resonant to resonant detection," EOS Annual Meeting, TOM2_3645_02, Paris, France, Oct. 27, 2010. 12. T. Otsuji and W. Knap. "Wireless communication using terahertz plasmonic-nano ICT devices," GDR-I Workshop on Terahertz Science and Technology, Paris, France, Sept. 27-28, 2010. (invited) 13. A. El Moutaouakil, T. Suemitsu, T. Otsuji, D. Coquillat, and W. Knap, "Nonresonant detection of terahertz radiation in high-electron mobility transistor structure using InAlAs/InGaAs/InP material systems at room temperature," ANM2010: 3rd Int. Conf. on Advanced Nano Materials, ANMM169, Agadir, Morocco, September 12-15, 2010. 14. S. Boubanga Tombet, W. Knap, and T. Otsuji, "Field effect transistors for fast terahertz detection and imaging," 35th International Conference on Infrared, Millimeter and THz Waves, Tu-P.25, Rome, Italy, Sept. 6-11, 2010. 15. A. El Moutaouakil, T. Suemitsu, T. Otsuji, D. Coquillat, and W. Knap, "Room temperature terahertz detection in high-electron-mobility transistor structure using InAlAs/InGaAs/InP material systems," 35th International Conference on Infrared, Millimeter and THz Waves, Tu-D3.5, Rome, Italy, Sept. 6-11, 2010. 16. Nina Dyakonova, A. El Fatimy, Y. Meziani, T. Otsuji, D. Coquillat, W. Knap, F. Teppe, S. Vandenbrouk, K. Madjour, D. Theron, C. Gaquiere, M.A. Poisson, S. Delage, "Tunable room temperature THz emission from AlGaN/GaN high electron mobility transistors," 35th International Conference on Infrared, Millimeter and THz Waves, Tu-C1.4, Rome, Italy, Sept. 6-11, 2010. 17. Amine El Moutaouakil, Tetsuya Suemitsu, Taiichi Otsuji, Hadley Videlier, Dominique Coquillat, Wojciech Knap, "Device loading effect on nonresonant detection of terahertz radiation in dual grating gate plasmon-resonant structure using InGaP/InGaAs/GaAs material systems," ISCS: Int. Symp. Compound Semicond. Dig., WED3-5, p. 274, Takamatsu, Japan, May 31-June 4, 2010.
France	**Peer-reviewed journals**	(none)
	Books or chapters in books	(none)
	Communications (conferences)	1. R. Paquet, D. Lapeine, S. Blin, J.-P. Guillet, P. Nouvel, J. Torres, A. Pénarier, L. Varani, P. Solignac, D. Coquillat, F. Teppe and W.

		Knap, "First Communication Link Using a 300-GHz Source and a Si Plasma-wave Detector," International TeraNano & GDRI Workshop, Osaka, Nov. 2011
Japanese	**Peer-reviewed journals**	(none)
	Books or chapters in books	(none)
	Communications (conferences)	1. 谷本 雄大，Stephane Boubanga-Tombet，Yuye Wang，南出 泰亜，伊藤 弘昌，Denis Fateev，Viacheslav Popov，Dominique Coquillat，Wojciech Knap，尾辻 泰一, "非対称二重格子状ゲート電極を有する HEMT を用いたテラヘルツ波検出," 応用物理学会春季学術講演会, 早稲田, 東京, March 15-18, 2012. 2. 谷本雄大, Stephane Boubanga-Tombet, 渡辺隆之, Yuye Wang, 南出泰亜, 伊藤弘昌, Denis Fateev, Vyacheslav Popov, Dominique Coquillat, Wojciech Knap, 尾辻泰一, "非対称二重回折格子状ゲート電極を有する InAlAs/InGaAs/InP HEMT を用いた超高感度プラズモニッククテラヘルツ波検出器," 電子情報通信学会電子デバイス研究会, 信学技報 Vol. 111, No. 338, pp. 57-61, Dec. 15, 2011. 3. 渡辺隆之，，赤川啓介，谷本雄大，Knap Wojciech，Coquillat Dominique，Teppe Frederic，末光哲也，尾辻泰一, "InP 系高電子移動度トランジスタによるサブテラヘルツイメージング," 春季 第 58 回応用物理学関係連合講演会, 26a-BX - 2, 厚木, March 26, 2011.
Outreach initiatives	**Popularization articles**	(none)
	Popularization conferences	(none)
	Others	(none)

<French side> Single partner Papers, etc

List of single-partner publications (involving a single partner)		
International	**Peer-reviewed journals**	1. H. Marinchio et al., "Plasma resonances in a gated semiconductor slab of arbitrary thickness," **Appl. Phys. Lett.** Vol. 98, 203504 (2011) 2. E. Peytavit, C. Coinon, and J.F. Lampin, "A metal-metal Fabry-Pérot cavity photoconductor for efficient GaAs terahertz photomixers", **J. Appl. Phys.**, Vol. 109, 016101, 2011. 3. G. Ducournau, P. Szriftgiser, T. Akalin, A. Beck, D. Bacquet, E. Peytavit, and J.F. Lampin, " Highly coherent terahertz wave generation with a dual-frequency Brillouin laser and 1.55 μm photomixer", **Opt. Lett.**, Vol. 36, 2044, 2011. 4. E. Peytavit, C. Coinon, and J.F. Lampin, "Low-temperature-grown GaAs photoconductor with high dynamic responsivity in the millimetre wave", **Appl. Phys. Express**, Vol. 4, 104101, 2011. 5. E. Peytavit, S. Lepiliet, F. Hindle, C. Coinon, T. Akalin, G. Ducournau, G. Mouret, and J.F. Lampin, "Milliwatt-level output power in the sub-terahertz range generated by photomixing in a GaAs photoconductor", **Appl. Phys. Lett.**, Vol. 99, 223508, 2011.
	Books or chapters in books	(none)
	Communications (conferences)	1. R. Paquet, D. Lapeine, S. Blin, J.-P. Guillet, P. Nouvel, J. Torres, A. Pénarier, L. Varani, P. Solignac, D. Coquillat, F. Teppe and W. Knap, "First Communication Link Using a 300-GHz Source and a Si Plasma-wave Detector," International TeraNano &GDRI Workshop, Osaka, Nov. 2011 2. H. Marinchio et al., "Plasma Oscillations in Nanotransistors: Application to THz Radiations Detection and Generation," ACTA PHYSICA POLONICA A No. 2 Vol. 119, p. 103 (2011) 3. E. Starikov et al., "Small-Signal Characterization of FET/HEMT for Terahertz Applications," ACTA PHYSICA POLONICA A No. 2, Vol. 119, p. 203 (2011) 4. P. Shiktorov et al., "High-Frequency Noise in Modern FET/HEMT Channels Caused by the Excitation of 2D-Plasma Waves," ACTA PHYSICA POLONICA A No. 2 Vol. 119, p. 117 (2011)

		5. P. Nouvel et al., "THz Emission Induced by an Optical Beating in Nanometer-Length High-Electron-Mobility Transistors," ACTA PHYSICA POLONICA A No. 2 Vol. 119, p. 199 (2011) 6. G. Ducournau, P. Szriftgiser, T. Akalin, A. Beck, D. Bacquet, E. Peytavit, J.F. Lampin, "Dual frequency Brillouin laser and 1.55 μm photomixer for highly coherent THz wave generation", 36th International Conference on Infrared, Millimeter and THz Waves, IRMMW-THz 2011, Houston, TX, USA, October 2011. 7. P. Latzel, E. Peytavit, E. Dogheche, J.F. Lampin, "Improving properties of THz photoconductors by bonding to a high thermal conductivity substrate", 36th International Conference on Infrared, Millimeter and THz Waves, IRMMW-THz 2011, Houston, TX, USA, October 2011. 8. G. Ducournau, S. Blin, D. Coquillat, A. Beck, T. Akalin, E. Peytavit, F. Schuster, B. Giffard, J. Torres, F. Teppe, P. Nouvel, A. Pénarier, L. Varani, J.F. Lampin, and W. Knap, "UTC-PD emitters and FET based receivers for sub-THz wireless communications system", International TeraNano &GDRI Workshop, Osaka, Nov. 2011.
France	**Peer-reviewed journals**	(none)
	Books or chapters in books	(none)
	Communications (conferences)	(none)
Outreach initiatives	**Popularization articles**	(none)
	Popularization conferences	(none)
	Others	1. Teralab website including (mainly) WITH project : http://teralab.wordpress.com/

<Japanese side> Single partner Papers, etc

List of single-partner publications (involving a single partner)		
International	**Peer-reviewed journals**	1. Y.M. Meziani, E. Garcia, E. Velazquez, E. Diez, A. El Moutaouakil, T. Otsuji, and K. Fobelets, "Strained silicon modulation FET as a new sensor for terahertz radiation," **Semicond. Sci. Technol.**, Vol. 26, No. 10, pp. 105006-1-4, 2011. 2. A. El Moutaouakil, T. Komori, K. Horiike, T. Suemitsu, and T. Otsuji, "Room Temperature Intense Terahertz Emission from a Dual Grating Gate Plasmon-Resonant Emitter using InAlAs/InGaAs/InP Material Systems," **IEICE Trans. Electron.,** Vol. E93C, No. 8, pp. 1286-1289, 2010. 3. K. Akagawa, S. Fukuda, T. Suemitsu, T. Otsuji, H. Yokohama, G. Araki, "Impact of T-gate electrode on gate capacitance in In0:7Ga0:3As HEMTs," **Phys. Status Solidi. (c)**, Vol. 8, Iss. 2, pp. 300-302, 2011. doi: 10.1002/pssc.201000475 4. T. Nishimura, N. Magome, and T. Otsuji, "An intensity modulator for terahertz electromagnetic waves utilizing two-dimensional plasmons in dual-grating-gate high-electron-mobility transistors," **Jpn. J. Appl. Phys.**, Vol. 49, No. 5, pp. 054301-1-7, 2010. 5. Shin'ichiro Hayashi, Koji Nawata, Hiroshi Sakai, Takunori Taira, Hiroaki Minamide, and Kodo Kawase, "High-power, single-longitudinal-mode terahertz-wave generation pumped by a microchip Nd:YAG laser", **Optics Express**, in press. 6. T. Nagatsuma, "Challenges for Ultrahigh-Speed Wireless Communications Using Terahertz Waves," **J. Terahertz Science and Technology**, Vol. 3, No.2, pp.55-65, 2010. 7. H.-J. Song, N. Shimizu, Y. Kado, and T. Nagatsuma, "Photonic Generation of Continuous Terahertz Waves and its Application to Communications and Sensing," **Proc. SPIE**, Vol. 7763, pp. 776307-776307-10, 2010. 8. T. Kleine-Ostmann and T. Nagatsuma, "A Review on Terahertz Communications Research", **J. Infrared Milli. Terahertz. Waves**, Vol. 32, No. 2, pp. 143-171, 2011. 9. T. Nagatsuma, "Terahertz Technologies: Present and Future," **IEICE Electronics Express**, Vol.8, No.14, pp.1127-1142, July, 2011. 10. H.-J. Song and T. Nagatsuma, "Present and Future of Terahertz Communications," **IEEE Trans. Terahertz Science and Technology**, Vol. 1, No. 1, pp.256-263, Sept. 2011.

	Books or chapters in books	1. T. Nagatsuma and H. Ito, "Advances in Photodiodes: High-Power RF Uni-Traveling-Carrier Photodiodes (UTC-PDs) and Their Applications, ISBN 978-953-307-163-3, InTech , 2011.
	Communications (conferences)	1. T. Otsuji, "Emission and detection of terahertz dadiation using two-dimensional electrons in III-V semiconductors and graphene," International TeraNano &GDRI Workshop Extended Abstract, 28I-11, Osaka, Nov. 28, 2011. (invited) 2. Y. Tanimoto, T. Watanabe, A. Satou, T. Otsuji, "Terahertz Injection-Locked Oscillation in Plasmon-Resonant Transistors," International TeraNano &GDRI Workshop, Osaka, Nov. 2011. 3. T. Yoshida, K. Akagawa, T. Otsuji, and T. Suemitsu, "InGaAs HEMTs with T-gate electrodes fabricated using HMDS-SiN mold," 38th International Symposium on Compound Semiconductors, Berlin, Germany, May 22-26, 2011. 4. T. Otsuji, "Terahertz emission, detection and modulation using two-dimensional plasmons in high-electron-mobility transistors featured by a dual-grating-gate structure," PIERS: Progress in Electromagnetics Research Symposium Proceedings, 3P2-7, pp. 1266-1271, Marrakesh, Morocco, March 20-23, 2011. (invited) 5. Y.M. Meziani, E. Diez, E. Velazquez, K. Fobelets, A. El Moutaouakil and T. Otsuji, "Strained Silicon Modulation FET as New Sensor for Terahertz Radiation," ANM2010: 3rd Int. Conf. on Advanced Nano Materials, ANMM269, Agadir, Morocco, September 12-15, 2010. 6. T. Otsuji, "Emission of terahertz radiation from two-dimensional electron systems in semiconductor nano-heterostructures," 35th International Conference on Infrared, Millimeter and THz Waves," Th-D1.1, Rome, Italy, Sept. 6-11, 2010. (invited) 7. Y. Meziani, A. El Moutaouakil, E. Velazquez, E. Diez, K. Fobelets, T. Otsuji, "Terahertz photomixing in Strained Silicon MODFET," 35th International Conference on Infrared, Millimeter and THz Waves, Mo-P.53, Rome, Italy, Sept. 6-11, 2010. 8. T. Otsuji, M. Suemitsu, E. Sano, and V. Ryzhii, "Emission of Terahertz Radiation from Two-Dimensional Electron Systems in Semiconductor Nano-Heterostructures," VCIAN: Villa Conference on Interactions Among Nanostructures Abstracts, p. 22, Santorini, Greece, June 21-25, 2010. (Invited) 9. K. Akagawa, S. Fukuda, T. Suemitsu, T. Otsuji, H. Yokohama, G. Araki, "Impact of T-gate electrode on gate capacitance in In0:7Ga0:3As HEMTs," ISCS: Int. Symp. Compound Semicond. Dig., WED3-4, p. 273, Takamatsu, Japan, May 31-June 4, 2010. 10. A. Dobroiu, C. Otani, "Challenges in calibrating THz detectors and sources," The Joint Conference for International Symposium on Terahertz Nanoscience (TeraNano 2011) and Workshop of Internationlal Terahertz Research Network (GDR-I THz 2011), Osaka, November 24-29, 2011. 11. Kouji Nawata, Ming Tang, Takashi Notake, Yuye Wang, Hiromasa Ito and Hiroaki Minamide, "Widely tunable narrow-band terahertz-wave source pumped by injection-seeded optical parametric generation," CLEO 2011, Baltimore Convention Center, Baltimore, United States, 3 May 2011. 12. T. Notake, M. Tang, Y. Wang, K. Nawata, H. Ito, and H. Minamide, "Hybrid Terahertz-Wave Source with Ultra wideband Tenability utilizing Organic DAST and BNA Crystals," CLEO 2011, Baltimore Convention Center, Baltimore, United States, 5 May 2011. 13. Hiroaki Minamide, "Ultra-broadband Terahertz generation and detection using a nonlinear optical technique," The 2011 International Symposium on Microwave/Terahertz Science and Applications (MTSA 2011), T3-2, Nanjing, June 19 to 22, 2011. 14. Kouji Nawata, Atsushi Sato, Kazuhiro Asai , Hiromasa Ito and Hiroaki Minamide, "3.4 THz generation based on DAST-DFG pumped by an all solid-state dual-wavelength Nd:YAG laser," Nonlinear Optics 2011, Kauai, Hawaii, United States, 17 July 2011. 15. S.Hayashi, H.Sakai, T.taira, H.Minamide,K.Kawase," High-power Single-longitudinal-mode Terahertz-wave Generation Pumped by a Microchip Nd:YAG Laser," Nonlinear Optics 2011, Kauai, Hawaii, United States, 17-22 July 2011. 16. S.Hayashi, K.Nawata, H.Minamide, S. Takahashi, K.Kawase, "High-power, Single-longitudinal-mode, Widely-tunable Terahertz-wave Source," Joint Conference of International Symposium on Terahertz Nanoscience (TeraNano 2011) Workshop of Internationlal Terahertz Research Network (GDR-I), Osaka, Japan, 24-29 Nov. 2011. 17. H. Minamide, "High-peak-power Terahertz-wave generation and

		sensitive detection using nonlinear optical wavelength-conversion," Joint Conference of International Symposium on Terahertz Nanoscience (TeraNano 2011) Workshop of Internationlal Terahertz Research Network (GDR-I), Osaka, Japan, 24-29 Nov. 2011. 18. T. Nagatsuma, "Applications of Terahertz Photodiodes to Communications and Sensing," 7th-Asia-Pacific Laser Symposium (APLS), Th-E1-1, Jeju, May 11-15, 2010.(Invited) 19. T. Nagatsuma, "Technology Trend of Telecommunications above 120 GHz," Asia Pacific Telecommunity, 17th APT Standardization Program Forum (ASTAP-17), Pataya, Tai, 5-9 July, 2010. (Invited) 20. H.-J. Song and T. Nagatsuma, "Photonic Generation of Continuous Terahertz Waves and its Application to Communications and Sensing," SPIE Optics+Photonics Meeting, San Diego, 1-5 August, 2010. (Also in Proc. SPIE 7763, 776307 (2010); doi:10.1117/12.861731) (Invited) 21. T. Nagatsuma, "Extreme Bandwidth Wireless Communications Using Terahertz Waves," 20th International Conference on Applied Electromagnetics and Communications (ICECom 2010), Dubrovnik, Croatia, 20-23 September, 2010. (Invited) 22. T. Nagatsuma, "100-400 GHz Band Wireless Communications Technology Based on Photonic Signal Generation," Asia-Pacific Radio-Science Conference (AP-RASC2010), Toyama, Japan, 22-26 September, 2010. (Invited) 23. T. Nagatsuma, "Recent Developments and Future Callenges in THz Communications", GDR-I Workshop on Terahertz Science and Technology, Paris, France, Sept. 27-28, 2010. (Invited) 24. T. Nagatsuma, T. Kumashiro, K. Takada, M. Kawamura, H.-J. Song, K. Ajito, and N. Kukutsu, "Photonic Generation of THz Waves and Their Applications to Sensing and Communications," International Symposium on Frontier of Terahertz Spectroscopy IV, Matsumoto, Japan, 20-21 October, 2010. (Invited) 25. T. Nagatsuma, H.-J. Song, Y. Fujimoto, T. Takada, M. Kawamura, K. Ajito, N. Kukutsu, Y. Kado, A. Wakatsuki, Y. Muramoto, "300-GHz-Band Wireless Link Based on Photonic Signal Generation," European Optical Society Annual Meeting (EOSAM2010), Paris, France, 26-29 October, 2010. (Invited) 26. T. Nagatsuma, T. Takada, H.-J. Song, K. Ajito, N. Kukutsu, Y. Kado, "Millimeter- and THz-wave Photonics Towards 100Gbit/s Wireless Transmission," The 23rd Annual Meeting of the IEEE Photonics Society, Denver, USA, 7-11 November, 2010. (Invited) 27. T. Mukai, M. Kawamura, T. Takada, and T. Nagatsuma, "1.5-Gbps wireless transmission using resonant tunneling diodes at 300 GHz", Tech. Dig. Optical Terahertz Science and Technology 2011 Meeting, MF42, Santa Barbara, March 13-17, 2011. 28. T. Nagatsuma, T. Takada, M. Kawamura and D. Asa, "300-GHz Band Wireless Communications Based on Diode Technologies," PIERS2011, Session 3P2, Marrakesh, Morocco, March 20-23, 2011. (Invited) 29. T. Nagatsuma, "New APT Report on Technology Trends of Telecommunications above 100 GHz," The Eighteenth APT Standardization Program Forum (ASTAP-18), Bangkok, Thailand, May 25, 2011. (Invited) 30. T. Nagatsuma, "Photonic Generation of Terahertz Waves for Communications and Imaging International Workshop on THz Electronics and Communications," Seoul., Korea, June 24, 2011. (Invited) 31. T. Nagatsuma, "Free-space THz Communications: Past and Future Directions," THz Science and Technology-The Castle Meeting-, Marburg, Germany, July 3-6, 2011. (Invited) 32. T. Nagatsuma, "Extreme Bandwidth Terahertz Wireless Communications Technologies," 30th URSI General Assembly, Workshop on Advances in Optical-Wireless Communications, Istanbul, Turkey, August 13, 2011. (Invited) 33. T. Nagatsuma, "Extreme Bandwidth Wireless Communications Based on Photonic Terahertz Signal Generation," 37th European Conference and Exhibition on Optical Communication (ECOC2011), Geneva, Switzerland, Sep. 18-22, 2011. (Invited) 34. T. Takada, S. Hisatake, T. Nagatsuma, D. Kim, K. Sakurai and J. Hirokawa, "Characterization of Waveguide Slot Antenna Array for 300-GHz-band Wireless Link System," International Symposium on Terahertz Nanoscience (TeraNano2011), 28P-12, p. 229, Osaka, Japan, Nov. 28, 2011. 35. T. Mukai, T. Shiode, M. Kawamura, and T. Nagatsuma,

		"Development of Resonant Tunneling Diode Oscillators and Detectors to Realize Terahertz Applications," International Symposium on Terahertz Nanoscience (TeraNano2011), 29I-04, pp. 148-150, Osaka, Japan, Nov. 29, 2011. (Invited) 36. J. Hirokawa, D. Kim, K. Sakurai, M. Ando, T. Takada, and T. Nagatsuma, "Design and Measurement of Plate-laminated Waveguide Slot Array Antennas at 120 GHz and 350 GHz Band," Asia Pacific Microwave Conference (APMC2011), TU6E-01, Melbourne, Australia Dec. 5-8, 2011. 37. T. Shiode, T. Mukai, M. Kawamura, and T. Nagatsuma, "Giga-bit Wireless Communication at 300 GHz Using Resonant Tunneling Diode Detector," Asia Pacific Microwave Conference (APMC2011), WE6A-01, Melbourne, Australia, Dec. 5-8, 2011.
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	Communications (conferences)	1. 縄田耕二・野竹孝志・川俣大志・松川　健・祁　峰・南出泰亜 1, "注入同期 KTP-OPG 励起光源を用いた広帯域波長可変テラヘルツ波光源," 電子デバイス研究会, 東北大学 電気通信研究所 片平キャンパス内 ナノ・スピン総合研究棟, 仙台, Dec. 14-15 2011. 2. 南出泰亜、"非線形光学効果を用いた高効率テラヘルツ波発生検出の最先端"、第 19 回光波シンセシス研究会、仙台、12 月、2011 年. 3. 縄田耕二，野竹孝志，Yuye Wang，川俣大志，南出泰亜，"狭線幅 KTP-OPG 励起光源を用いた高効率・波長可変テラヘルツ波光源の開発," 2011 年秋季第 7 2 回応用物理学会，1a-F-10，山形，Sep. 1　2011. 4. 南出泰亜、伊藤弘昌、"非線形光学技術による最先端テラヘルツ波発生・検出"、第 9 回レーザー学会「マイクロ固体フォトニクスの新展開ージャイアントマイクロフォトニクスの創成ー」専門委員会講演会、パシフィコ横浜、Apr.20　2011. 5. 縄田耕二，野竹孝志，唐明，王與燁，川俣大志，伊藤弘昌，南出泰亜，"注入同期型励起光源を用いた高出力テラヘルツ波光源開発，"　第 58 回応用物理学関係連合講演会，神奈川工科大学，神奈川，Mar.2011. 6. 野竹孝志，唐明，王與燁，縄田耕二，川俣大志，伊藤弘昌，南出泰亜，"DAST/BNA ハイブリッド差周波テラヘルツ発生光源の為の 355nm 励起 2 波長 BBO-OPO の開発，"　第 58 回応用物理学関係連合講演会，神奈川工科大学，神奈川，Mar.2011 7. 大谷知行, 佐々木芳彰, 宮丸文章, 春日 博, 大森 整, "先端加工技術で拓くテラヘルツ研究と応用," 理研シンポジウム 第 4 回「先進ものづくり技術によるアナライザーキーコンポーネント開発基盤の構築状況」, 理研和光, 2011.8.10. 8. 永妻忠夫，"未開の電波～テラヘルツ波～の通信応用を考える"，情報通信学会マルチメディア研究会，大阪，2010 年 5 月 20 日． 9. 永妻忠夫，"テラヘルツ波無線の現状と今後の展望"，応用物理学会超伝導分科会第 41 回研究会，大阪，2010 年 6 月 24 日． 10. 永妻忠夫，"３００ＧＨｚ帯を利用したギガビット無線リンク" 電気学会電子・情報・システム部門大会，熊本，2010 年 9 月 3 日． 11. 永妻忠夫，"テラヘルツ無線通信の現状と将来展望"，電子情報通信学会・電子デバイス研究会，仙台，2010 年 12 月 16 日．

		12. 朝　大亮･ 久武信太郎･ 岩月勝美（NTT）･ 永妻忠夫，"光周波数コムによるマイクロ波信号発生の位相安定化手法の検討"，　電子情報通信学会，　東京，　2011 年 3 月. 13. 荒川和輝･ 高田卓馬･ ソンホジン･ 味戸克裕･ 若月　温･ 村本好史･ 久々津直哉･ 永妻忠夫，　"光技術を用いたテラヘルツ無線における光源の検討(2)キャリア･ノイズ比が及ぼす影響"，電子情報通信学会，東京，2011 年 3 月. 14. 高田卓馬･ 荒川和輝･ ソンホジン･ 味戸克裕･ 若月　温･ 村本好史･ 久々津直哉･ 永妻忠夫，　"光技術を用いたテラヘルツ無線における光源の検討(1)　変調度が及ぼす影響"，電子情報通信学会，　東京，　2011 年 3 月. 15. 川村昌史･ 向井俊和･ 高田卓馬･ 塩出剛士･ 永妻忠夫，"アンテナ集積型 RTD 発振器を用いた 300GHz 帯無線リンク"，電子情報通信学会，東京，2011 年 3 月. 16. 朝　大亮･ 久武信太郎･ 岩月勝美･ 永妻忠夫，　"光周波数コムの光キャリア位相安定化法の検討"，電子情報通信学会，北海道，　2011 年 9 月. 17. 高田卓馬･ 永妻忠夫･ 久武信太郎･ 金　東眞･ 櫻井仁夫･ 廣川二郎，"350 GHz 帯導波管スロットアレーアンテナを用いた無線通信実験"，電子情報通信学会，北海道，2011 年 9 月. 18. 永妻忠夫"テラヘルツ波帯の情報通信利用について"，総務省近畿総合通信局･ テラヘルツ波帯の情報通信利用を目指した公開実験，2011 年 2 月 4 日. 19. 永妻忠夫"テラヘルツ波帯の情報通信利用に関する調査検討会　報告書の概要"総務省近畿総合通信局 産学官連携セミナー～テラヘルツテクノロジーと超ブロードバンド情報通信の展望～，2011 年 6 月 27 日. 20. 永妻忠夫"超ブロードバンド無線の展望　～マイクロ波、光波、 そしてテラヘルツ波～"電気四学会関西支部講演会，2011 年 11 月 25 日. 21. 永妻忠夫"100GHz を超える周波数の無線伝送技術について"電波産業会･ 放送新技術調査研究会･ 次世代デジタル放送伝送技術検討作業班･ 講演会，2011 年 12 月 22 日.
Outreach initiatives	**Popularization articles**	1. "理化学研究所見学会 報告," はくさん（仙台工業団地共同組合機関誌）17 号, 2012.1.
	Popularization conferences	1. 大谷知行, "サイエンスカフェ テラヘルツテクノロジー ＜見えないものを見せる力＞," 理化学研究所和光本所一般公開, 理研和光キャンパス, 2011.4.23. 2. 総務省近畿総合通信局、テラヘルツテクノロジーフォーラム共催研究会「テラヘルツテクノロジーと超ブロードバンド情報通信の展望」, 大阪大, 2011.6.27. 3. 南出泰亜, "【最先端研究】近未来の新しい光「テラヘルツ光」," 理化学研究所講演会 'もっと知る、もっと役立つ、最先端科学から身近な科学まで,' 仙台国際センター, 2011.7.30.
	Others	1. 仙台工業団地協同組合見学会, 理化学研究所, 2011.9.16. 2. 宮城第一高等学校見学, 理化学研究所, 2011.10.7. 3. 東北大学大学院工学研究科見学, 理化学研究所, 2011.10.19. 4. ボーイスカウト名取第 1 団見学, 理化学研究所, 2011.10.22.

D.2 OTHER VALORIZATION FACTORS

List of factors. Indicate the titles, years and comments

International patents obtained	(none)
International patents pending	1. Title of Invention: A Terahertz Conversion Apparatus, Patent Application No.: PCT/JP2010/007074, Application Date: 2010, December, 3rd, Applicants: TU, MP, Univ. Slamanca, Inventors: T. Otsuji, V. Popov, W. Knap, Y.M. Meziani, N. Dyakonova, D. Coquillat, F. Teppe, J.E. Velazquez Perez, D. Fateev.
French National patents obtained	(none)
Japanese National patents obtained	(none)
French National patents pending	1. Title of Invention: A Terahertz Conversion Apparatus, Patent Application No.: PCT/JP2010/007074, Application Date: 2010, December, 3rd, Applicants: TU, MP, Univ. Slamanca, Inventors: T. Otsuji, V. Popov, W. Knap, Y.M. Meziani, N. Dyakonova, D. Coquillat, F. Teppe, J.E. Velazquez Perez, D. Fateev.
Japanese National patents pending	1. Title of Invention: A Terahertz Conversion Apparatus, Patent Application No.: PCT/JP2010/007074, Application Date: 2010, December, 3rd, Applicants: TU, MP, Univ. Slamanca, Inventors: T. Otsuji, V. Popov, W. Knap, Y.M. Meziani, N. Dyakonova, D. Coquillat, F. Teppe, J.E. Velazquez Perez, D. Fateev.
Operating licences (obtained / transferred)	(none)
Company creations or spin-offs	(none)
New collaborative projects	(none)
Scientific symposiums	(none)
Others (specify)	(none)

E APPENDICES