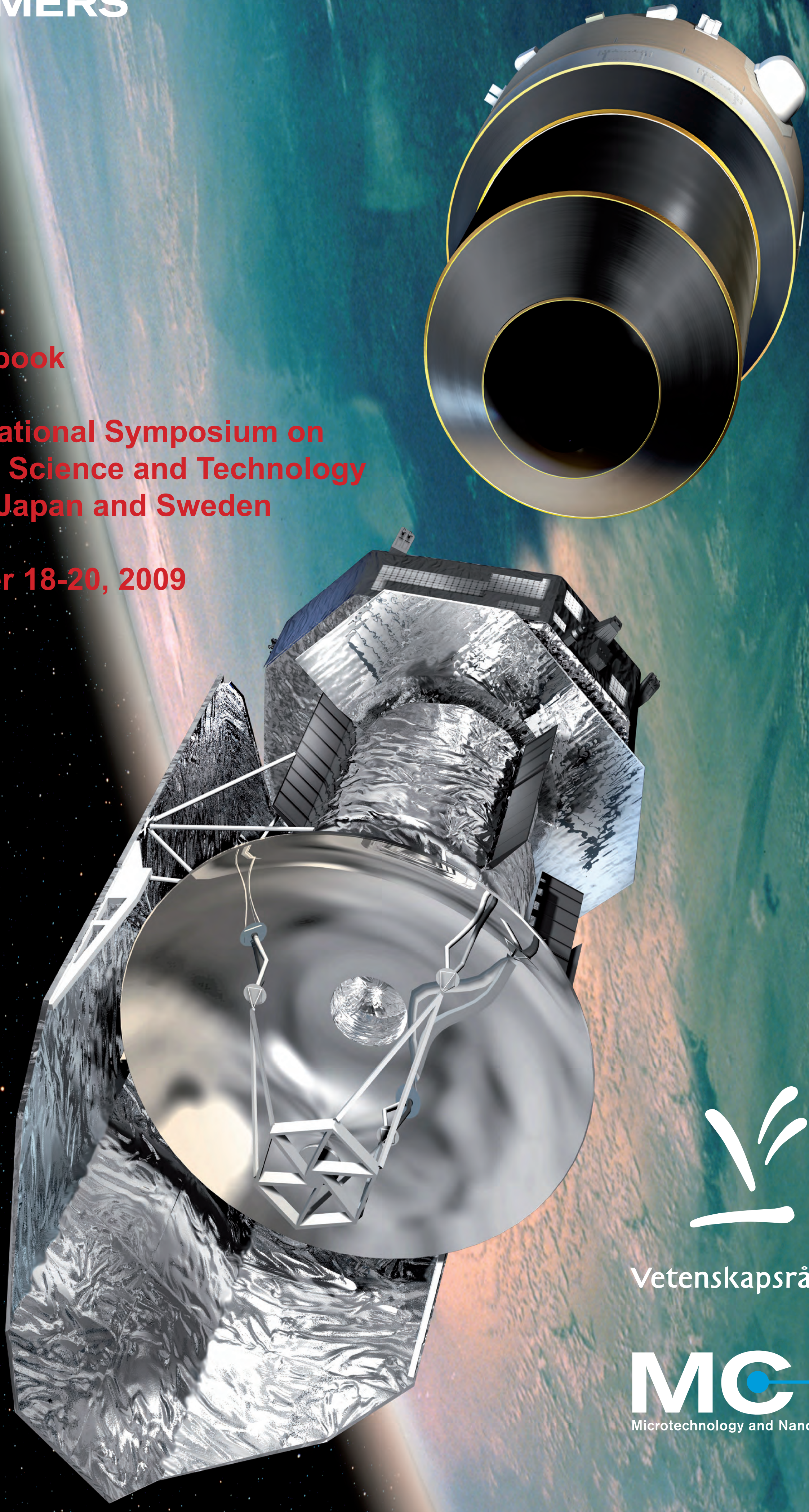
CHALMERS

abstract book

2nd International Symposium on Terahertz Science and Technology between Japan and Sweden

November 18-20, 2009
Göteborg
Sweden



Vetenskapsrådet

MC2
Microtechnology and Nanoscience

November 18 - 20, 2009, Göteborg, Sweden

Short title: Japan-Sweden Terahertz Symposium (JSTS)

Chalmers University of Technology
Department of Microtechnology and Nanoscience - MC2
Physical Electronics Laboratory
SE-412 96 Göteborg, Sweden
Phone: +46-(0)31 772 10 00
http://www.chalmers.se/mc2/EN/

ISSN 1652-0769
Technical Report MC2-160

Editor: Jan Stake

Cover: Herschel separates from upper stage, ESA – D. Ducros, 2009.

TABLE OF CONTENTS

WELCOME TO JAPAN-SWEDEN TERAHERTZ SYMPOSIUM 2009	1
ORGANISING STAFF	3
MAPS AND TRAVEL INSTRUCTIONS	4
LIST OF LECTURES	7
PROGRAM AT GLANCE	8
ABSTRACTS	11

WELCOME TO JAPAN-SWEDEN TERAHERTZ SYMPOSIUM 2009

The organisers and hosts warmly welcome you to the second International Symposium on Terahertz Science and Technology between Japan and Sweden, at Chalmers University of Technology, Göteborg, on November 18-20, 2009. The symposium is organised by the Department of Microtechnology and Nanoscience (MC2) at Chalmers. The aim is to create a forum and platform where researchers from the two countries can discuss latest results and trends in the field of terahertz science and technology. This year we have two keynote and 19 invited lectures divided into nine sessions.

Sandwiched between the optical on the short wavelength side and radio on the long wavelength extreme, the terahertz (THz) or far-infrared has long been considered the last remaining scientific gap in the electromagnetic spectrum. The broad spectrum of THz applications has attracted researchers from different disciplines dealing with optics and photonics, microwave engineering and semiconductor physics. The role of this meeting is not only bridging the THz-gap but also strengthening the collaboration between Japan and Sweden.

Chalmers is a university of technology in which research and teaching are conducted on a broad front within technology, natural science and architecture. Chalmers was founded in 1829. The university is named after the major benefactor, William Chalmers, one of the directors of the successful Swedish East India Company in Göteborg. Chalmers became an independent foundation in 1994. The meeting will be held at William Chalmers private residence, Chalmerska huset, which was erected in 1805-1807 and designed in a neoclassical style.

The workshop is sponsored by the Swedish Research Council (VR) and MC2, Chalmers. We would like to thank these organisations for their support. We would also like to thank everyone who helped to arrange Japan-Sweden Terahertz Symposium (JSTS) 2009: the international steering committee for advice; the local organising committee: Eva Hellberg, Aleksandra Malko, Aik-Yean Tang, Dr. Sergey Cherednichenko, Dr. Biddut Banik and Prof. Dag Winkler for all practical efforts; Eriko Naito and Prof. Anders Karlsson at the Embassy of Sweden in Tokyo; our host Anna Bergius Hartman during the stay in Chalmerska huset; Dr. Göran Alestig for arranging the lab tour; invited speakers and everyone who attends or contributes to this event.

On behalf of the local organising committee, we would like to welcome you all and wish you a pleasant and fruitful stay in Göteborg.

Welcome!

Jan Stake
JSTS 2009 Chairman

ORGANISING STAFF

ORGANISING COMMITTEE

PROF. JUN-ICHI NISHIZAWA, CHAIR	SOPHIA UNIVERSITY
PROF. MIKAEL ÖSTLING	ROYAL INSTITUTE OF TECHNOLOGY
PROF. STEFAN BENGTSSON	CHALMERS UNIVERSITY OF TECHNOLOGY
PROF. MASANORI HANGYO	OSAKA UNIVERSITY

LOCAL ORGANASING COMMITTEE

JAN STAKE

EVA HELLBERG

AIK YEAN TANG

ALEKSANDRA MALKO

SERGEY CHEREDNICHENKO

BIDDUT BANIK

HERBERT ZIRATH

LOCATIONS, MAPS AND TRAVEL INSTRUCTIONS

ELITE PLAZA HOTEL

Västra Hamngatan 3
Göteborg

CHALMERSKA HUSET

Södra Hamngatan 11
Göteborg

Chalmerska Huset takes its name from William Chalmers and was erected in 1805-1807. After being employed for ten years as a director of the East India Company, based in Macau and Canton, Chalmers returned to Göteborg in 1793. He subsequently purchased Holtermanska Huset, a two-storey wooden building at Södra Hamngatan 11. The building was destroyed in a devastating fire in 1802, which laid waste to the whole of the area between Östra and Västra Hamngatan, from Vallgraven to Hamnkanalen. Chalmers decided to erect a building in stone on the same site and he commissioned Göteborg City Architect Carl Wilhelm Carlberg for the design work. Carlberg was a highly distinguished architect and his achievements included Gunnebo, a private residence that was completed in 1796 and which attracted a great deal of attention and admiration. Chalmerska Huset was designed in the same neoclassical style as Gunnebo, which was also reflected in the interior.

The building was completed in 1807 although the pleasure William Chalmers derived from living there was relatively brief. He died in 1811, aged 63. Shortly before his death Chalmers bequeathed half of his estate to Sahlgrenska Hospital and half to Frimurarebarnhuset in Göteborg for the establishment of an industrial school "for poor children who had learnt to read and write". This school was to become the foundation of Chalmers University of Technology. The building was sold and in 1850 it was bought by Oscar Ekman. He founded Skandinaviska Kreditaktiebolaget, which later merged with Enskilda Banken to eventually become SEB.

On SEB's 150th anniversary in 2006, the building was donated back to Chalmers University of Technology.

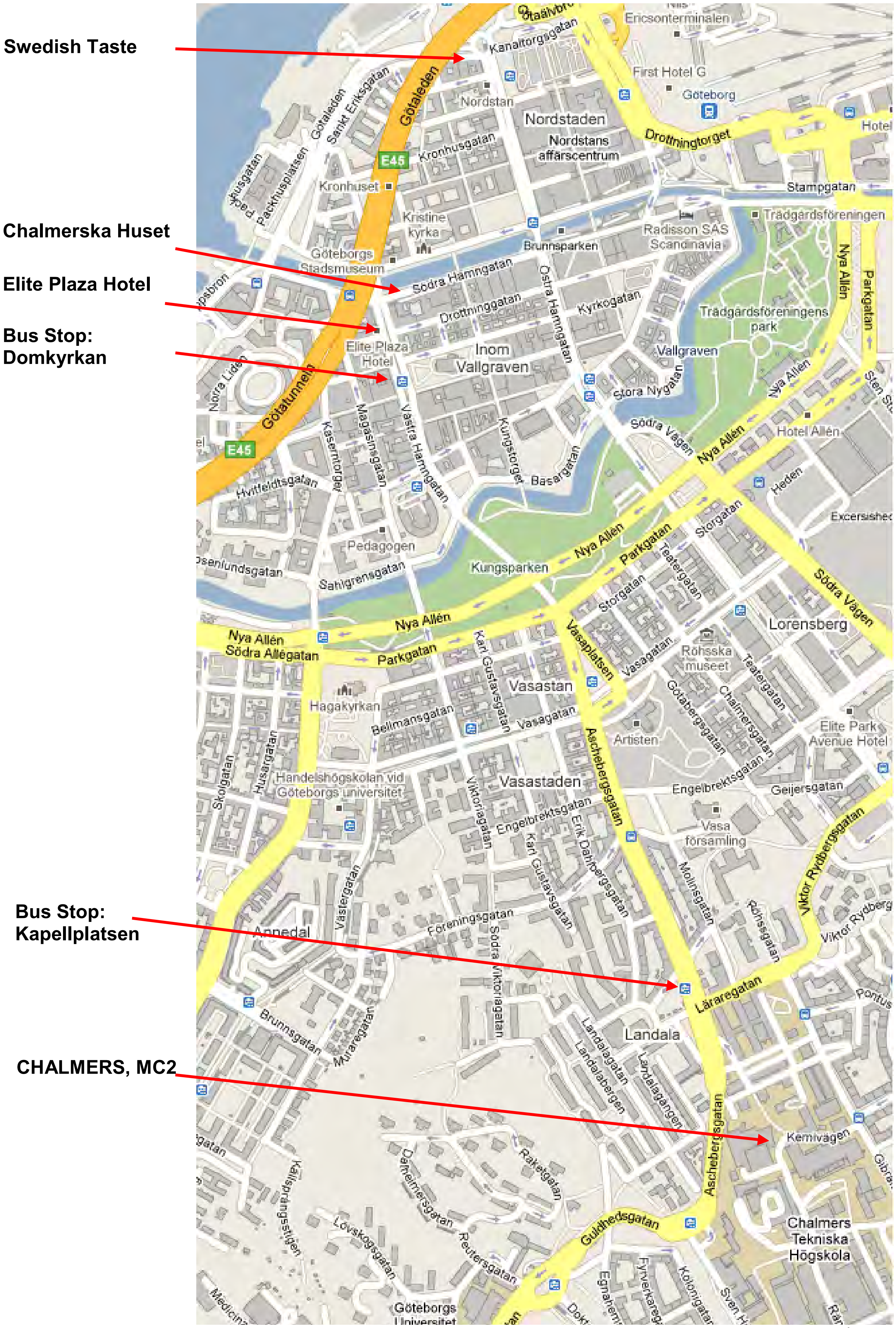
MC2-BULDING, CHALMERS UNIVERSITY OF TECHNOLOGY

Campus Johanneberg
Kemivägen 9
Göteborg

From *Domkyrkan* to *Kapellplatsen:* Bus number 16 (towards *Högsbohöjd*) or 19 (towards *Mölndal*).
More information: *www.vasttrafik.se*

RESTAURANT: SWEDISH TASTE

Sankt Eriksgatan 6
Göteborg



www.maps.google.com

List of Lectures

Keynote Lectures

Prof. Jun-ichi Nishizawa, Sophia University
From Maser to Laser. How the Laser happened and was extended to terahertz in my laboratory Fourth part of my research life

Prof. Erik Kollberg, Chalmers
GHz to THz receivers: 50 years of development

Invited Speakers

Masanori Hangyo, Osaka University
Materials in the Terahertz Region

Toshitaka Idehara, University of Fukui
High power THz technologies using gyrotrons as high power THz radiation sources

Keita Ohtani, Tohoku University
Development of THz Quantum Cascade Lasers at Tohoku University

Kiyomi Sakai, National institute of Information and Communication Technology
Plasmonic devices in the terahertz-waves region

Nobuhiko Sarukura, Osaka University
Terahertz waveguides and proposed optical parametric devices

Tetsuo Sasaki, Sophia University
High resolution terahertz spectroscopy for defect detection

Tadao Tanabe, Tohoku University
GaP Terahertz signal generator and its applications for spectral monitoring of dynamic reaction

Keisuke Tominaga, Kobe University
Low-Frequency Dynamics in Condensed Phases Studied by Terahertz Radiation Spectroscopy

Yoshizumi Yasuoka, National Defense Academy in Japan
Uncooled antenna coupled terahertz radiation detectors

Victor Belitsky, Chalmers
Terahertz instrumentation for radio astronomy

Tomas Bryllert, Caltech/JPL
A 670 GHz imaging radar for concealed objects detection

Leonid Kuzmin, Chalmers
Ultra-sensitive cold-electron bolometers for THz receivers

Gunnar Malm, Royal Institute of Technology KTH
Understanding the noise floor in uncooled silicon-germanium bolometers

Sergey Cherednichenko, Chalmers, Omnisys Instruments AB
Optical design and verification of the 183 GHz Water Vapor Radiometer for ALMA

Jan Stake, Chalmers
Integrated Schottky receivers and graphene for future THz electronics

Jan Svedin, Swedish Defence Research Agency
A 210 GHz 3D imaging radar system based on an antenna-integrated MMIC receiver front-end and an ultracompact HBV transmitter source module

Stanley Wissmar, ACREO
Group IV materials for THz sensing

Josip Vukusic, Chalmers
High power compact multiplier sources and imaging applications

Herbert Zirath, Chalmers
Highly integrated receivers for millimetre wave applications based on mHEMT technology

PROGRAM AT GLANCE

Wednesday November 18, 2009

Location: Kollektorn, MC2-bulding, Chalmers campus Johanneberg

15:00	Opening **Stefan Bengtsson**, Chalmers Vice president
15:15	Keynote lecture 1 **Jun-ichi Nishizawa**, Sophia University *From Maser to Laser. How the Laser happened and was extended to Terahertz in my laboratory* *Fourth part of my research life*
16:00	Keynote lecture 2 **Erik Kollberg**, Chalmers *GHz to THz receivers: 50 years of development*
18:00	**Welcome reception** Chalmerska huset

Thursday November 19, 2009

Location: Chalmerska huset, Södra Hamngatan 11

09:00-9:05	Opening greetings **Jun-ichi Nishizawa**, Sophia University
09:05-9:10	Opening remarks **Jan Stake**, Chalmers
09:10-9:15	Welcome to Chalmers **Prof. Dag Winkler**, Head of Department of Microtechnology and Nanoscience, Chalmers
09:15-9:45	Invited lecture 1 **Masanori Hangyo**, Osaka University *Materials in the Terahertz Region*
09:45-10:15	Invited lecture 2 **Gunnar Malm**, Royal Institute of Technology KTH *Understanding the noise floor in uncooled silicon-germanium bolometers*
10:15-10:30	**Coffee break**
10:30-11:00	Invited lecture 3 **Keita Ohtani**, Tohoku University *Development of THz Quantum Cascade Lasers at Tohoku University*
11:00-11:30	Invited lecture 4 **Herbert Zirath**, Chalmers *Highly integrated receivers for millimetre wave applications based on mHEMT technology*
11:30-12:00	Invited lecture 5 **Nobuhiko Sarukura**, Osaka University *Terahertz waveguides and proposed optical parametric devices*
12:00-13:15	**Lunch**

13:15-13:45	Invited lecture 6 **Victor Belitsky**, Chalmers *Terahertz instrumentation for radio astronomy*
13:45-14:15	Invited lecture 7 **Yoshizumi Yasuoka**, National Defense Academy in Japan *Uncooled antenna coupled terahertz radiation detectors*
14:15-14:45	Invited lecture 8 **Stanley Wissmar**, ACREO *Group IV materials for THz sensing*
14:45-15:00	**Coffee break**
15:00-15:30	Invited lecture 9 **Kiyomi Sakai**, National institute of Information and Communication Technology *Plasmonic devices in the terahertz-waves region*
15:30-16:00	Invited lecture 10 **Josip Vukusic**, Chalmers *High power compact multiplier sources and imaging applications*
16:00-16:10	**Break**
16:10-16:40	Invited lecture 11 **Tetsuo Sasaki**, Sophia University *High resolution terahertz spectroscopy for defect detection*
16:40-17:20	Invited lecture 12 **Jan Svedin**, Swedish Defence Research Agency *A 210 GHz 3D imaging radar system based on an antenna-integrated MMIC receiver front-end and an ultracompact HBV transmitter source module*
19:00	**Banquet** Location: Swedish Taste, Sankt Eriksgatan 6, Göteborg

Friday November 20, 2009

Location: Chalmerska huset, Södra Hamngatan 11

09:00-9:15	**Coffee**
09:15-9:45	Invited lecture 13 **Toshitaka Idehara**, University of Fukui *High power THz technologies using gyrotrons as high power THz radiation sources*
09:45-10:15	Invited lecture 14 **Tomas Bryllert**, Caltech/JPL *A 670 GHz imaging radar for concealed objects detection*
10:15-10:30	**Coffee break**
10:30-11:00	Invited lecture 15 **Tadao Tanabe**, Tohoku University *GaP Terahertz signal generator and its applications for spectral monitoring of dynamic reaction*

11:00-11:30	Invited lecture 16 **Sergey Cherednichenko**, Chalmers, Omnisys Instruments AB *Optical design and verification of the 183 GHz Water Vapor Radiometer for ALMA*
11:30-12:00	Invited lecture 17 **Keisuke Tominaga**, Kobe University *Low-Frequency Dynamics in Condensed Phases Studied by Terahertz Radiation Spectroscopy*
12:00-13:15	**Lunch**
13:15-13:45	Invited lecture 18 **Leonid Kuzmin**, Chalmers *Ultra-sensitive cold-electron bolometers for THz receivers*
13:45-14:15	Invited lecture 19 **Jan Stake**, Chalmers *Integrated Schottky receivers and graphene for future THz electronics*
14:15-14:20	Closing remarks
14:45-17:00	Laboratory tours and discussions Location: MC2, Chalmers

WEDNESDAY

NOVEMBER 18, 2009

LOCATION: KOLLEKTORN, MC2-BULDING, CHALMERS CAMPUS JOHANNEBERG

KEYNOTE LECTURE 1

FROM MASER TO LASER. HOW THE LASER HAPPENED AND WAS EXTENDED TO TERAHERTZ IN MY LABORATORY. FOURTH PART OF MY RESEARCH LIFE

JUN-ICHI NISHIZAWA
SOPHIA UNIVERSITY

Jun-ichi Nishizawa was born in Sendai City, Japan, on 1926. He received B.S. and Ph.D. degrees from Tohoku University in 1948 and 1960, respectively. Following a year as a Research Assistant, he became an Assistant Professor in 1954 and a Professor in 1962. He served during the terms of 1983-1986 and 1989-1990 as the Director of the Research Institute of Electrical Communication, Tohoku University, and 1990-1996 as the President of Tohoku University. After that, during 1998-2005(Mar.) he served as the President of Iwate Prefectural University. From April 2005, he is the President of Tokyo Metropolitan University. He is also Member of the Japan Academy. He is awarded Japan Academy Prize, IEEE(Institute of Electrical & Electronics Engineers, USA) Jack A. Morton Award, Honda Prize, The Order of Cultural Merits (Bunka-Kunsho), IEEE Edison Medal and First Order of Merit. Finally, IEEE established Jun-ichi Nishizawa Medal in 2002 in honor of his works (ranging from fundamental semiconductor materials and devices through optical communication and power systems).

Jun-ichi Nishizawa
Sophia University, 7-1 Kioi-cho, Chiyoda-ku,
Tokyo 102-8554 JAPAN
e-mail: nishizawa@hanken.jp

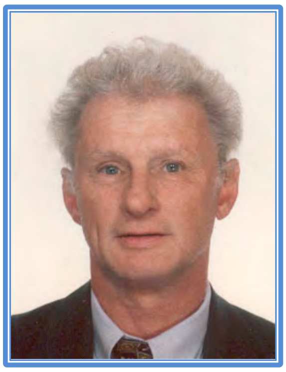
Recently, inventor of Laser was replaced from Townes 1958 to G. Gould 1957 based on a memo written on his notebook for the experiment on 13th Nov. 1957 and now new patent was registered in 1987. However, my patent 22nd April, 1957 seems to be earlier 7 months compared with Gould's. The fundamental idea was found by Fraunhofer and I thought of it in the mid school at the age of 13. After the application of the patent, I asked to support the realization of the idea but unfortunately failed. Afterwards, I continued the invention and the study of glass fiber, vapor pressure controlled III-V nearly perfect crystal growth and terahertz electro-magnetic wave generation. The THz oscillator was composed with a piece of GaP crystal. With Anti-Stokes Raman effect higher frequency can be generated and after, with Stokes Raman effect, it could generate the Raman frequency 12.1 THz in 1983. Afterwards, today we succeeded to realize wide change of frequency as a function of the injection angle and as an example $Q \approx f/\triangle f$ is more than 10^6 without cooling at around the frequency of 3 THz, which seems to be the world record now. As a result of application of this frequency shift in the characteristic, we can observe the frequency shifts by the generated defects in organic compound; ex. glucose after the bombardment of γ-ray, which is also the world first success to detect crystalline defect in organic compound. These results are expected to be applied for the detection and study of cancer. The details of contents will soon be published in Proceedings of the Japan Academy, Series B (http://www.jstage.jst.go.jp/browse/pjab).

Keywords: Laser, Terahertz oscillator, Crystal and structural vibration, Detection of crystal structural vibration, Detection of crystalline defect in organic compound, Mapping by reflection and by penetration, Non invasive diagnosis

KEYNOTE LECTURE 2

GHZ TO THZ RECEIVERS: 50 YEARS OF DEVELOPMENT

ERIK KOLLBERG
CHALMERS



Erik L. Kollberg (M'82, SM'83, F'91) was born in Stockholm in 1937. In 1970 he received his PhD at Chalmers University of Technology, in Göteborg, Sweden. In 1979 he became full professor at Chalmers. From 1967 to 1987 he was the head of the group developing low noise receivers for the Onsala Space Observatory telescopes. He was acting Dean of Electrical and Computer Engineering 1987-90. In 1995 he founded Chalmers center for high speed electronics (CHACH).

He has been performing research on microwave, millimeter wave and submillimeter wave devices and low noise receivers including maser amplifiers, Schottky diode and SIS mixer receivers. He has also worked on resonant tunneling diode oscillators, harmonic multipliers and is the inventor of the heterostructure barrier varactor diode. His present main research interests are in the areas of millimeter wave and THz devices and applications, in particular hot electron bolometer mixers. He has published more than 300 papers.

Prof. Kollberg and his group received the 1982 Microwave Prize given at the 12th European Microwave Conference in Helsinki, Finland. In 1983-84 he chaired the MTT Chapter in Sweden. He has been a guest professor at Ecole Normal Superieure, Paris, France and a Fairchild Scholar at California Institute of Technology. The year 2000 he was awarded an Honorable Doctorate at the Helsinki University of Technology. In 2007 he received the European Microwave Association Distinguished Service Award. He is a member of the Royal Swedish Academy of Science and the Royal Swedish Academy of Engineering Sciences.

Erik Kollberg
Physical Electronics lab., Department of Microtechnology and Nanoscience, Chalmers University of Technology, SE-412 96 Sweden
e-mail: erik.kollberg@chalmers.se

The author became a student of Professor Olof Rydbeck, founder of the Onsalal Space Observatory, in 1961. The talk will describe the development of low noise receivers for radio astronomy from about 1960 until today as seen from the authors perspective. This development has been successful allowing Onsala to stay in the fore front of radio astronomy.

In the late nineteen fifties, the only type of microwave-millimeter wave receivers was point contact mixer receivers. A giant improvement became available with the invention of the maser amplifier in 1954. Experimental maser amplifiers useful for practical receiver systems were reported in the early 1960-ies, offering more than an order of magnitude improvement in noise performance. At Onsala a telescope with a diameter of 25 m was dedicated 1964 and became equipped with masers ranging in frequency from 1 GHz to 9 GHz, offering a world record sensitivity.

The “new” 20 m millimeter wave telescope at Onsala was dedicated 1976. Realizing masers for frequencies above about 50 GHz is possible but in practice very difficult. For the 20 m telescope maser amplifiers for 20-35 GHz were designed and successfully built. However, to reach 100 GHz and above, cooled Schottky diode mixers were developed.

In early nineteen eighties we were among the first in the world to develop Superconductor-Insulator-Superconductor (SIS) mixers, and equip the 20 m telescope with very low noise SIS mixers. Mixers for frequencies up to 115 GHz were following. The Onsala group developed further mixers for frequencies above 100 GHz.

Finally For frequencies for above one THz, we developed hot electron bolometer (HEB) mixers that since May 6 are in operation on Herschel, the ESA-NASA submillimeter wave infrared space telescope.

THURSDAY
NOVEMBER 19, 2009
LOCATION: CHALMERSKA HUSET, SÖDRA HAMNGATAN 11

INVITED LECTURE 1

MATERIALS IN THE TERAHERTZ REGION

MASANORI HANGYO
OSAKA UNIVERSITY

Masanori Hangyo was born in Toyama, Japan, in 1953. He received the B. S., M. S., and Dr. S degrees from Kyoto University in 1976, 1978, and 1981, respectively. From 1981 to 1990 he was a research associate of Osaka University, Faculty of Engineering. From 1990 to 1996 he was an associate professor of Research Center for Superconducting Materials and Electronics, Osaka University and became a professor in 1996. From 2000 to 2004 he was a professor of a newly established Research Center for Superconductor Photonics and since 2004 he has been a professor of Institute of Laser Engineering, Osaka University after the unification of the institutes. Now he is a vice-director of the institute. His research interests are THz radiation from various materials and devices by exciting with femtosecond lasers and its application to spectroscopy and imaging. He demonstrated THz radiation from high-T_c superconductors by exciting with femtosecond lasers in 1995 in collaboration with Dr. K. Sakai's group of Communications Research Laboratory, Ministry of Posts and Telecommunications. From FY1999 to FY 2002, he led the project "Development of Laser-Terahertz Technology", which was the first systematic research project of THz technology using lasers in Japan, supported by the Grant-in-Aid for Scientific Research on Priority Areas from MEXT.

Masanori Hangyo
Institute of Laser Engineering, Osaka University, 2-6 Yamadaoka, Suita,
Osaka 565-0871, JAPAN
e-mail: hangyo@ile.osaka-u.ac.jp

Metamaterials are the artificial materials with periodic structures much less than the wavelengths of electromagnetic waves. It is possible to realize effective permittivity and permeability which is impossible or difficult to find in natural materials. The terahertz region is quite suitable for investing metamaterials because the sizes of elements are several tens of microns and the total size of the sample is about 1 cm^3 for 3 dimensional ones, which is possible to access by existing fabrication techniques. In this presentation, I talk about two topics; 1. a system made of two metallic slabs with periodic cut-through slit arrays and 2. a two-dimensional metamaterial made of dielectric cube array.

Figure 1 (a) shows the configuration of the system made of two metallic slabs with periodic cut-through slit arrays. It has been already reported that the single slab behaves as a dielectric slab having the effective refractive index $n_1 = d/w$ and the thickness h/n_1. We will show here that the system shown in Fig. 1 (a) is equivalent to three dielectric slab system as shown in Fig. 1 (b). We made the sample with brass and measured the transmission spectra for various values of □*z* and □*x*, and they are fitted with the theoretical transmission spectra of the dielectric slab model by taking the refractive index of the middle layer n_2 as a fitting parameter. The obtained results are plotted by closed circles in Fig. 2 together with the theoretical values (shown by solid curves) obtained by the modal expansion method for the system corresponding to Fig. 1 (a). The experiment and theory agrees quite well. This result shows that the effective refractive index of the middle layer can be controlled by □*z* and □*x*. The reason for the enhancement of the refractive index with □*x* is interpreted by the geometrical distance which the electromagnetic wave travels in the air gap.

Next, we made a two-dimensional TiO_2 cube array on a sapphire substrate. TiO_2 has a dielectric constant larger than 100 and the absorption constant is relatively low. By utilizing the Mie resonance, the negative effective permittivity or negative effective permeability can be obtained in some frequency regions experimentally.

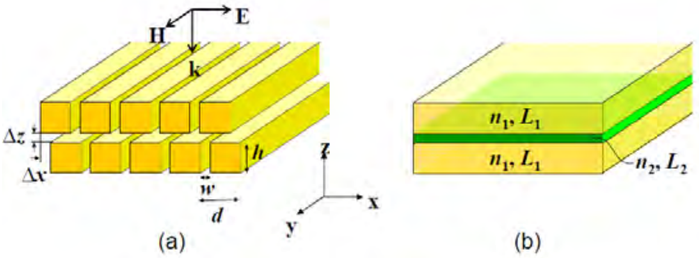


Fig. 1

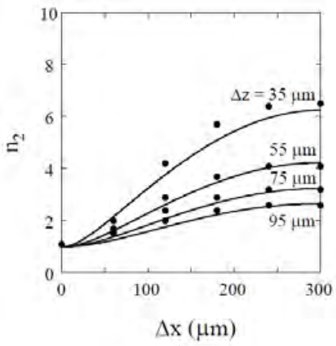


Fig. 2

INVITED LECTURE 2

UNDERSTANDING THE NOISE FLOOR IN UNCOOLED SILICON-GERMANIUM BOLOMETERS

GUNNAR MALM
ROYAL INSTITUTE OF TECHNOLOGY KTH

Bengt Gunnar Malm was born in Stockholm, Sweden, in 1972. He received the M.S. degree in engineering physics and radiation science from Uppsala University, Uppsala, Sweden, in 1997, and the Ph.D. degree in solid-state electronics from Royal Institute of Technology (KTH), Stockholm, in 2002. Currently, he is a Senior Researcher at the Solid-State Device Lab, School of Information and Communication Technology, KTH. His research interests include characterization, modeling, and process development of Si- and SiGeC-based devices and circuits for RF/wireless and high-speed applications, optimization and modeling of RF properties, noise and distortion and thermal effects. Recent work includes SiGe IR bolometers, nano-silicon photonic devices and noise issues in spintronic oscillators. He has co-supervised 3 PhD student projects SiGe, SiC and nano-silicon photonic devices, and has published or co-authored more than 30 scientific papers in international journals and conferences. He has contributed to 2 book chapters and a number of invited conference papers. Dr. Malm is a member of IEEE and has served as a reviewer for IEEE Transaction on Electron Devices, IEEE Electron Device Letters, and Solid State Electronics. He is program committee member for the annual GigaHertz Symposium Sweden.

B. Gunnar Malm
Royal Institute of Technology KTH
e-mail : gunta@kth.se

During the recent years, single-crystalline SiGe material has demonstrated as an outstanding thermistor material for uncooled LWIR bolometers. Such thermal detectors have a wide variety of infrared applications (security, automotive, etc). The main advantages of SiGe-detectors compared to the existing thermal detectors (vanadium oxide or amorphous silicon) are low cost fabrication, high thermal response and high signal-to-noise ratio. The full bolometer system consists of micromachined thermistors in form of pixel arrays which respond to the absorbed infrared radiation by changing of resistivity. The detector arrays are bonded to a read-out circuit to amplify the generated electronic signal. High performance thermal detectors are designed for high response to heat absorption in terms of high thermal coefficient resistivity (TCR) and high signal-to-noise ratio. A SiGe /Si (quantum well/barrier) multilayer stack is assigned as intrinsic part of the bolometer with two highly boron-doped contact layers on the top and bottom. This study focuses on the epitaxial layer structure and its influence on the low-frequency noise level. The noise measurements of MQWs were performed carefully by eliminating all external contributions and the noise spectroscopy provided the noise characteristic parameters. The results demonstrate that the noise depends on the geometric size of the MQW and it increases with decreasing of the pixel area. The investigations show the noise level in the bolometer structures is sensitive to any dopant segregation from the contact layers and the variation in the noise was more than one order of magnitude for samples with different SiGe stacks. The results were analyzed in the framework of extended defects due to critical strain levels but also in terms of parameters such as surface roughness and interface passivation.

INVITED LECTURE 3

DEVELOPMENT OF THZ QUANTUM CASCADE LASERS AT TOHOKU UNIVERSITY

KEITA OHTANI
TOHOKU UNIVERSITY

Keita Ohtani was born in Kobe, Japan, in 1970. He received the B.E., M. S., and Ph. D. degree in electronic engineering from Tohoku University in 1994, 1996, and 1999, respectively. Currently, he is an assistant professor, Research Institute of Electrical Communication (RIEC), Tohoku University. His research interest includes intersubband transitions in semiconductor quantum structures, molecular beam epitaxy of group III-V and group II-VI oxide, and quantum optics in semiconductor nanostrcutures. He is a member of the Japan Society of Applied Physics (JSAP).

K. Ohtani
Laboratory for Nanoelectronics and Spintronics, Research Institute of Electrical Communication, Tohoku University, Katahira 2-1-1, Aoba-ku, Sendai 980-8577, Japan
e-mail:keita@riec.tohoku.ac.jp

Quantum cascade lasers (QCLs) are long wavelength semiconductor lasers utilizing intersubband optical transitions in quantum well structures. Since QCLs exhibit a high optical output power at the spectrum region from mid-infrared (MIR) to terahertz (THz) by making use of carrier recycling, they are expected to be one of the promising candidates for a light source in this spectral region. Until now we have focused on three kinds of semiconductors (InAs [1], GaAs, and ZnO [2]) as a QCLs material and developed InAs/AlSb MIR QCLs [1, 3-6] and GaAs/AlGaAs THz QCLs [7]. Here we describe recent research progress of our THz GaAs/$Al_{0.15}Ga_{0.85}As$ QCLs.

All the samples were grown on semi-insulating GaAs(001) substrates by a solid-source molecular beam epitaxy. The active/injection layers were designed by a scheme of longitudinal optical (LO) phonon depopulation [8]. The active region contained 175 repeats of active-injection layers. X-ray diffraction measurements show that the grown layer thickness is in agreement with the target thickness within an error of 2%. At present stage we have successfully demonstrated the operation of THz QCLs in the frequency range from 3.1 to 3.8 THz.

Thermally activated LO phonon scattering of the carriers in the excited subband is one of sources to limit characteristic temperature of threshold current density. In order to estimate thermally activated LO phonon scattering time of 3.8 THz QCLs we analyze temperature dependence of threshold current density by comparison with computed data. Our fitting model indicates that the thermally activated LO phonon scattering time increases exponentially with temperature and approaches 2 psec at room temperature, which reveals that the population inversion condition is satisfied at room temperature because of fast carrier depopulation from the ground subband of present active structure [7]. The LO phonon depopulation scheme [8] is thus promising for high-temperature operation of THz QCLs.

A THz optical waveguide with high confinement factor and low loss is essential to increase the maximum operation temperature of THz QCLs. We have employed a metal-metal waveguide and established its fabrication process. Compared with THz QCLs based on a single plasmon waveguide, we found that for metal-metal waveguide devices the threshold current density decreases a factor of 20% and the maximum operation temperature increases about 40 K. The present maximum operation temperature of our metal-metal waveguide THz QCLs is 145 K with an emission frequency of 3.4 THz.

References:
[1] K. Ohtani and H. Ohno, Appl. Phys. Lett. **82**, 1003 (2003) [2] M. Belmoubarik, K. Ohtani, and H. Ohno, Appl. Phys. Lett. **92**, 191906 (2008) [3] K. Ohtani, K. Fujita, and H. Ohno, Appl. Phys. Lett. **87**, 211113 (2005) [4] K. Ohtani, K. Fujita, and H. Ohno, Electron. Lett. **43**, 520 (2007) [5] K. Ohtani, Y. Moriyasu, H. Ohnishi, and H. Ohno, Appl. Phys. Lett. **90**, 261112 (2007) [6] K. Ohtani, H. Ohnishi, and H. Ohno, Appl. Phys. Lett. **92**, 041102 (2008) [7] Tsung-Tse Lin, Keita Ohtani, and Hideo Ohno, Appl. Phys. Exp. **2**, 022102 (2009) [8] B. S. Williams, H. Callebaut, S. Kumar, Q. Hu, and J. Reno, Appl. Phys. Lett. **83**, 1005 (2003)

INVITED LECTURE 4

HIGHLY INTEGRATED RECEIVERS FOR MILLIMETER WAVE APPLICATIONS BASED ON MHEMT TECHNOLOGY

HERBERT ZIRATH
CHALMERS

Herbert Zirath was born in Göteborg in 1955. He took a MScEng in Electrical Engineering in 1980 from Chalmers University of Technology. In 1986, he was awarded a PhD in Electrical and Computer Engineering, also from Chalmers. He then worked as a project leader for a national research project within the National Micoelectronics Programme, NMP-4, with the task of starting a research facility on ultra-fast components based on III-V compounds. In 1995, he became "biträdande professor". From 1993 to 1995 he also worked part-time (20%) at the National Defence Research Establishment, Department of Information Technology, as a research manager. Since 1995, he has worked part-time at Ericsson Microwave Systems as a technical advisor on components and circuits for microwave communication. He is also a member of the TFR review board, programme director for the SSF programme "High Frequency Electronics" and he has scientific responsibility for activities in CHACH (CHAlmers Center for High-speed technology).

Herbert Zirath
Microwave Electronics Laboratory, Chalmers University of Technology
e-mail: herbert.zirath@chalmers.se

Recent advances in transistor development have resulted in MMIC-processes which are suitable for monolithic integrated frontends for several hundred GHz. Such processes are interesting for applications like high datarate wireless communication, radiometers, and radar sensors. MMIC-processes based on silicon and III-V semiconductors are considered today as an alternative to Schottky diode based receivers up to and above 300 GHz. The presentation will cover a general review on the status of integrated receivers based on SiGe HBT, CMOS, GaAs mHEMT and InP-HEMT relative to Schottky diode based receivers. Recent results on highly integrated receivers, based on a 100nm mHEMT technology, intended for an active 220 GHz FMCW imaging system will be presented. The receiver MMIC consists of an integrated antenna followed by a three-stage amplifier and a subharmonically pumped resistive mixer. An x2 frequency multiplier and a buffer stage are used for the LO-chain. The measured DSB noise temperature of the receiver is 1300-1600 K and the bandwidth is 20 GHz. The area of the integrated receiver is 3x2 mm. Antenna integrated mixers were investigated as well for the same frequency and could be an alternative if the circuit area should be minimized for instance in multipixel receivers. A conversion loss of 10 dB was achieved for a single-ended resistive mixer at an LO-power of 0 dBm.

INVITED LECTURE 5

TERAHERTZ WAVEGUIDE AND PROPOSED OPTICAL PARAMETRIC DEVICES

NOBUHIKO SARUKURA
OSAKA UNIVERSITY

Nobuhiko Sarukura received his B.S., MS, and Ph.D. degrees from the University of Tokyo. He has previously worked at NTT Corporation, the Institute of Physical and Chemical Research (RIKEN), and as Associate Professor at the Institute of Molecular Science. He was also a visiting associate professor at Tohoku University and University of Tokyo. At present, he is a professor at the Institute of Laser Engineering, Osaka University, working on vacuum ultraviolet, extreme ultraviolet light sources, and terahertz science. Professor Sarukura has been a head editor of the Japanese Journal of Applied Physics since 2000.

Nobuhiko Sarukura
Institute of Laser Engineering, Osaka University, 2-6 Yamadaoka, Suita, Osaka, 565-0871
e-mail:sarukura-n@ile.osaka-u.ac.jp

The terahertz (THz) region (100 GHz - 10 THz) of the electromagnetic spectrum has generated considerable interest in the last decade or so because of certain distinct behaviors of various materials at these frequencies. Spectroscopic applications of THz radiation have already been extended to identification and characterization of biomolecules, environment monitoring, semiconductor and medical imaging, and even law enforcement. The progress in THz technology, however, has been hampered by the inherent free space absorption in the THz region and the lack of intense pulsed radiation sources. These limitations of THz propagation and generation have fueled the search for materials and device designs that would serve as THz waveguides and/or intense THz sources. We have demonstrated several photonic crystal-based THz waveguide designs. Additionally, we propose a THz optical amplifier design based on the THz birefringence of BBO crystal. Previously, we have reported a THz integrated optics device comprising of an InAs wafer, a lens duct, and a Teflon photonic crystal fiber waveguide; which we call a THz Pigtail. This optical device module improves coupling of the THz transients generated in the InAs wafer upon femtosecond laser irradiation, unto a THz fiber waveguide. Additionally, we have also reported the demonstration of a photonic bandgap planar THz waveguide using a new material, Cytop. This material is transparent over a very wide range of wavelengths; from UV to the sub-millimeter wave region. In collaboration with the Optical Fibre Technology Centre at the University of Sydney, we have also reported THz waveguiding in hollow-core microstructured polymer optical fibers The frequency range and shift of the transmission bands between different sized waveguides suggested photonic bandgap guidance. In both the planar and the hollow-core waveguides, finite-difference time domain calculations were performed to support the experimental results. Quite recently, our group reported on the THz birefringence of BBO crystal. The measured refractive index contrast, $\Delta n/n$ value of ~0.118, is remarkably high This crystal has been widely accepted as an excellent nonlinear material for harmonic generation in the optical frequency region. Our results show that BBO crystals may also prove useful as THz nonlinear optical materials. After proper geometric considerations, it is suggested that BBO-based optical parametric amplifiers may be realized to offer the possibility of high-power pulsed THz sources for saturation absorption spectroscopy.

TERAHERTZ INSTRUMENTATION FOR RADIO ASTRONOMY

VICTOR BELITSKY
CHALMERS

Victor Belitsky received his M.Sc. degree from the Moscow Telecommunication Institute, Moscow, USSR, in 1977, and Ph.D. degree in experimental physics from the Institute of Radio Engineering and Electronics, USSR Academy of Sciences, Moscow, USSR, in 1990. He is currently professor and head of the Group for Advanced Receiver Development, at the Department of Radio and Space Science, Chalmers University of Technology, Gothenburg, Sweden. His research interests cover wide range from technology and components to systems in the field of millimeter and sub-millimeter instrumentation for radio astronomy and environmental science.

Victor Belitsky
Chalmers University of Technology
e-mail: victor.belitsky@chalmers.se

Radio Astronomy was always a frontrunner in the demand on terahertz technology. Millimetre and sub-millimetre wave receivers operate at ground-based observatories for more than 20 years with real Terahertz instruments making its way to ground-based [1] and space-based observatories, e.g., Herschel HIFI, during last years.

In this talk, we will look at the key requirements to the radio astronomy and environmental science terahertz receivers using heterodyne technology. The most promising and established technologies for high-resolution spectroscopy instrumentation will be discussed. Using results of the Group for Advanced Receiver Development for Onsala Space Observatory 20 m telescope, for Atacama Pathfinder Experiment (APEX) telescope and ALMA Project Band 5, we will illustrate the trends and achievements in the terahertz instrumentation for radio astronomy.

References:

[1] D. Meledin, A. Pavolotsky, V. Desmaris, I. Lapkin, C. Risacher, V. Perez, D. Henke, O. Nyström, E. Sundin, D. Dochev, M. Pantaleev, M. Strandberg, B. Voronov, G. Gol'tsman, and V. Belitsky, "A 1.3 THz Balanced Waveguide HEB Mixer for the APEX Telescope", IEEE Trans., MTT, pp. 89 – 97, vol. 57, n. 1, 2009.

INVITED LECTURE 7

UNCOOLED ANTENNA COUPLED TERAHERTZ RADIATION DETECTORS

YOSHIZUMI YASUOKA
NATIOLAN DEFENSE ACADEMY IN JAPAN

Yoshizumi Yasuoka received his M.E and D.E degrees in Electronic Engineering from Tohoku University, in 1966 and 1969, respectively. From 1969 to 1973 he was a research fellow at the Technical Research and Development Institute of Japan Defense Agency. In 1973 he joined the Department of Electrical Engineering at National Defense Academy as a lecturer. He was a visiting scientist at the University of California, Berkeley from 1977 to 1978. He became a professor of Electronic Engineering at the National Defense Academy in 1980. He became Dean of Graduate School of Science and Engineering in 1992, Director of Academic Department in 2000, and Vice President in 2002. He retired the National Defense Academy in 2004. Now he is a Professor Emeritus at the National Defense Academy and a Visiting Professor at Kokushikan University.

His research interests are infrared sensing devices, thin film antennas, millimeter and terahertz radiation detectors, high-Tc superconductors and micro-fabrication technology etc. He was President of the Japan Society for Infrared Science and Technology (Currently Advisor), and is Chairperson of the JSPS 182th Committee on Terahertz Science, Technology and Industrial Development. He is also a member of the Institute of Electronics, Information and Communication Engineers, and Japan Society for Applied Physics.

Yoshizumi Yasuoka
Department of Electrical and Electronic Engineering, National Defense Academy
1-10-20 Hashirimizu, Yokosuka 239-8686 JAPAN
e-mail: y.y.yasuoka@rose.plala.or.jp

Recently, the terahertz (THz) frequency region has attracted considerable attention as the remaining frequency resource for applications such as communications, imaging, medical diagnostics, health monitoring, agriculture, and so on, and many researchers have been developing electronic devices for realizing these applications. So far, a THz time-domain spectroscopy (THz-TDS) has been mainly used for these applications. However, it is important to develop the THz radiation detectors as well as the radiation sources to promote the THz wave applications further.

In the infrared frequency region, thermal and quantum detectors have been utilized, and a quantum detector has excellent characteristics in the frequency region higher than 30 THz. However, it is necessary for the quantum detector to be cooled down to the liquid helium temperature in the THz frequency region. A bolometer which is one of the thermal detectors is able to operate at room temperature in the THz frequency region, and real-time imaging of 3.1 THz radiation from the Quantum Cascade Laser has been demonstrated, using vanadium oxide microbolometer infrared focal plane arrays of 320 x 240 with 37□m pitch. However the microbolometer would be difficult to work in the frequency region lower than 1THz.

Antenna coupled devices such as MOM diodes and Schottky barrier diodes and warm carrier devices are notable candidates for detectors and mixers work at room temperature in the THz frequency region. Since these devices receive the THz wave signals by their antennas, and rectify them with their nonlinear current-voltage characteristics, they need to have the contact area as small as possible in order to decrease the response time. Then the device properties strongly depend on the improvement of nanotechnology.

In this paper, the fabrication and detection properties of the antenna coupled devices, especially slot antenna coupled Schottky barrier diodes and warm carrier devices are discussed. Single slot antenna coupled warm carrier devices which have contact areas less than 8 x 10^{-10} cm^2 were fabricated using a micro-fabrication technique. The fabricated devices had the noise equivalent incident power density (NEI) of the 3.8 x 10^{-5} W/cm^2 $Hz^{1/2}$ for 700 GHz irradiation. Sensitivity of the devices improved up to 1.38 x 10^{-8} $W/cm^2Hz^{1/2}$ by attaching an extended hemispherical lens. Single slot antenna coupled GaAs Schottky barrier diodes which have contact areas around 3 x 10^{-8} cm^2 were also fabricated, and the receiving and mixing properties were measured at 94 and 170 GHz. The devices had the NEI of 1.9 x 10^{-8} $W/cm^2Hz^{1/2}$, and it improved up to 1.2 x 10^{-10} W/cm^2 $Hz^{1/2}$ by attaching an extended hemispherical lens. Harmonic mixing beat signals were observed up to a harmonic number of 7.

In order to expand operating frequency of the devices, it is necessary to decrease the contact area between the metal and semiconductor further. For this purpose, the fabrication of the device using an electron beam lithography associated with a focused ion beam would be useful.

INVITED LECTURE 8

GROUP IV MATERIALS FOR THZ SENSING

STANLEY WISSMAR
ACREO

Stanley Wissmar, is a senior research scientist and responsible for Acreo's uncooled terahertz thermistor materials and devices. He has since 2003 worked with infrared imaging sensors (QWIP's – Quantum Well Infrared Photodetector) in what is now a spin-off company named IrNova. Since 2005 he develops uncooled bolometer sensors within several EU projects, PIMS, FNIR and ICU which will be used as collision avoidance systems for automotive applications.

He has earlier experience in manufacturing optical components for telecom applications. Between 2000-2001 he worked as a process engineer at Zarlink Semiconductor fabricating VCSEL laser components.

Stanley Wissmar*[1], Henry Radamson[2]
[1]ACREO, Department of Nanoelectronics
[2]KTH Royal Institute of Technology
*e-mail : stanley.wissmar@acreo.se

Terahertz has attracted attention from both millimeter and infrared technologies. Currently, solutions consist of expensive sensor systems limiting the amount of applications. Acreo and KTH are performing research on group IV thermistor materials for uncooled sensors to obtain a low cost solution. The approach is to use thermistor material based on Ge on Si quantum dots on microbolometers. It has been demonstrated that SiGe monocrystalline materials have superior properties to amorphous silicon or VOx regarding the temperature coefficient of resistivity and 1/f noise. Unfortunately, the calculated critical thickness for strained SiGe material show unreasonable layer thickness for high Ge amounts. To avoid this, Ge dots instead of SiGe layers are preferred.

This presentation focuses on in general present Acreo and KTH activities within the terahertz field and in particular on the optimization of Ge on Si quantum dots for uncooled sensors.

INVITED LECTURE 9

PLASMONIC DEVICES IN TERAHERTZ-WAVES REGION

KIYOMI SAKAI
NATIONAL INSTITUTE OF INFORMATION AND COMMUNICATION TECHNOLOGY

Kiyomi Sakai was born in Osaka, Japan, on April 26, 1939. He received B. M.E. and Dr. E. degree from Osaka University in 1962, 1964 and 19 respectively. In 1966 he joined the Department of Applied Physics at Osa University as a research assistant, and then worked as assistant professor a associate professor. In 1991, he moved to Kansai Advanced Research Cer (*present* KARC/NICT), where he was appointed Director of Laboratory Quantum Electronics until March, 2000 when he retired. Since then he a belongs to Support Center for Advanced Telecommunications Technolo Research, Foundation (SCAT). He is currently a senior advisory staff at b organizations. Since April 2009, he is visiting professor of Research Center Development of Far-Infrared Region, University of Fukui. His principal resea interests are terahertz technology and its applications to the various fields. was awarded the Minister of Posts and Telecommunications Prize in 1966 his activities in the field of far-infrared and terahertz technology. He has guic more than 15 students to obtain the Dr.E. and been the author of 1 text bo 10 book chapters and more than 200 scientific papers published international journal and conferences. He is a member of the Japan Society Applied Physics, the Laser Society of Japan and the Spectroscopic Society Japan. He is also a member of the Japan Society of Infrared Science a Technology, served as the president in 1999 and 2000, and now serves as advisor of the society. He is a member of THz Technology Forum which h been organized recently and serves as the president of the forum.

He is strongly attached to the IRMMW/THz-community by commit involvement over many years and repeated organization of conferences.

Kiyomi Sakai
Kobe Advanced Research Center (KARC)
National Institute of Information and Communications Technology (NICT)
e-mail : sakai@nict.go.jp

Development of ultra-short optical pulse lasers, development of quantum cascade lasers and various fabrication technologies have caused innovations in technologies of the spectral gap between light waves and microwaves. The new ones, called *terahertz (THz) technology* as a whole, give rise to variety of possibilities to use in the basic research and various applications. Spectroscopy is one of the fields which have been given a lot of advantages by the THz technology. Spectroscopy is essentially important in this region, nevertheless the popularity of today seems to have been brought by the imaging.

The author has presented spectroscopic studies that have been done and some important THz imagings at this series of symposium held last year (K. Sakai, Proc. Int'l Symposium on Terahertz between Japan and Sweden 2008, **1**, 54(2008)).

This year's talk starts from the talk on novel aspect of imaging and moves to the talk on plasmonic devices interested lately. The talk once traces back to the age of Herz and surveys the progress of plasmonic devices. They include wire grids, metal meshes, reciprocal structures of meshes, filters and the Martin-Pupllett configuration. The survey arrives at the conclusion how plasmonic devices make up an important part of THz applications by showing cosmic background experiments finally led to the Nobel Prize in Physics in 2006.

References :

1) K. Sakai and L. Genzel, "Far Infrared Metal Meshes Filters and Fabry-Perot Interferometry", *Reviews of Infrared and Millimeter Waves,* Vol. 1, ed. K.J. Button (Plenum Press, New York, 1983)p. 155.

INVITED LECTURE 10

HIGH POWER COMPACT MULTIPLIER SOURCES AND IMAGING APPLICATIONS

JOSIP VUKUSIC
CHALMERS

Josip Vukusic received his diploma and Ph.D. degree in photonics from Chalmers University of Technology, Göteborg, Sweden, in 1997 and 2003 respectively.

From 2004 he is with the Physical Electronics Laboratory working on THz-technology. His is currently involved in modeling, fabrication and characterization of frequency multipliers and photomixers for THz generation. Dr. Vukusic has over 40 publications in journals and conferences. He has experience in areas such as device modeling, high frequency characterization and submicron device fabrication. The research fields/technology he has been involved with are vertical-cavity surface-emitting lasers, diffractive optics, quantum dots, heterostructure barrier varactors, metal-semiconductor-metal photoconductors, uni-traveling-carrier photodetectors, schottky diodes, frequency multipliers and fiber-optics.

He is a co-founder of the company Wasa Millimeter Wave AB and co-applicant of a US patent on semiconductor laser technology. Has developed and commercialized a software package for the comprehensive modelling of semiconductor lasers. Has been engaged as consultant for several start-ups as well as large, established companies.

Josip Vukusic
Physical Electronics Laboratory, Department of Microtechnology and Nanoscience,
Chalmers University of Technology, SE-412 96 Sweden
e-mail: josip.vukusic@chalmers.se

There is a need for room-temperature, compact sources in the THz spectral region (0.1 THz – 10 THz) which can be addressed from the electronic side by frequency up-conversion. By exciting a nonlinear component at lower frequencies we can harness the generated higher order harmonics. This process of frequency multiplication is successfully employed using the heterostructure barrier varactor (HBV) diode. The advantage of the HBV is the symmetric/anti-symmetric C-V/I-V that only allows odd multiplication, i.e x3, x5, x7 etc, which is beneficial leverage when targeting high frequencies. Also, the HBV operates bias-free which simplifies connective circuitry resulting in a more compact and robust solution. Since the voltage handling capability of the HBV can be scaled by cascading the epitaxial growth this device is well suited for high power generation.

We intend to present recent progress in the development of compact, high power HBV-based multiplier sources. A doubling of the bandwidth has been achieved for a tripler by augmenting the circuit design. Also, characterization results of W-band MMIC triplers will also be presented. These state-of-the-art results are very promising when continuing to scale InP-based MMICs to higher frequencies, i.e sub mm-wave.

In addition, a 108 GHz HBV based tripler source is utilized in an imaging setup. A catadioptric lens and tapered waveguide detector are scanned over an extended (2-D) object. Several imaging examples in transmission mode will be presented.

HIGH RESOLUTION TERAHERTZ SPECTROSCOPY FOR DEFECT DETECTION

TETSUO SASAKI
SOPHIA UNIVERSITY

Tetsuo Sasaki was born in Takasaki City, Japan, in 1969. He received M.S. and Dr. Eng degrees in Mechatronics and Precision Engineering from Tohoku University in 1995 and 1998, respectively (Dr. thesis "Studies on high-speed Static Induction Thyristor (SIThy)"). 1998-1999, 2001-2008, he worked as a Researcher in Semiconductor Research Institute, Semiconductor Research Foundation, Sendai, Japan. 1999-2001, he was an Invited Researcher, Telecommunications Advancement Organization of Japan (TAO). Currently, he is an associate professor in Center for Priority Area (CPA), Tokyo Metropolitan University. His research interests include defects in semiconductor crystal and its application to high-power semiconductor devices, THz generation and its application to THz spectroscopy for Medicine, Biochemistry, etc.

Tetsuo Sasaki* and Jun-ichi Nishizawa
Sophia University, Semiconductor Research Insitute
Kioi-cho 7-1, Chiyoda-ku, Tokyo 102-8554, Japan
*e-mail: tsasaki@sophia.ac.jp

We have developed terahertz (THz) Signal Generators based on the proposal by Nishizawa in 1963 [1] to generate THz-wave via the resonance of lattice and molecular vibrations. Also Nishizawa realized a Gallium Phosphide (GaP) semiconductor Raman laser in 1979 [2] and generated a 12.1THz wave with a peak power as high as 3W in 1983 [3]. GaP crystal is an important element for high power and high purity THz-wave generation. Nishizawa developed the temperature difference method under controlled vapor pressure (TDM-CVP) liquid phase epitaxy (LPE) for precise stoichiometry controlled semiconductor crystal growth [4] and applied it to provide GaP crystal for THz-wave generation. Our THz Signal Generators are originally developed based on a lot of original works by Nishizawa. Nowadays, we have realized widely frequency tunable, high frequency purity, high power THz Signal Generators by difference-frequency generation (DFG) in Gallium Phosphide (GaP) crystals and applied them to THz spectrometers as light sources [5].

One of the most valuable uses of THz spectroscopy must be defect detection in organic materials. We have shown defects in organic material induced by gamma-ray radiation could be observed as a slight deviation of absorption frequencies in the THz region [6]. Defect detection in organic materials by high resolution and high accuracy THz spectrometry will develop new applications in lots of fields. For example, chemically refined products like as legal or illegal drugs would be revealed its maker, factory, or country, since different defects will be involved by different purification process or environment.

In the presentation, we are going to state our original development of THz generators. And we would like to show some examples of spectrum for organic materials containing defects.

References:
1) J. Nishizawa, Denshi Kagaku 14 (1963) 17.
2) J. Nishizawa, K. Suto, J. Appl. Phys. 51 (1980) 2429.
3) K.Suto, J. Nishizawa, IEEE J. Quantum Electron 19 (1983) 1251.
4) J. Nishizawa, Y. Okuno, IEEE Trans Electron Devices ED-22 (1975) 716.
5) J. Nishizawa, K. Suto, T. Sasaki, T. Tanabe T. Kimura, J. Phys. D: Appl. Phys. 36 (2003) 2958.
6) J. Nishizawa, T. Sasaki, K. Suto, M. Ito, T. Yoshida and T. Tanabe, Int J Infrared Milli Waves 29 (2008) 291.

INVITED LECTURE 12

A 210GHz 3D IMAGING RADAR SYSTEM BASED ON AN ANTENNA-INTEGRATED MMIC RECEIVER FRONT-END AND AN ULTRACOMPACT HBV TRANSMITTER SOURCE MODULE

JAN SVEDIN
SWEDISH DEFENCE RESEARCH AGENCY

Jan Svedin received the M.Sc. degree in applied physics and electrical engineering and the Ph.D. degree in theoretical physics from the Linköping Institute of Technology, Linköping, Sweden, in 1986 and 1991, respectively. Presently, he is working at the division of Information Systems at the Swedish Defence Research Institute. His current research interests are focused on antennas, components and subsystems for mm- and submm-wave imaging systems.

Jan Svedin[1*], Staffan Rudner[1,2], Gunnar Thordarsson[3], Sten E. Gunnarsson[2], Niklas Wadefalk[2], Sergey Cherednichenko[2], Iltcho Angelov[2], Herbert Zirath[2], Jan Stake[2], Tomas Bryllert[2], Josip Vukusic[2]
[1]Swedish Defence Research Agency; [2]Department of Microtechnology and Nanoscience, Chalmers University of Technology, SE-412 96 Sweden; [3]SAAB, Järfälla, Sweden
*e-mail: jan.swedin@foi.se

The development of a 210 GHz radar system intended to study security applications such as personnel scanning is reported. The system is designed to operate with a transmit antenna floodlighting the target scene and a mechanically scanned antenna-integrated receiver module. Range and cross-range resolution is achieved using the FMCW and the SAR technique, respectively. For increased performance and potential future volume production the receiver front-end is based on highly integrated MMICs manufactured using the IAF 0.1 μm GaAs mHEMT process made available through a Swedish-German MoU. A single-chip MMIC solution is being developed containing feed antenna, LNA, mixer and an LO multiplier-chain. The transmitter part is based on a high-power HBV quintupler source-module.

FRIDAY

NOVEMBER 20, 2009

LOCATION: Chalmerska huset, Södra Hamngatan 11

HIGH POWER THZ TECHNOLOGIES USING GYROTRONS AS HIGH POWER THZ RADIATION SOURCES

TOSHITAKA IDEHARA
UNIVERSITY OF FUKUI

Toshitaka Idehara received his MSc degree in physics and the DSc degree from Kyoto University in 1965 and 1968 respectively. He has been with University of Fukui since 1968 where he holds a position as associate professor in the Faculty of Engineering till 1990 and a position as professor between 1990 and 1999. He established Research Center for Development of Far Infrared Region in 1999 where he holds a position as a professor. Between 1999 and 2006, he was the director of the research center. After 2006, he is the supervisor of research in the center.

He was a visiting professor in 1985 with University of California (Davis), Department of Science. Since 1987, he organized international collaboration programs on 'High Frequency Gyrotron Development and Application' with University of Sydney, Stuttgart University, Karlsruhe Research Center, Institute of Applied Physics of Russian Academy of Science, Warwick University, etc. He was President of Japan Society of Infrared and Technology between 2005 and 2007. Since 2004, he has served as an Editor in Chief, International Journal of Infrared and Millimeter Waves. The title of the journal was changed in the beginning of this year. The present title is Journal of Infrared, Millimeter and Terahertz Waves.

His current research interest is Development of High Frequency Gyrotrons as High Power THz Radiation Sources and Their Application to High Power THz Technologies. He has supervised 5 Doctor theses works, and been the author of 6 books and about 380 scientific papers published in international journals and conferences. He has just received in April 2009 the Prizes for Science and Technology from Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT).

Toshitaka Idehara
Research Center for Development of Far Infrared Region, University of Fukui (FIR FU)
3-9-1 Bunkyo, Fukui-shi 910-8507, JAPAN
e-mail: Idehara@fir.fukui-u.ac.jp

The new high power THz radiation sources - CW gyrotron series in Research Center for Development of Far Infrared Region, Uiversity of Fukui (FIR FU), so-called Gyrotron FU CW Series [1], [2] are being developed for application to high power THz technologies. We have already developed Gyrotrons FU CW I, II, III, VI and V and Gyrotrons FU CW VI, VII, IIA and VIIA are being constructed.

In this paper, a brief introduction of these gyrotrons and applications to many kind of high power THz technologies are presented. The first application is development of high frequency DNP-NMR at 600 MHz for analysis of complicated protein molecule [3], the second is accurate measurement of hyperfine structure of positronium, the third is measurement with high resolution of magnetic resonance using an X-ray as a probe light, the fourth is submillimeter wave scattering measurement of plasma, the fifth is sintering of high quality ceramics for long-life controlling stick of nuclear plants and the sixth is development of new medical technology. All of these technologies are realized by using high power sub-THz or THz radiation sources. In FIR FU, we are applying our THz gyrotron series for development of these new THz technologies.

I have introduced our gyrotrons in the previous symposium held in Tokyo last year. In this second symposium, I would present mainly about the new high power THz technologies opened by using the gyrotron as radiation sources.

References:

1) T. Idehara, I. Ogawa, T. Saito, S. Mitsudo,Y.Tatematsu, La Agusu, H. Mori and S. Kobayashi, Development of THz gyrotrons and application to high power THz technologies, Terahertz Science and Technologies, Vol. 1, no.2, pp.100-106 (2008).

2) T.Idehara, T. Saito, I. Ogawa, S. Mitsudo, Y. Tatematsu and S. Sabchevski, The potential of the gyrotrons for development of the sub-terahertz and the terahertz range – a review of novel and prospective application, Thin Solid Films (2008), doi: 10.1016/j.tsf.2008.09.061.

3) T. Idehara, T. Saito, I. Ogawa, S. Mitsudo, Y. Tatematsu, La Agusu, H. Mori and S. Kobayashi, Development of Terahertz FU CW Gyrotron Series for DNP-NMR, Applied Magnetic Resonance 34 (2008) 265-275.

A 670GHz IMAGING RADAR FOR CONCEALED OBJECTS DETECTION

TOMAS BRYLLERT
CALTECH / JPL, CHALMERS

Tomas Bryllert received the degree of M.S. in Physics and the Ph.D. in Semiconductor Physics from Lund University, Sweden, in 2000 and 2005 respectively.

In 2006 he joined the Microwave Electronics Laboratory at Chalmers University of Technology, Sweden, where his main research interest was device- and circuit-technology for terahertz frequency multipliers

During 2007-2009 Dr. Bryllert was at the Jet Propulsion Laboratory (JPL), Pasadena, CA, funded by a research fellowship from the Wallenberg foundation - working on submillimeter-wave imaging radar and terahertz time-domain imaging systems.

Starting in September 2009, Dr Bryllert is with the Physical Electronics Laboratory at Chalmers, working on circuits and devices for millimeter wave applications. He is also, since 2007, CEO of Wasa Millimeter Wave AB – a company that develop and produce millimeter wave modules.

Tomas Bryllert
Physical Electronics Laboratory, Department of Microtechnology and Nanoscience,
Chalmers University of Technology, SE-412 96 Sweden
e-mail: bryllert@chalmers.se

We present a 670 GHz imaging radar, for concealed objects detection, that has sub-centimeter resolution in all three spatial dimensions. The FMCW radar transceiver is built on a back-end of commercial microwave components – with a front-end of custom designed frequency multipliers and mixers. The acquired images will be compared with those achieved with more traditional sub-millimeter wave active imaging techniques.

Most millimeter wave imaging systems developed up to this date are passive imagers that rely on *temperature differences* in the scene to provide the contrast – a hidden gun may be cooler than the skin of person. Also, for systems deployed outdoors, the cold sky acts to enhance contrast in passive mm-wave imaging.

It is straightforward to add illumination to a passive system to transform it into an active system. The illumination could consist of a single frequency continuous wave source or a high power noise source that radiates within a broad spectral band. In an active system the *reflected power* is detected by the receiver which means that the reflectivity of the objects in the scene provides the contrast. A severe limitation of active imagers is that the reflectivity of objects at mm-wave frequencies is strongly dependent on the angle of incidence of the illuminating power; this results in specular effects and an unpredictable brightness of objects which makes the images difficult to interpret.

A different approach to active imaging is to use radar technique. Profiting from the enormous bandwidth that can be achieved at submillimeter-wave frequencies and the short wavelength (~0.5 mm at 600 GHz), a resolution below one centimeter can be achieved in all three spatial dimensions. In the radar approach the image is reconstructed from the *range data* and is independent of the amount of power that is reflected, which eliminates the problem of specular effects and brightness ambiguities that plague regular, non-radar, active imaging.

This work was supported by the National Aeronautics and Space Administration., The Naval Explosive Ordnance Disposal Technology Division, with funding provided by the DoD Physical Security Equipment Action Group (PSEAG).

GaP Terahertz Signal Generator and Its Applications for Spectral Monitoring of Dynamic Reaction

TADAO TANABE
TOHOKU UNIVERSITY

TadaoTanabe was born in Sapporo City, Japan, on February 7, 1973. He received the M.S. and Doctor of Engineering degrees from Tohoku University, Sendai, Japan, in 1997 and 2000, respectively. In 2000, he became a Researcher at Venture Business Laboratory, Tohoku University, and in 2001, he became a Research Associate in the Department of Materials Science, Graduate School of Engineering, Tohoku University. His research interests include THz technologies, optoelectronic semiconductor materials, particularly interface control, and optoelectronic devices such as Raman amplifiers and THz generators.

Tadao Tanabe*[1], Jun-ichi Nishizawa[2], Yutaka Oyama[1],
[1]Department of Materials Science, Graduate School of Engineering, Tohoku University
[2]Center for Priority Area, Tokyo Metropolitan University
*e-mail: tanabet@material.tohoku.ac.jp

In 1963, Nishizawa proposed the generation of THz waves via resonance of phonons and molecular-vibrations in compound semiconductors [1,2], following the realization of a GaP semiconductor laser [3,4]. An electro-magnetic wave with a frequency of 12.1 THz was generated from GaAs pumped by GaP Raman laser, at a power of 3W [5]. Our group also succeeded in generating wide frequency-tunable THz wave signals from GaP with Q-switched pulse pumping. We constructed an automatic-scanning spectral measurement system in the THz frequency region using GaP. THz spectra have been measured for the infrared-active modes of dry biomolecules such as saccharides, DNA-related molecules, and amino acids.

For practical applications, we have recently developed THz diagnosis technologies of dynamic reactions. THz spectrum is sensitive to a crystallization condition. In polymerization reaction of organic on metal surface, THz diffuse reflectance spectrum reflects on the molecular weight. Deformation of polyethylene can be monitored using polarized THz spectroscopy. The THz-EYE diagnoses the inside of object even with covered by materials. THz ATR (attenuated total reflection) spectroscopic measurements are applied for sensing of living things.

Furthermore, THz signal generators have been developed with various functions. Generation of narrow-linewidth THz waves has very useful applications in the fields of high-resolution spectroscopy, optical communications and in-situ security screening. The CW THz waves are generated from GaP by using semiconductor lasers. The linewidth is about 4 MHz. A 30 cm-long portable THz-wave generator is constructed using two Cr:Forsterite lasers pumped using a single Nd:YAG laser. In case of THz wave generation from a waveguide-designed GaP, the waveguide effect has function of a high-efficient generation and an elliptically polarized THz wave generation.

References:
[1] J. Nishizawa “History and characteri-stics of semiconductor laser” Denshi Kagaku 14 (1963) 17.
[2] J. Nishizawa “Esaki diode and long wavelength laser” Denshi Gijutu 7 (1965) 101.
[3] J. Nishizawa, Japan patent 273217, 1957.
[4] J.Nishizawa,K.Suto, J. Appl. Phys. 51 (1980) 2429.
[5] K.Suto, J. Nishizawa, IEEE J. Quantum Electron 19 (1983) 1251.
.

INVITED LECTURE 16

OPTICAL DESIGN AND VERIFICATION OF THE 183 GHZ WATER VAPOR RADIOMETER FOR ALMA

SERGEY CHEREDNICHENKO
CHALMERS, OMNISYS INSTRUMENTS AB

Sergey Cherednichenko, was born in 1970 in Mariupol, Ukraine. He received the Diploma with Honour in Physics in 1993 from Taganrog State Pedagogical Institute (Russia), and Ph.D. degree in radio physics in 1999 from Moscow State Pedagogical University.

He has worked as a lecturer in general and experimental physics at Taganrog State Pedagogical Institute (1993-1995). He has been a visiting scientist at Chalmers University of Technology (Sweden), and Rutherford Appleton Laboratory (UK). Currently he is working at the Department of Microtechnology and Nanoscience at Chalmers University of Technology (Gothenburg, Sweden) as a post-doc (2000-2002s), Assistant Professor (2003-2006), and Senior Researcher (currently). He has been leading development of terahertz mixers for the Herschel Space Observatory, and multipixel terahertz receiver for ESA. His research interests include terahertz and millimetre wave heterodyne receivers and systems, RF measurements, optical and X-ray detectors, antennas, material properties at Millimeter wave and THz frequencies (Fourier Spectroscopy), thin superconducting films technology and their physical properties

.

Sergey Cherednichenko [1,2], Anders Emrich [2]
[1] Physical Electronics Laboratory, Department of Microtechnology and Nanoscience,
Chalmers University of Technology, Göteborg, Sweden
[2] Omnisys Instruments AB, V.Frölunda, Sweden
e-mail: serguei@chalmers.se

Atacama Large Millimeterwave Array (ALMA) is being built at a high altitude Atacama Desert in Chile. It will consist of 50 12m telescopes with heterodyne instruments to cover a large frequency range from about 30GHz to nearly 1THz. In order to facilitate the interferometer mode of operation all receivers have to be phase synchronized. It will be accomplished by phase locking of all local oscillators from a single reference source. However, a noticeable part of the phase error is caused as the signal propagates through the Earth atmosphere. Since this effect originates from the fluctuations of water vapors, it can be accounted for by carefully measuring the spectral width of one of water vapor resonance absorption lines. This will be done with a submillimeter heterodyne radiometer, Water Vapor Radiometer (WVR). WVR will measure the sky brightness temperature in the beam path of every telescope across the 183GHz water line with a spectral resolution of about 1GHz.

Accuracy of the calculated optical delay is determined by the combination of the radiometric accuracy of the WVR and of the errors originated in the WVR illumination of the telescope. We will describe major challenges in the design of the WVR to comply with the stringent requirements set to the WVR. Several approaches to simulate the quasioptical waveguide which brings the signal from the telescope's subreflector to the mixer horn, were used: fundamental mode Gaussian beam propagation, combined ray tracing with diffraction effects (using package ZEMAX), and a full vector electromagnetic simulations (using GRASP). The computational time increases rapidly from the first method to the last one. We have found that ZEMAX results are quite close to the one from GRASP, however obtained with nearly instant computation, which allows multiple iterations during system optimization. The beam pattern of the WVR and of WVR with the optical Relay (used to bring the signal from the telescope's main axis to the WVR input window) was measured by a scalar beam scan at four planes in the far field. The experimental results correspond to the simulated ones with a high accuracy. The WVR illuminated the telescope subreflectos with less than 1.5% spill over while maintaining a high aperture efficiency. We developed an approach to calculate the beam center position at the subreflector (with is at 6m from the WVR) from our test data (at maximum 2m from the WVR) in order confirm the maximum beam deviation does not exceed 20mm, i.e. 1/15 of the beam width.

INVITED LECTURE 17

LOW-FREQUENCY DYNAMICS IN CONDENSED PHASES STUDIED BY TERAHERTZ RADIATION SPECTROSCOPY

KEISUKE TOMINAGA
KOBE UNIVERSITY

Keisuke Tominaga was awarded his Ph.D. degree from Kyoto University, Japan in 1990 and joined the Department of Chemistry, University of Minnesota, where he was a postdoctoral associate working under supervision of Professor Paul F. Barbara. He became a research associate at Institute for Molecular Science, Japan in 1992. He joined the Department of Chemistry, Kobe University as an associated professor in 1998. In 2001 he became a professor of Molecular Photoscience Research Center, Kobe University, and he is a director of the research center now.

His main research interest is to investigate chemical reactions and relaxation phenomena in condensed phases, especially in liquids. Molecules in liquids interact with each other in a complex manner, and this complicated interaction is a source of various aspects of the dynamical behaviors in liquids. In order to understand chemical events in condensed phases including reactions in biological molecules, it is necessary to investigate fundamental properties in the condensed phases in a molecular level. His primary tool for studying the dynamics of liquids is ultrafast spectroscopy. The techniques he employs include fluorescence up-conversion, transient absorption, nonlinear optical spectroscopy, and terahertz radiation spectroscopy. It is now possible to generate routinely laser pulses that are a few tens of femtoseconds in duration, which is on the characteristic time scale of the fastest chemical events in solution. Ultrafast pulses give us the ability to initiate events in liquids and then to monitor these events im real time.

.

Keisuke Tominaga
Molecular Photoscience Research Center, Kobe University, Nada, Kobe 657-8501 JAPAN
e-mail: tominaga@kobe-u.ac.jp

The low-frequency region below several terahertz (THz; 1 THz = 33.3 cm^{-1}) corresponds to intermolecular modes of complexes and intramolecular modes with a weaker potential force and/or larger reduced mass. Intermolecular interactions such as hydrogen bonding, van der Waals forces, and charge-transfer interactions play important roles in various chemical and biological processes. Moreover, the low-frequency spectra also reflect molecular dynamics on a time scale from picoseconds to femtoseconds. Especially, this low-frequency region is important for expression of proteins. When proteins express their functions, large conformational changes often occur. These conformational changes result from collective motions of a large number of atoms. Such motions of proteins have characteristic frequencies in the low-frequency region below a few tens of wavenumbers. Furthermore, it is well known that when proteins express their functions water molecules trapped internally and those surrounding the proteins play an important role. In this work, we have measured the low-frequency spectra of bacteriorhodopsin (BR) at various conditions of hydration and temperature using terahertz time-domain spectroscopy. We investigated effect of hydration and temperature on the low-frequency spectra of BR and discuss the relation with expression of their function.

From the obtained spectra of the refractive index and absorption coefficient we calculated Reduced Absorption Cross Section (RACS) in the low-frequency region which is proportional to vibrational density of state (VDOS). It was found that the RACS of the BR samples shows a power-law behavior (RACS$\propto \nu^{\alpha}$). At room temperature, the power-law of the dry sample is α = 1.97±0.02. The value of the exponent α becomes smaller as the amount of hydration increases. For harmonic oscillators of a three-dimensional crystal lattice, its VDOS is proportional to a square of frequency. By comparing the ideal case, anharmonic coupling among the low-frequency modes of BR becomes larger as the amount of hydration increases. Furthermore, the temperature dependence of the exponent is similar for both the dry and hydrated samples in the temperature range from -100°C to -40°C However, above -40°C the hydrated samples show stronger temperature dependence than the dry samples. It shows that for the hydrated sample anharmonic coupling is induced above -40°C by increasing temperature. This change is due to the dynamical transition that was reported by the study of inelastic neutron scattering.

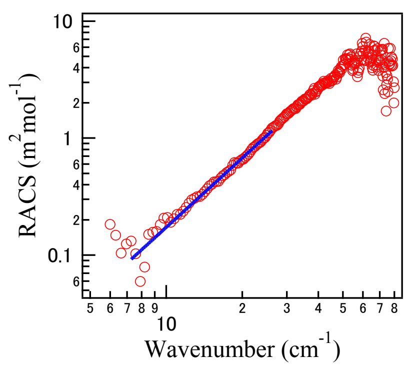
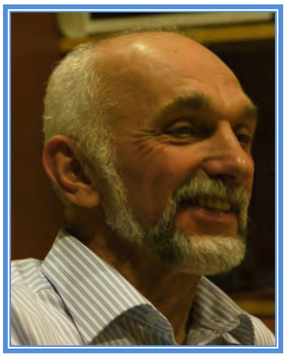


Fig.1 RACS of BR in the THz region.

ULTRA-SENSITIVE COLD-ELECTRON BOLOMETERS FOR THZ RECEIVERS

LEONID KUZMIN
CHALMERS



Leonid Kuzmin was born in Russia. In 1971 he has received his MSc degree from Moscow University, and three years later PhD from the Institute of Radio Engineering and Electronics. In 1977 he was awarded by Candidate of Science, which corresponds to PhD in Physics, for his thesis “Nondegenerate single-frequency parametric amplification using Josephson junctions with self-pumping”. In 1984 he was awarded by Discovery Agency from the USSR Committee of Discoveries for his “Phenomenon of nondegenerate single-frequency parametric regeneration of oscillations in systems with weak superconductivity”. He became a Doctor of Science in 1997,

During his scientific career he held positions in Moscow State University (Russia), Chalmers University of Technology (Sweden) and PTB (Germany). From March 2009 he is a Professor at the Chalmers University of Technology. Currently he is working on development of Cold-Electron Bolometers for the European balloon telescope BOOMERANG, with possible application for Japan-ESA Space Spectrometer SPICA and ESA Space Polarometer B-Pol and Far Infrared Interferometer FIRI.

His major fields of interest are: single electronics, Josephson effect, superconductor electronics and low noise microwave devices.

Leonid Kuzmin
Department of Microtechnology and Nanoscience,
Chalmers University of Technology, Sweden
e-mail: leonid.kuzmin@chalmers.se

In this document we present a programme for developing arrays of mm-wave to FIR bolometers for the next generation of astronomical instruments that should lead to the next breakthrough in Cosmology. The research programme is based on the full development of the Cold-Electron Bolometer (CEB) invented at Chalmers University. The CEB is a detector with strong electro-thermal feedback based on direct electron cooling of the absorber. The operational principle is the same as for TES (Transition-Edge Sensor) but additional dc heating is replaced by effective electron cooling. As a result, electron temperature is decreased and incoming power is removed from the absorber. These two factors considerably improve performance of the CEB and bring high sensitivity and high saturation power.

These detectors should have a very high sensitivity, i.e. 10^{-18} W/Hz$^{1/2}$ in case of photometry and 10^{-20} W/ Hz$^{1/2}$ when used to read-out a spectrometer with a resolution R = 10^3- 10^4. The CEBs can easily be integrated into planar antennas.

Development of the array of 90 CEBs for 350 GHz is planned the BOOMERANG-3 balloon telescope (Paolo de Bernardis, Rome University). The developed system could be transferred to the ESA space polarimeter B-Pol and tested for other projects: Japan - ESA space spectrometer SPICA and ESA far infrared interferometer FIRI. The programme would allow to make a substantial contribution to short-term and long-term Cosmology experiments. The SPICA could be subject of Japan – Sweden collaboration for development of Ultra-sensitive THz receivers.

Development of an ultra-sensitive and fast Optical /UV CEB photon counter with array of CEBs. To test a novel promising concept of the Matrix Photon Counter with CEBs. Comparison of spatial, energy and temporal (arrival time) resolution with KID and TES technologies.

INVITED LECTURE 19

INTEGRATED SCHOTTKY RECEIVERS AND GRAPHENE FOR FUTURE THZ ELECTRONICS

JAN STAKE
CHALMERS

Jan Stake was born in Uddevalla, Sweden in 1971. He received the degrees of M.S. in electrical engineering and Ph.D. in microwave electronics from Chalmers University of Technology, Göteborg, Sweden in 1994 and 1999 respectively.

In 1997 he was a research assistant at the University of Virginia, Charlottesville, USA. From 1999 to 2001, he was a Research Fellow in the millimetre wave group at the Rutherford Appleton Laboratory, UK, working on MMW/Sub-MMW components. He then joined Saab Combitech Systems AB as a Senior System Consultant, where he worked with RF/ microwave technology in automotive, space and defence industry until 2003. From 2000 to 2006, he held different academic positions at Chalmers and was also the Head of the Nanofabrication Laboratory (clean room) at MC2 between 2003 and 2006. During the summer 2007, he was a visiting professor in the Submillimeter Wave Advanced Technology (SWAT) group at Caltech/JPL, Pasadena, USA. He is currently a Professor and the Head of the Physical Electronics Laboratory at the department of Microtechnology and Nanoscience (MC2), Chalmers, Göteborg, Sweden. His current research are graphene electronics, high power Heterostructure Barrier Varactor (HBV) multipliers and Uni-Travelling-Carrier Photodiode mixers (UTC-PDs) for terahertz signal generation, novel Schottky diode mixer circuits for sub-millimetre wave applications and terahertz technology for biomedical applications. He is also a co-founder of Wasa MillimeterWave AB.

[a,c]Jan Stake, [a]Omid Habibpour, [c]Aik-Yean Tang, [c]Huan Zhao, [a]Vladimir Drakinskiy, [b,c]Peter Sobis, [a]Josip Vukusic, and [a]Tomas Bryllert
[a]Physical Electronics lab., Department of Microtechnology and Nanoscience, Chalmers University of Technology, SE-412 96 Sweden. E-mail: jan.stake@chalmers.se
[b]Omnisys Instruments AB, V. Frölunda, Sweden.
[c]GigaHertz Centre, Department of Microtechnology and Nanoscience, Chalmers

THz or submillimetre-wave sensing covers the frequency range from 300 GHz to 10 THz (wavelengths from 1 mm to 30 μm). With energy levels in the 1.2-40 meV range, terahertz interactions with matter involve intermolecular, rather than atomic transitions. This gives rise to some imaging and spectroscopy applications that are unique to this particular region of the electromagnetic spectrum. Still, the terahertz spectral region is by far the least explored portion of the electromagnetic spectrum. A great obstacle has been the absence of robust and reasonable inexpensive receiver components that can operate at room temperature. This talk will consist of two parts: a) room temperature technology for THz applications and b) emerging Graphene based THz-electronics.

There is a need for compact heterodyne receivers operating in the sub-millimetre wave band above 300 GHz for earth observation instruments and space science missions. The sub-millimetre wave or terahertz domain allows studying several meteorological phenomena such as water vapour, cloud ice water content, ice particle sizes and distribution, which are important parameters for the hydrological cycle of the climate system and the energy budget of the atmosphere. At “low frequencies”, up to around 300 GHz, discrete (standard) diodes and even HEMT MMIC technology can be used. Monolithically integrated diode circuits (MMICs) are needed at higher frequencies, say >400 GHz, due to transmission line losses and the fabrication tolerances. We are currently pursuing studies of high functionality THz mixers (SSB) and in-house fabrication of monolithically integrated Schottky diode circuits. Results and progress on single side band mixers, integration techniques and optimisation of terahertz Schottky diodes will be presented.

Graphene, a single two-dimensional atomic layer of carbon atoms, brings a possibility of creating novel electronic devices especially at THz band because of its unique band-structure as well as its high intrinsic electron and hole mobility. There are several theoretical papers predicting the nonlinear electromagnetic response of the graphene. We are currently investigating odd harmonic generation in suspended graphene when illuminated by a strong pump source at around 100 GHz. Initial results with an antenna integrated graphene circuit will be presented.

The talk will cover the latest results obtained from Chalmers on Schottky diode mixers for terahertz frequencies (sensors), as well as results from initial investigations of Graphene based electronics.

Three-colour far-infrared image of M51, the ‘whirlpool galaxy’ made by Herschel/PACS.
Credits: ESA and the PACS Consortium