Fundamentals and Engineering Considerations of Terahertz Technologies: from Devices to Applications

Organisers
Dimitris Pavlidis, Boston University & National Science Foundation, USA
Imran Mehdi, Jet Propulsion Laboratory (JPL), USA
Javier Mateos, University of Salamanca, Spain

Abstract
THz technology development is a vibrant scientific field with new discoveries and techniques being utilized to advance the State-of-the-Art. While novel material systems such as graphene have shown promise in the THz range, fully functional systems in the THz range are also becoming more common. This workshop will bring together experts from various academic, national labs and commercial enterprises to discuss the most recent advances in their respective fields and to provide insight into what the future might hold for exploration of this frequency range. It will focus on a variety of materials such as traditional III-Vs, III-Nitrides and Graphene, as well as various device concepts for efficient THz generation and detection. The operation of the components to be discussed is based on plasmonics, photoconductors, plasma waves, photomixing, Resonant Tunneling, Negative Differential Resistance. Devices such as Quantum Cascade Lasers and Self-switching Diodes will also be addressed. The Workshop is intended primarily for young scientists and engineers who are interested in learning about this emerging field, but is also useful for individuals with a more advanced understanding of related concepts. The topics addressed include fundamental and engineering considerations. The latest results in Terahertz technologies will also be presented.
8:40 - 9:10 Terahertz Applications and Upcoming Space Missions
Imran Mehti, Jet Propulsion Laboratory, Pasadena, CA, USA

Abstract
Despite great scientific interest since at least the 1920's, the THz frequency range remains one of the least tapped regions of the electromagnetic spectrum mostly due to lack of robust technology. For over 25 years the sole niche for THz technology has been in the high resolution spectroscopy and remote sensing areas where heterodyne and Fourier transform techniques have allowed astronomers, chemists, Earth, planetary and space scientists to measure, catalog and map thermal emission lines for a wide variety of lightweight molecules. As it turns out, nowhere else in the electromagnetic spectrum do we receive so much information about these chemical species. In fact, the universe is bathed in THz energy, most of it going unnoticed and undetected. The talk will address various THz applications. The status of the THz technology will be reviewed and the challenges faced will be discussed. Various critical needs will be reviewed. They include smaller packages better devices/circuits of innovative character and higher bandwidth, higher efficiencies (DC and RF), robust scalable back-ends and standardized testing. The existing sub-millimeter missions and payloads will be described together with proposed future instruments.

9:10 - 9:40 Fundamentals and Latest Results on Nitride-based Two- and Three-Terminal Devices for frequencies extending to Terahertz
Dimitris Pavlidis, Boston University, USA

Abstract
III-Nitride based devices present very attractive characteristics for electronic applications, including high saturation velocity and high breakdown voltage. Applications with frequency of operation ranging from microwaves to millimeter-waves and Terahertz can therefore benefit enormously from them. The basic properties of both two- and three terminal devices made with III-Nitrides will be presented and related to material characteristics and their Terahertz system applications. The talk will address fundamental properties of materials and devices including their design, processing and characterization. Designs for fundamental frequency signal generation using Negative Differential Resistance, as well as frequency multiplication with two terminal devices capable of handling the large power available using solid-state approaches at millimeter frequencies will be discussed. The latest developments on the above components, as well as devices such as Resonant Tunneling Diodes, and Tunneling Hot Electron Transfer Amplifiers will be discussed.

10:50 - 11:20 Frequency increase and high functionality of room-temperature terahertz oscillators using resonant tunneling diodes
Masahiro Asada and Satoshi Suzuki, Tokyo Institute of Technology, Japan

Abstract
Compact and coherent source is a key component for various applications of the terahertz wave. In this talk, our recent results of terahertz oscillators using GainAs/AlAs resonant tunneling diodes (RTDs) will be reported. Using a combination of an RTD with short transit time and a planar slot antenna with reduced loss, a fundamental oscillation up to 1.86 THz has been obtained at room temperature. Direct intensity modulation up to 30 GHz, which is convenient for high-speed wireless data transmission, and wide frequency sweep with integration of varactor diodes have also been demonstrated.

11:20 - 12:00 THz Optoelectronic devices
Yanko Todorov, Stefano Barbieri, Djamal Gacemi, Maria Amanti, Angela Vasanelli and Carlo Sirtori, Université Paris-Diderot, France

Abstract
In the THz frequency range efficient detectors and emitters based on semiconductor quantum structure are still difficult to realise. Efficient sources have been strongly impulsed by terahertz quantum cascade lasers, while on the detection side there is still not a dominant solution. To increase the efficiency of THz devices we have studied hybrid light-matter systems, where the energy exchange between light and matter is controlled by the photonic environment or by cooperative effects of huge collections of interacting electrons. Plasmonic THz photodetectors have been realized by implementing the absorbing region of a THz quantum well detector with an antenna-coupled microcavity array. These results demonstrate a clear improvement in the performance of THz detectors that operates, with background limited performance, up to 25K. Novel optoelectronic emitters operating in the ultra strong coupling regime have shown emission at 3THz. Finally superradiance emission have been observed from an electrically injected heavily doped quantum well.

13:50 - 14:20 Physical Limits and Latest Developments of Terahertz Plasma Field Effect Transistor Detectors
W. Knapp, D. But, A. El Fatimy, P. Buzatu, O. Klimenko, N. Diakonova, L2C & TERALAB Montpellier University &CNRS, Montpellier, France

Abstract
TWO -dimensional electron plasma in nanometer size field effect transistors can oscillate in Terahertz (THz) frequencies, far beyond transistors fundamental cut- off frequencies. Interest in using nanometer field effect transistors (FETs) for THz applications was initiated in the early '90s by the theoretical work of Dyakonov and Shur who predicted that the channel of a FET could act as a resonator for plasma waves and that THz radiation can be efficiently rectified FET. Rectification and detection of THz radiation is also possible in the non-resonant case, (low electron mobility) when plasma waves decay at the distance smaller than the channel length. Typical length of this region ranges from 30nm to 300nm. Therefore, both resonant and nonresonant plasma wave THz detection requires nanometer scale FETs. The real large scale interest in using FETs as THz detectors started around 2004 after first experimental demonstration of sub-THz and THz detection in silicon CMOS FETs. Both pioneering works have clearly stated importance of Si- CMOS FETs which present the advantages of room temperature operation, very fast response times, easy on-chip integration with read-out electronics and high reproducibility leading to straight-forward array fabrication. We propose a review of important and recent (2012/2013) results on terahertz detection using nanometer size FETs. The subjects were selected in a way to stress some new
physical aspects and developments rather than purely technological or engineering improvement.

We would like to address the basic physics related problems like power dependence of the photoresponse, temperature dependence, of the response [5], and helicity sensitive detection.

Until now, most work on nanometer FETs detectors considered mainly THz imaging applications. We show also the progress in the application of nanometer FETs as detectors in THz wireless communication. Finally we would like to present results from THz detection by graphene transistors. And discuss possible developments of future THz detectors using nanowires

14:20 - 15:00 Graphene-based terahertz optoelectronic devices
Berardi Sensale-Rodriguez, University of Utah, USA

Abstract
This talk will discuss how the unique physical properties of graphene can be harnessed to develop novel high-performance active terahertz devices and systems. Recent applications of graphene as the active medium in reconfigurable terahertz metamaterials - such as electroabsorption modulators, phase shifters, and tunable filters - will be discussed, as well as the advantages of these graphene-based devices for spectroscopy, imaging, and beam forming applications.

15:00 - 15:30 High performance terahertz radiation sources based on plasmonic photoconductors
Mona Jarrahi, University of California in Los Angeles (UCLA), USA

Abstract
Use of nano-antennas and plasmonic light concentrators in photoconductive terahertz sources has proven to offer significantly higher terahertz radiation powers by enhancing photoconductor quantum efficiency while maintaining photoconductor ultrafast operation. In this talk I will present an overview of some of the recent advancements in photoconductive terahertz sources based on plasmonic contact electrodes, enabling significant enhancement in efficiency and output power of photoconductive terahertz sources. I show that the significant performance enhancement offered by plasmonic contact electrodes can be utilized to achieve record-high optical-to-terahertz conversion efficiencies as high as 7.5% and milliwatt terahertz power levels in both continuous-wave and pulsed operation at optical pump wavelengths ranging from 800 nm to 1550 nm.

16:10 - 16:40 GaAs-Based Extrinsic-Photoconductive THz Sources Driven at 1550 nm
E.R. Brown, J.R. Middendorf, and J.S. Cetnar, Wright State University, USA

Abstract
A breakthrough in the THz field during the past 20 years has been the advent of ultrafast semiconductor materials having ultrafast (< 1 ps) electron-hole recombination time and therefore the ability to generate useful levels of THz radiation by laser-excited switching and photomixing. The leading material for this advancement has been low-temperature-grown (LTG) GaAs, and the laser technology has been Ti:sapphire mode-locked lasers (for switching) or GaAs-based single-frequency diode lasers (for photomixing), both emitting between 750 and 800 nm, and the mechanism is generally ultrafast intrinsic photoconductivity. This presentation will summarize recent research to develop GaAs-based THz sources driven at 1550-nm where laser sources are much more affordable and easy to integrate into systems large because of devices and components from the 1550-nm fiber-optic telecommunications industry. The mechanism for THz generation in GaAs at 1550-nm is attributed to ultrafast extrinsic photoconductivity. The understanding of this mechanism requires several topics in solid-state physics, including electron transport in metallic-dopant impurity bands, strong sub-band gap radiative absorption by such impurities, strong electron capture cross sections to produce ultrafast lifetime, and of course THz qualification by fabrication and characterization of real devices embedded in planar antennas.

16:40 - 17:10 Photomixing mW THz sources
G. Ducournau, P. Latzel, F. Pavanello, E. Peytavit, M. Zaknoune, J.-F. Lampin, IEMN, Villeneuve d’Ascq, France

Abstract
We will present our new approaches concerning high power photomixers at 0.8 µm wavelength: Fabry-Pérot LT-GaAs metal-metal resonators. We will show that with this device particularly robust against thermal destruction, a lower impedance is possible. Using impedance matching we will show that more than 1 mW can be produced around 250 GHz. Furthermore this device can be used as a downconverter with low conversion losses. We will show also our new results concerning uni-travelling-carrier photodiodes at 1.55 µm wavelength.