FP6-IST-511415

TeraNova

Novel Terahertz Sensing & Imaging Systems For Biotechnology, Healthcare, Security & Process Monitoring

Integrated Project

Information Society Technologies: Optical, Opto-electronic & Photonic Functional Components

PUBLISHABLE FINAL ACTIVITY REPORT

(Deliverable: D2.6)

APPENDICES

APPENDIX I

TECHNICAL HIGHLIGHTS - BY WORKPACKAGE AND THEME (A, B & C)

A1

INITIAL OBJECTIVES

A near IR laser, suitable for use in a broadband THz system with the following character-istics: pump power < 2W; fibre delivery over 1.5m; 0.2m^2 footprint; €20K price; >100MHz repetition rate.

PROGRESS

Period #1

1. An ultra-compact Ti: Sapphire laser sources optimized for THz applications have been constructed. The footprint of opto-mechanical components including the pump laser and diagnostic devices could be reduced to 0.13 m². At the same time improved quality for dispersive mirrors reduces the requirement for high expensive solid state pump lasers. No more than 1.5 W is necessary to achieve up to 200 mW average power from a 20 fs Ti: Sapphire laser which is more than sufficient for a powerful THz-TDS measurement. Hence the price of the commercial fs-laser could be cut in half compared to a oscillator pumped by a 5 W source five years ago.
2. A saturable Bragg mirror has been initially introduced into the cavity in order to initiate and stabilise mode locking. In the course of this work package it was replaced by an automated mechanical starter to have highest efficiency without compromising the stability of the laser.
3. Integrated diagnostics have been included which enable the system to be operated by a non-expert.

Period #2

4. Due to careful balancing of dispersion compensation as well as the laser parameters, it was possible to transmit femtosecond pulses over 1.5 m of single mode fibre.
5. With this arrangement, an average laser power of greater than 45 mW and less than 90 fs in duration yields a peak power of greater than 6.8 kW ex fibre.

Period #3

6. The life-time of an intra-cavity THz antenna mirror in a femtosecond laser is increased up to four times.
7. Compact small pump sources (2 to 2.5 W) can be used with laser.
8. Regardless of life-time, 2.5 W intra-cavity power with 30 fs pulses can be achieved on the antenna with a 5 W pump source. Although long-term stability issues are still preventing commercial usage this study gives much insight and shows the limits of the current technology.

Work completed at M36.

A2

INITIAL OBJECTIVES

Quantum cascade lasers with: 1THz operation (200K operation by M24 and Peltier cooling at M48); Routine power >10mW; and single mode operation.

PROGRESS

Period #1

1. Quantum cascade laser (QCL) structures have been realized fully covering the region 2 – 2.5 THz, following optimization of the active region design and developments in waveguide technology.
2. The region 1.5 – 2 THz has also been tackled with the application of magnetic field; a procedure that has also been yielding important information on the electron dynamics and on the relevance of lateral confinement.
3. Distributed feedback technology has been successfully implemented and various approaches have been developed that could be applied independently of the emission wavelength. Single mode devices have then been fabricated in a variety of devices.
4. External cavity operation has also been studied and the possibility of selecting longitudinal modes has been proven.
5. Phonon-based structures (for possible high temperature operation) have been studied in detail leading to designs routinely exhibiting operation above 100 K.
6. Lasing has been demonstrated for the first time in the InP-based QCLs.
7. A new world record low emission frequency of 1.6 THz for THz QCLs without a magnetic field using the design proposed by UniNe ed system, which is potentially more promising for high temperature operation.

Period #2

8. A new world record low emission frequency of 1.35 THz achieved by UniNe with single well active regions and application of magnetic field.
9. The first external cavity THz QCL, implemented by SNS and showing tuning over 90 GHz (hop-free continuous over 15 GHz).
10. The successful combination of THz time domain measurement techniques with THz quantum cascade lasers. This allows the determination of waveguide loss and gain bandwidth in the frequency range between 0.5 and 4 THz.
11. The threshold gain that can be obtained with QCLs is as large as 20 cm^{-1} and the gain bandwidth is 300 GHz for the bound-to-continuum design of structure.
12. Temperature dependent measurements in QCLs unveil additional absorption processes activated at higher temperatures.
13. Successful combination of THz time domain measurement techniques with THz quantum cascade lasers. Allows the determination of waveguide loss and gain bandwidth in the frequency range between 0.5 and 4 THz.
14. The threshold gain is as large as 20 cm^{-1} and the gain bandwidth is 300 GHz for the bound-to-continuum design.

Period #3

15. THz Quantum Cascade Laser (QCL) operation has been extended to 1.2 THz without magnetic field.
16. QCL operation has been extended to 800 GHz with magnetic field.
17. Threshold current densities < 1A/cm2 have been achieved in magnetic field
18. InP-based THz lasers have been demonstrated above liquid nitrogen temperature.

19. InP-based THz QCLs have been operated in continuous wave.
20. Single-mode non-periodic DFB lasers have been demonstrated.
21. The first measurement of linewidth enhancement factor for a THz QCL has been made.

Period #4

20. InP-based THz lasers with double-metal waveguides: continuous wave operation up to 70 K, pulsed above 100 K, with low electrical consumption.
21. Vertical emission microdisk and micro ring lasers: ~ 5 degrees beam divergence and up to 10 mW output power.
22. First evidence of coupled cavity operation in lasers with Fibonacci diffraction gratings.

A3

INITIAL OBJECTIVES

Laser mixed systems with the following characteristics: Tuneability over 1THz; operation with small, cheap (optical fibre) diodes; THz Power output to 1 microwatt using cheap photodiodes; and developments with QCLs, to include integrated sources with good stability and heat management.

PROGRESS

Period #1

1. A NIR dual frequency laser operating at 1.06μm has been built to test photomixers.
2. Nonlinear optical generation of tuneable, CW THz has been investigated in a semiconductor waveguide. The modal pattern in the guide has been simulated and the design optimized for maximum phase matching.
3. QCLs have been designed for emission at 15μm. These will eventually be used in a dual frequency QCL-based scheme to generate CW THz radiation.

Period #2

4. A 2μm-thick LT grown InGaAs photomixer has been realised and THz outputs have been observed with a power of a few nanowatts.
5. A THz QCL has been grown which is both the source of THz radiation and the nonlinear medium. When pumped with a NIR beam sidebands are observed. These results show the possibility of a strong interaction between the NIR and THz ranges and therefore a promising scheme for THz generation.

Period #3

6. THz side-band generation on a telecom optical carrier at 1.55μm has been demonstrated.
7. Direct modulation at 13 GHz of a 3 THz QCL, followed by an up-conversion at telecom wavelength, has been demonstrated.
8. Non-linear ridge waveguides for nonlinear mixing at 1.03 μm have been realised.

Period #4

9. A dual frequency Er:Yb:glass laser has been realised with an output power compatible, if necessary, with further amplification in an EDFA.
10. This laser is now ready to perform non-linear mixing experiments in both the passive IR/THz waveguides and the THz QCLs (including a near IR waveguide).
11. 15μm QCLs have been optimised in order to reach room temperature operation. THz side-band generation on a telecom optical carrier at 1.55μm has been demonstrated.

A4

INITIAL OBJECTIVES

This Workpackage addresses detection schemes designed to exploit the potential offered by QCL sources. The aim is to build sensitive, non-cryogenic, and phase-sensitive opto-electronic detection with unprecedented large dynamic range and bandwidth. Therefore, the objectives are: (i) A heterodyne detection system with a THz QCL as local oscillator; (ii) Detection system based on laser mixing in a non-linear crystal; (iii) Exploring the potential of THz QC structures for amplification of few-cycle THz pulses and building a modulator with a THz QC structure as an active medium.

PROGRESS

Period #1

1. Time domain THz spectroscopy of the probe pulses experiencing the modulation in active/passive THz QCL was performed.
2. An optical system resembling a microscope objective at THz frequencies has been designed, built and satisfactorily tested. Such system enabled efficient coupling into the THz waveguides.
3. We have demonstrated a modulation of a THz QCL by means of near-infrared pulses from Ti:Sapphire laser. The output power of the THz QCL thus can be modulated -100% to +30% of the nominal output power.

Period #2

4. Successful combination of THz time domain measurement techniques with THz quantum cascade lasers. Allows the determination of waveguide loss and gain bandwidth in the frequency range between 0.5 and 4 THz. The threshold gain as large as 20 cm^{-1} and the gain bandwidth of 300 GHz was observed for the bound-to-continuum THz-QCL design.

Period #3

5. Development of a highly efficient method of coupling of free space propagating THz waves into waveguide of THz-QCL has been accomplished.
6. Amplification of a narrow band (FWHM~150 GHz) coherent THz pulse at 2.0 and 2.9 THz, by means of THz-QCL gain medium, has been achieved.
7. The first scientific demonstrator of a compact THz emitter/amplifier unit has taken place.
8. Based on the interaction of broadband THz waves with a quantum cascade structure has been previously investigated, we have evaluate the potential of different THz-QCL designs for building a THz amplifier. In particular, we have focused on gain-bandwidth, gain- saturation, and gain-recovery features for different schemes of optical transitions (i.e. with phonon depopulation or scattering depopulation).

Period #4

9. Amplification with factor ten has been accomplished for the compact THz emitter/amplifier unit.
10. The experimental method devised at TU Wien has been applied for the development of the THz – QC gain medium with bandwidth ~ 0.5 THz. The Project Partners, University Paris VII and University Neuchatel, have provided the necessary theoretical input for THz-QCL gain region optimization with respect to the experimental data provided by TU Wien.
    Consequently, University Paris VII has designed a (so-called) mini-broadband THz-QCL that has been tested with respect to gain-bandwidth in the unique terahertz

experimental set-up at TU Wien. The gain region of device consists of three different regions, each exhibiting gain with spectral width of about 0.15. A combination of those regions provides gain with almost 0.5 THz bandwidth.

B1

INITIAL OBJECTIVES

Development of a high-throughput biochip genetic diagnostic system, which will also be compact and inexpensive. Final implementation with QCLs

PROGRESS

Period #1

1. A biochip sensor has been designed. Planning of the project has been undertaken.

Period #2

2. The THz biosensor-chips that have been developed within the *TeraNova* project are the only devices in the world that use a modular chip-based concept of separable THz components. This is highly significant, as it implies very low-cost biochips can be realized.
3. In the resonant sensing approach used by the DNA sensor chips in the *TeraNova* project, the quality factor is an essentially important parameter to achieve high sensitivity detection. Resonators with a maximum Q-factor of Q = 400 have been realized which is by a factor of approximately 40 times larger than metallic waveguide based resonators that have been demonstrated by other groups.

Period #3

4. A world-first concept for fluidic sensing at THz frequency based on a dielectric THz waveguide, including a micro-fluidic channel, was developed and tested. The sensor approach is able to handle and detect fluid sample volumes in the pl-range.
5. A numerical model for surface-functionalized DNA sensors was developed. The model enables a precise and resource-efficient calculation of the sensor response to DNA monolayer hybridization.
6. Sensor-chips developed in *TeraNova* remain the only devices in the entire world that use a modular chip-based concept of separable THz components, providing an enabling route to low-cost biochips.
7. Frequency Selective Surface (FSS) sensor chips were optimized and a full theoretical understanding of their operation mode was achieved.
8. An optimized QCL based biochip reader setup was established which allows high spatial resolution (200µm), high dynamic range (14 bit) measurements.

Period #4

9. Successful demonstration of a new flow-through capillary waveguide coupler configuration enabling the in-line probing of controlled fluid sample volumes for bio-sensing in fluidic environment has been accomplished.
10. The use of a modular polymer chip-based concept of separable THz components has been demonstrated.
11. Extensive investigation of the operation of the Frequency Selective Surface chips has been performed.
12. A QCL reader set-up which offers high spatial resolution and high dynamic range has been perfected.

B2

INITIAL OBJECTIVES

Development of a THz near-field microscope with the following characteristics: Range 300GHz – 3 THz; Spatial resolution 2–3 μm; 15 minute scan time for 50x50 pixel image of a small crystallite; and a price tag of €300K.

Period #1

1. A near-field THz microscope has been constructed.
2. An analysis of field-tip interactions has been undertaken; the role of the antenna as a filter has been clarified.
3. Increased resolution is noted when the tip is vibrated and the result is interpreted in terms of the origin of the near field at different parts of the tip.

Period #2

5. A model, based on a wire antenna, was developed to describe the properties of the near-field of a metal tip. This model is shown to be superior to existing models, which treat the tip as a metal sphere or a cone.
6. Measurements on biological samples, provided by Renishaw, were performed
7. Near-field microscopy of THz plasmons was performed with sub-wavelength spatial, and sub-oscillation-period temporal resolution. Measurements are suggestive of new method to increase field strength at metal tips.

Period #3

8. Measurements of the near-field of a single, sub-wavelength hole in a metal film have been performed and compared with an analytical model from Bouwkamp (1950). Using THz-TDS, tests of this model have been performed using broadband near-field THz microscopy.
9. These near-field measurements indicate that the most important predictions made by the model are correct. The model is an improvement over a standard published model, which was known to contain errors even though both models correctly predict the far-field of such a hole.
10. The results show the usefulness of the newly developed method to increase the spatial resolution in THz imaging and allow us to perform measurements which were, up to now, practically impossible to do. They also show the feasibility of another route to perform microscopy: by using small apertures to increase the spatial resolution and by measuring the electric field in the near-field of the hole where the signals are strong.
11. In collaboration with Andrea Markelz from Buffalo, NY, the near-field of some small organic crystals has been measured. The results were mixed: in that some samples seemed to show a resonance, whereas other showed no resonance. Clearly, more work is needed to confirm that these resonances are associated with molecular vibrations of the organic molecular crystals.

Period #4

12. Experiments on the THz transmission of various metal structures have been performed, such as metal holes, spheres, antennas, and metamaterials.
13. A dramatically enhanced understanding of the properties of the near-field of these structures has been obtained.
14. Two- dimensional THz electric fields have been measured and values compared with theory.

B3

INITIAL OBJECTIVES

The main objective of this Workpackage is to obtain knowledge on the use of THz radiation (frequency range between 0.1 and 5 THz) to monitor, in a contact-less fashion, semiconductor surface, epitaxial layers, and bulk parameters important for European semiconductor manufacturers. We will collect expertise on usage of the semiconductor wafer scanning experimental system built within the project. We will produce a user requirement specification which will be fed to the industrial partners and exploitation Workpackage. Except of standard reflectometry employed in the system, we will explore the potential of THz Ellipsometry and Interferometry for measurement method with higher sensitivity to highly doped layers.

Period #1

1. An initial experimental version of the scanner system has been built and used to verify simple models of the optical parameters of semiconductors used typically for analysis.

Period #2

2. A terahertz spectroscopy technique to access semiconductor parameters was implemented and compared with the techniques standard in this field.
3. Evaluation of the relevant THz emitter/detector combinations was performed with the focus on the sensitivity, reliability and robustness.
4. A scientifically relevant wafer scanner was built and extensively tested.

Period #3

5. A THz emitter with electronically-controlled polarisation of generated THz waves has been developed and tested in a THz scientific semiconductor scanner.
6. Ellipsometry instrumentation for the THz frequency range has been realised and implemented in the scientific semiconductor scanner. This instrumentation consists of the generation, manipulation and detection of the polarisation status of THz waves.

Period #4

7. The potential of the interferometry measurement method for further improvement of the semiconductor scanner system sensitivity was evaluated. The interferometry technique enables the fast and precise characterisation of a semiconductor wafer using a reference sample method. The completed system allows the fast mapping of non-homogeneity in doping, etc., of semiconductor wafers.

B4

INITIAL OBJECTIVES

Investigations of THz sensing, imaging and spectroscopy with the following objectives: Establish complete database of THz signatures of dangerous drugs and explosives; Ability to recognize spectra rapidly; Gain a more complete understanding of THz-frequency vibrational motion; prediction of vibrational frequencies of important molecular crystals; Recognize and characterize minute amounts of sample material; Compare ability of THz to perform this task with other methods; Gain a complete understanding of effects of material inhomogeneities on THz propagation; and establish database of spectroscopic signatures for use in other future work e.g. tomography.

(In view of the complexity of this Workpackage, results are presented according to task and not by period.)

Task B4.1 **Investigation of materials of security relevance.** ***Partners: Leeds, Durham, DTU.***

1. Detailed comparisons have been achieved between terahertz and Raman spectroscopy of drugs-of-abuse and explosives, using pure materials mixed in polyethylene and PTFE matrices.
2. Operation of broadband (>8 THz) terahertz spectroscopy system optimised fro spectroscopy.
3. Detailed variable-temperature measurements of exemplar drugs-of-abuse and explosives over the temperature range 4 – 300 K, providing a key data set for theoretical simulations of terahertz spectra.
4. Detailed measurements of 'street' drugs-of-abuse samples, demonstrating an ability to distinguish the key drug component in a range of 'seized' drug compounds.
5. Establishment of key collaborations with governmental agencies in the UK (HM Revenue and Customs, HM Government Communications Centre; Defence Science and Technology Laboratory; and the Home Office Science Development Branch), including those responsible for customs and security, to evaluate the potential of terahertz spectroscopy for security applications, and the effects of THz scattering on remote sensing of illegal materials.
6. Significant extension has been made to the range of THz spectral fingerprints acquired for both drugs-of-abuse and common cuttings agents, and the re-analysis of previous data to ensure that all results provide both absorption and refractive index data.
7. Measurement of terahertz transmission through a range of common packaging materials employed in freight transport, using FedEx envelopes as exemplars, and demonstration that spectral signatures can still be acquired when drug samples (for example, cocaine) are concealed by packaging materials.
8. Demonstrations that theoretical simulations can be used to give realistic fits to the observed spectral signatures in a number of exemplar explosive and drug samples.
9. Demonstration that diffuse reflection spectroscopy, using a single frequency quantum cascade laser source, can be used to probe scattering in powder samples.
10. Continued on-going interactions with key governmental agencies in the UK (HM Revenue and Customs, HM Government Communications Centre; Defence Science and Technology Laboratory; and the Home Office Science Development Branch), including those responsible for customs and security, to evaluate the potential of terahertz spectroscopy for security applications, and the effects of terahertz scattering on remote sensing of illegal materials, giving a longer-term prospect for uptake of the technology.

11. The improvements in relevant THz functional components (Theme A) that have been made in the course of the programme, together with the advances in basic understanding of the underlying spectroscopic and propagation science that have also been achieved in *TeraNova* (Theme B), have informed a paper study of the possibility of developing practical THz security systems. It is concluded that: (a) short range (30 cms or less) are now totally feasible for imaging and spectroscopic identification of hidden contraband; (b) medium range (around one metre), for example in Portal Detection, now appear to be essentially feasible for operation at THz frequencies; (c) long range (ten metres)are feasible for single-point spectroscopy in a system where THz identification was combined with a millimetre wave scanner (e.g. that operating at 270GH made by Thruvision.); and (d), very long range are not yet achievable without the development of new, high power devices. These are unlikely to be realised using the QCL approach taken in *TeraNova*, but might be based on vacuum tube devices. The new Framework VII Project, OPTHER is therefore well placed to take this work forward.

Task B4.2 **Investigation of Pharma Products Leeds, Durham, Teraview**

- Wound up after 12 months.

Task B4.3 **Spectroscopy of materials of biological relevance**

1. Detailed investigations of the terahertz properties of biomolecules: poly-adenylic and poly-cytidylic acids, with the observation of differences in terahertz transmission between the molecules.
2. Density functional perturbation theory (DFPT) simulations of thymine using the CASTEP software package, showing good agreement to experimental features.
3. Development of a microspectrometer.
4. Determination of glucose and alcohol concentrations in aqueous solutions.
5. Completion of theoretical work on the assignment of low-frequency vibrational modes in molecular crystals.
6. Demonstration of excellent agreement between terahertz spectra and simulations for specific molecules of biological relevance, e.g. sucrose, thymine, benzoic acid.
7. Successful application for funding, based on results obtained within the *TeraNova* network, for access to computer resources at the Danish Centre for Scientific Computing. These facilities will allow study of the anomalous blue shifts observed in terahertz spectra with changing temperature, and the identification of specific vibrational modes, *inter alia*, and allow many of the experimental results obtained within the *TeraNova* programme to be explained more fully.
8. Demonstration of a reflection spectrometer for assessing minute quantities of liquids (≈ mL), using water-alcohol and water-sugar mixtures as exemplars. This allowed determination of the alcohol content in beverages.
9. Demonstration of the ability to distinguish between inflammable and water-based liquids, through plastic and glass bottles, with clear security screening implications. This was reported extensively by the Danish media.
10. Demonstration of quantitative spectroscopy inside a parallel-plate waveguide, potentially reducing the required amount of sample to the μL range.
11. Demonstration of THz pulse propagation in a new class of polymer-based photonic crystal fibres designed for the THz frequency range.
12. Near-field characterization in collaboration with TU Delft of the modal structure inside a photonic crystal fibre, including a direct visualization of single-mode propagation over a broad frequency range.

***Task B4.4* The effects of scattering on THz spectroscopy, sensing and imaging**

1. .Phantom structures designed for experimental measurements and comparison with theory.
2. Scattering has been modelled using a phase distribution model, and good agreement obtained between theory and experiment for garments.
3. Development and validation of the Phase Distribution Model and Propagator Model for terahertz radiation passing through phantoms and commonly-encountered materials.
4. Development of post-detection processing techniques to improve the resolution of small objects secreted within inhomogeneous media and reveal additional information from time domain data.
5. Patenting and publication of the post-processing software (validated by experiment), which is also applicable to X-ray imaging, radar signals, and to the development of a terahertz endoscope for possible medical application.
6. Realisation of a measurement system for angle scattering studies: this has been used to validate the theory of terahertz radiation propagation in a concentrated scattering medium and for initial tomographic measurements. The system uses a fibre-fed terahertz receiver.
7. Broadband THz frequency tomography systems have been realized which have the capability to detect hidden objects as small as one millimetre within packaging or other material. QCL measurements have also been undertaken that demonstrate the potential of multi-wavelength frequency-domain THz imaging for the detection and identification of materials in reflection geometry.

Task#B4.5* Emerging Materials: *TeraView

1. New 'emerging materials' identified, and hyperspectral image processing used to enhance contrast in images.
2. Construction of a multiple detector system to investigate, for the first time, how a combination of scattered and specular reflection signals can be used to help characterise and distinguish different materials.

Task#B4.6* Feasibility study of bio/chemical security sensor system: *TeraView

- Evaluation of the feasibility of constructing a terahertz biochemical security sensor.
- Task wound up after M24.

C2

INITIAL OBJECTIVES

The main objective of this work package is the development of a demonstrator of the semiconductor scanner based on terahertz waves. The typical frequency range that is employed spans from 0.5 THz up to 3 THz. The scanner uses a femtosecond Ti: Sapphire laser to generate terahertz electromagnetic waves as well as to detect them after they interacted with the semiconductor under test. The scanner is intended to be a table-top system with associated user interface.

PROGRESS

Period #3

1. Setup of the semiconductor THz-scanner has been completed, including laser integration and optical alignment.
2. The decision for an appropriate THz detection scheme for the scanner has been made in favour of a photoconductive (antenna based) THz detector.
3. A re-designed and improved femtosecond laser (optimised for fibre delivery and THz generation/detection) has been developed and integrated.
4. A novel dispersion management system with chirped mirrors is being developed; this promises more simple and compact fibre delivery.
5. First results of a hybrid integrated, two-colour unit (THz-quantum cascade lasers) have been obtained. The lasers operate at 85 K using the hybrid approach with a single plasmon waveguide and a double metal chips.

Period #4

6. The semiconductor scanner Demonstrator was essentially complete. The report period has been largely spent in system optimisation, including software optimisation. The integration of a re-designed and improved femtosecond laser (optimised for fibre delivery and THz generation/detection) into the final scanner has been completed. Appropriate THz emission/detection for units have been built.
7. A novel dispersion management system, with chirped mirrors, is being developed with potential for a more simple and compact fibre delivery.
8. A two colour laser source at 3.1 THz and 3.9 THz has been realized and given to TU-Wien for evaluation of the potential of two colour THz laser technology in the scientific semiconductor scanner.
9. Performance of the Demonstrator has been verified on samples pf relevance to the semiconductor device industry (pseudomorphic HEMT structures).
10. An early stage prototype with limited functionality has been realised. This combines a fibre-fed THz Time Domain Reflectometer with a high frequency probe arrangement. It is intended to be used to probe failure mechanisms in ICs (through encapsulation). The current spatial resolution of the system is 10 micrometres. A well known End User has agreed to trial the system in their production facility.

C3

INITIAL OBJECTIVES

The Workpackage targets the development of a THz microsensor that could be integrated into a microfluidic environment to perform specific sensing operations on individual living cells. The activity will be focused on spermatozoa, with the objective of distinguishing between X and Y cells. To reach this goal, several tasks will be performed, ranging from spectroscopy on small volumes of pre-sorted cells to determine the configuration, frequency range, etc. with the best S/N ratio, to the development of the necessary components for the micro-integrated sensor, to the final demonstration of the sensor operation on individual living cells. For the purpose both time-domain spectroscopy and dual-frequency differential measurements with quantum cascade lasers sources will be utilized as they provide complimentary characteristics. The most promising system will be implemented in to the final demonstrator.

PROGRESS

Period #3

1. Nine different preparation processes have been developed at the Spallanzani Institute and spermatozoa samples passed on to partners SNS and Siegen.
2. Siegen University has performed a preliminary investigation of the spermatozoa samples using both wide bandwidth and QCL THz sources; clear spectroscopic structures are found that relate to the spermatozoa materials.
3. Siegen University has realised a QCL microfocal transmission analysis setup.
4. SNS has been assembling the optical system for performing spectroscopy at the single cell level. First test data have now been obtained.
5. Femotolasers has been producing the fibre-delivery source that will be used in the time-domain analysis system.

Period #4

6. SNS has realized a THz system for single cell imaging based on QCL sources and on the use of apertures to select the area from which the signal is collected. The system is now fully operational and its resolution as an imaging apparatus has been tested using metal shapes. At the moment ~ $\lambda/15$ has been achieved with a ~ 3 THz QC laser. Requests for the use of such a system by external parties have already been received.
7. Aperture and system design of the imaging demonstrator have been optimized by SNS in terms of materials choice, source polarization, optics f/number. The set-up is now enclosed in a controlled atmosphere and proper software is available for operation.
8. Extensive testing of the SNS demonstrator has been performed on sperm cells supplied by Spallanzani. The best density conditions and substrate materials have been analysed. A signal to noise ratio of 30 dB is available now with wavelength-size aperture. Though very good, this is not yet sufficient to distinguish single spermatozoa from the background. In the near future the pyroelectric detector will be substituted with a bolometer to improve the sensitivity by several orders of magnitude. Funding for this equipment has recently been secured at the national level.
9. The first THz images of other cells have been obtained at Pisa. A single epithelial tumour cell has been imaged: although the latest pictures need considerable improvement, there is now clear evidence that this approach will be successful. Instituto Spallanzani has completed the investigation of protocols for asserting the biological quality of the semen samples after their preparation for THz analysis.
10. In parallel, Siegen has been developing a system for on-line THz analysis in a microfluidic environment. The system is under test with both a pulsed system based on Femtolasers fibre-delivery source and QC lasers.

11. .The microcapillary integrated THz resonator has been fabricated and the demonstrator assembled in Siegen. Its operation has been tested both with the TDS source developed by Femtolasers and QC lasers. Contrast ratios of up to 10% have been demonstrated in Siegen between water and air in the microcapillary, probing with the THz beam a volume of just fractions of a nanolitre.
12. Tests of the Siegen demonstrator are underway with a fast detector to assess the capability of tracing the response with a high-speed fluid containing the individual cells.

APPENDIX II

PUBLICATIONS IN REFEREED JOURNALS, BOOK CONTRIBUTIONS & PATENTS

Period One

[1] *Advances in THz quantum cascade lasers: fulfilling the application potential* , A. Tredicucci, L. Mahler, T. Losco, J. Xu, C. Mauro, R. Köhler, H. E. Beere, D. A. Ritchie, and E. H. Linfield , *Proceedings of SPIE* , **5738** *Novel In-Plane Semiconductor Lasers IV, Carmen Mermelstein, David P. Bour, Editors*, 146 (2005).

[2] *Optimum resonant tunnelling injection and influence of doping density on the performance of THz bound-to continuum cascade lasers*, J. Alton, S. Barbieri, C. Worral, M. Houghton, H. E. Beere, and D. A. Ritchie, *Proc. SPIE Int. Soc. Opt. Eng.* **5727**, 65 (2005).

[3] *Terahertz bound-to-continuum quantum-cascade lasers based on optical-phonon scattering extraction* G. Scalari, N. Hoyler, M. Giovannini and J. Faist, *Appl.Phys. Lett*. **86,** 181101 (2005).

[4] Buried waveguides in terahertz quantum cascade lasers based on two-dimensional surface plasmon modes, J. Alton, S. S. Dhillon, C. Sirtori , S. Barbieri, A. de Rossi, M. Calligaro, H. E. Beere, and D. A. Ritchie, *Appl. Phys. Lett..*, **86**, 071109 (2005).

[5] *Buried heterostructure 2.9-THz quantum cascade lasers operating up to 77K in continuous wave*, J. Alton, S. S. Dhillon, C. Sirtori , S. Barbieri, A. de Rossi, M. Calligaro, H. E. Beere, and D. A. Ritchie, *Proc. SPIE Int. Soc. Opt. Eng.* **5738**, 159 (2005).

[6] *Ultra-low threshold current quantum cascade lasers based on double-metal buried strip waveguides*, S. S. Dhillon, J. Alton, S. Barbieri, C. Sirtori, A. de Rossi, M. Calligaro, H. E. Beere, and D. A. Ritchie, *Appl. Phys. Lett..*, **87**, 071107 (2005).

[7] *Time and frequency resolved THz spectroscopy of micro- and nano-systems*, J. Kröll, J. Darmo, K. Unterrainer, *Acta Physica Polonica* **107**, 92-98 (2005).

[8] *Passive Millimetre-Wave & Terahertz Imaging and Technology*, J.M. Chamberlain, Proceedings of SPIE Volume **5619** (SPIE, Bellingham, WA, 2004), pp1-5 [ISBN: 0277-786X].

[9] *Generation of Terahertz Radiation in Nonlinear Waveguides*, A.S. Nikoghosyan, E.M. Laziev, R.M. Martrosyan, Hakhoumian, J.M. Chamberlain, R.A. Dudley and N.N. Zinov'ev, Conference Digest Of The 2004 Joint 29th International Conference on Infrared and Millimeter Waves and 12th International Conference on Terahertz Electronics (IEEE, New York) Editors: Thumm M, Wiesbeck W, pp 313-314, 2004 ISBN: 0-7803-8490-3.

[10] *Terahertz Transition Radiation*, A.S. Nikoghosyan, E.M. Laziev, R.M. Martirosyan, A.A. Hakhoumian, J.M. Chamberlain, R.A. Dudley & N.N. Zinov'ev, Conference Digest Of The 2004 Joint 29th International Conference on Infrared and Millimeter Waves and 12th International Conference on Terahertz Electronics (IEEE, New York) Editors: Thumm M, Wiesbeck W, pp 159-160, 2004 ISBN: 0-7803-8490-3.

[11] *THz sideband generation at telecom wavelengths in a GaAs-based quantum cascade laser*, S.S. Dhillon, C. Sirtori, A. de Rossi, M. Calligaro, H.E. Beere, S. Barbieri, E.H. Linfield, D.A. Ritchie, *Appl. Phys. Lett.*, **87**, 071101 (2005).

[12] *Continuous-wave THz generation through photomixing using a dual-frequency Yb3+:KGd(WO4)2 laser*, R. Czarny, M. Alouini, C. Larat, S. Dhillon, M. Krakowsky, S. Bansropun, V. Ortiz, C. Sirtori, B. Gerard and D. Dolfi, *Proceedings of SPIE, Passive Millimeter-Wave and Terahertz Imaging and Technology*, **5619**, 198-207 (2004).

[13] *Opto-electronic pulsed THz systems*, P.C.M. Planken, C.E.W.M. van Rijmenam, and R.N. Schouten, *Semicond. Sci. Techn*. **20**, s121 (2005).

teraNova
novel terahertz sensing & imaging systems

[14] *Modular parallel-plate THz components for cost-efficient biosensing systems.* M. Nagel, P. Haring Bolivar and H. Kurz, *Semicond. Sc. Techn.* **20,** 281-85 (2005).

[15] *Asynchronous optical sampling for high-speed characterization of integrated resonant THz-sensors.* C. Janke, M. Först, M. Nagel, and H. Kurz, *Opt. Lett.* **30**, 11, 1405-1408 (2005).

[16] *Cost-efficient THz-resonators for label-free detection of DNA hybridization.* M. Nagel and H. Kurz, Proc. SPIE Vol. **5864**, p. 152-160 (2005).

[17] *Terahertz Quantum Cascade Lasers - first demonstration and novel concepts* Alessandro Tredicucci, Rüdeger Köhler, Lukas Mahler, Harvey E. Beere, Edmund H. Linfield, and David A. Ritchie *Semicond. Sci. Technol*. **20**, S222 (2005).

[18] *Terahertz quantum cascade laser as local oscillator in a heterodyne receive* H. Hübers, S.G. Pavlov, A.D. Semenov, R. Köhler, L. Mahler, A. Tredicucci, H.E. Beere, D.A. Ritchie, and E.H. Linfield, *Opt. Express* **13**, 5890 (2005).

[19] *Optimization of enhanced terahertz transmission through arrays of subwavelength apertures*, C. Janke, J. Gómez Rivas, C. Schotsch, L. Beckmann, P. Haring Bolivar, and H. Kurz, *Phys. Rev.* **B 69**, 205314 (2004). doi:10.1103/PhysRevB.69.205314.

[20] *Time-domain measurements of surface plasmon polaritons in the terahertz frequency range*, J. Saxler, J. Gómez Rivas, C. Janke, H.P.M. Pellemans, P. Haring Bolívar, and H. Kurz, *Phys. Rev*. **B 69**, 155427 (2004). doi:10.1103/PhysRevB.69.155427.

[21] *Thermal switching of the enhanced transmission of terahertz radiation through subwavelength apertures*, J. Gómez Rivas, P. Haring Bolivar, and H. Kurz, *Opt. Lett*. **29** (14), 1680 (2004). http://www.opticsinfobase.org/abstract.cfm?id=80572.

[22] *Propagation of surface plasmon polaritons on semiconductor gratings*, J. Gómez Rivas, M. Kuttge, P. Haring Bolivar, H. Kurz, and J.A. Sánchez-Gil, *Phys Rev. Lett*. **93** (25), 256804 (2004). doi:10.1103/PhysRevLett.93.256804.

[23] *Transmission of THz radiation through InSb gratings of subwavelength apertures*, J. Gómez Rivas, C. Janke, P. Haring Bolívar and H. Kurz, *Opt. Expr.* **13 (**3), 847-859 (2005).

[24] *Modular parallel-plate THz components for cost-efficient biosensing systems*, M. Nagel, P. Haring Bolivar and H. Kurz, *Semic. Sc. and Techn*. **20** (7), S281-S285 (2005).

[25] *Temperature dependence of the permittivity and loss tangent of high-permittivity materials at terahertz frequencies*, K. Berdel, J. Gómez Rivas, P. Haring Bolivar, P. de Maagt, H. Kurz, *IEEE Trans. Microw. Th. And Techn* **53** (4), 1266-1271 (2005).

[26] *Time resolved broadband analysis of slow-light propagation and superluminal transmission of electromagnetic waves in three-dimensional photonic crystals*, J. Gómez Rivas, A. Farré Benet, J. Niehusmann, P. Haring Bolívar, and H. Kurz, *Phys. Rev. B 71* (15), 155110 (2005).

[27] *Terahertz science, engineering and systems—from space to earth applications*, P. de Maagt, P. Haring Bolivar and C. Mann, *Encyclopedia of RF and Microwave Engineering*, Ed. by K. Chang, pp. 5175-5194 (John Wiley & Sons, Inc., 2005). ISBN 0-471-27053-9.

[28] *MBE growth of terahertz quantum cascade lasers*. H.E. Beere, J.C. Fowler, J. Alton, E.H. Linfield, D.A. Ritchie, R. Köhler, A. Tredicucci, G. Scalari, L. Ajili, J. Faist, and S. Barbieri. *J. Cryst. Growth* **278**, 756 (2005).

[29] High-performance operation of single-mode terahertz quantum cascade lasers with metallic gratings. L. Mahler, A. Tredicucci, R. Köhler, F. Beltram, H.E. Beere, E.H. Linfield, and D.A. Ritchie. *Appl. Phys. Lett*. **87**, October 24 (2005).

[30] *High-performance operation of single-mode terahertz quantum cascade lasers with metallic gratings*. L. Mahler, A. Tredicucci, R. Köhler, F. Beltram, H.E. Beere, E.H. Linfield, and D.A. Ritchie. *Appl. Phys. Lett*. **87**, 181101, October 24 (2005).

[31] *Terahertz time-domain spectroscopy and imaging of artificial RNA strands*, B.M. Fischer, M. Hoffmann, H. Helm, R. Wilk, F. Rutz, T. Kleine-Ostmann, M. Koch, and P. Uhd Jepsen, *Opt. Express* **13**, 5205-5215 (2005).

[32] *Dynamic range in terahertz time-domain transmission and reflection spectroscopy*, P. Uhd Jepsen and B. M. Fischer, *Opt. Lett*. **30**, 29-31 (2005).

[33] *Chemical recognition in terahertz time-domain spectroscopy and imaging*, B. Fischer, M. Hoffmann, H. Helm, G. Modjesch, and P. Uhd Jepsen, *Semicond. Sci. Technol*. **20**, S246-S253 (2005).

Period Two

[35] *Frequency-dependent characterization of THz Sommerfeld wave propagation on single-wires.* M. Wächter, M. Nagel, and H. Kurz, *Opt. Expr*. **13** (26): 10815-10822 (2005).

[36] *THz biosensing devices: fundamentals and technology.* M. Nagel, M. Först and H. Kurz, J. Phys.: *Condens. Matter* **18**, 601–618 (2006).

[37] *Corrugated waveguide based genomic biochip for marker-free THz read-out.* M. Nagel and H. Kurz, *Int. J. Infrared Millimeter Waves*, **27**, 4, 517-529 (2006).

[38] *Low index discontinuity THz waveguides.* M. Nagel, A. Marchewka and H. Kurz, *Opt. Express*, **14**, 21 (2006).

[39] *Scattering in THz imaging*, J.R. Fletcher, G.P. Swift, De Chang Dai, D. Beggs, R.A. Abram, M. Kaliteevski, J. Levitt, A. Gallant, J.M. Chamberlain, *Proceedings of SPIE Volume*: **5989**. Technologies for Optical Countermeasures II; Femtosecond Phenomena II; and Passive Millimetre-Wave and Terahertz Imaging II Editor(s): David H. Titterton, Sean M. Kirkpatrick, Razvan Stoian, Roger Appleby, J. Martyn Chamberlain, Keith A. Krapels/ Pages 320-325 [ISBN 0-8194-6011-7].

[40] *Terahertz scattering: comparison of a novel theoretical approach with experiment*, G. Peter Swift, De Chang Dai, John R. Fletcher, Andrew J. Gallant, James A. Levitt, Richard A. Abram, Daryl M. Beggs, Mikhail A. Kaliteevski, J. Martyn Chamberlain. *Proc. SPIE Vol.* **6120**, p. 186-194, Terahertz and Gigahertz Electronics and Photonics V; R. Jennifer Hwu, Kurt J. Linden; Eds. {ISBN 0-8194-6162-8}.

[41] *Doping in quantum cascade lasers. II. GaAs/Al0.15Ga0.85As terahertz devices*, L. Ajili, G. Scalari, M. Giovannini, N. Hoyler and J. Faist, *J. Appl. Phys.*, **100**, pp. 043102–1–043102–3 (2006).

[42] *Electrically switchable, two-color quantum cascade laser emitting at 1.39 and 2.3 THz*, G. Scalari, C. Walther, J. Faist, H. Beere and D. Ritchie, *Appl. Phys. Lett.*, vol. **88**, no. 14, pp. 141102–1–141102–3 (2006).

[43] *Biomedical terahertz imaging with a quantum cascade laser*, S. Kim, F. Hatami, J. Harris, A. Kurian, J. Ford, D. King, G. Scalari, M. Giovannini, N. Hoyler, J. Faist and G. Harris, *Appl. Phys. Lett.*, vol. **88**, no. 15, pp. 153903–1–153903–2 (2006).

[44] *Turn-key compact high temperature terahertz quantum cascade lasers: imaging and room temperature detection*, E. Brundermann, M. Havenith, G. Scalari, M. Giovannini, J. Faist, J. Kunsch, L. Me-chold and M. Abraham, *Optics Express*, vol. **14**, no. 05, pp. 1829–1841 (2006).

[45] *Design, fabrication and optical characterization of quantum cascade lasers at terahertz frequencies using photonic crystal reflectors*, L.A. Dunbar, V. Moreau, R. Ferrini, R. Houdré, L. Sirigu, G. Scalari, M. Giovannini, N. Hoyler and J. Faist, *Optics Express*, vol. **13**, no. 22, pp. 8960–8968 (2005).

[46] *InGaAsAlInAs/InP terahertz quantum cascade laser*, L. Ajili, G. Scalari, N. Hoyler, M. Giovannini and J. Faist, *Appl Phys. Lett.*, vol. **87**, pp. 141107–1–141107–3 (2005).

[47] *MBE growth of terahertz quantum cascade lasers*, H. Beere, J. Fowler, J. Alton, E. Linfield, D. Ritchie, R. Kohler, A. Tredicucci, G. Scalari, L. Ajili, J. Faist and S. Barbieri, *J. Cryst. Growth*, vol. **278**, pp. 756–764 (2005).

[48] *Terahertz bound-to-continuum quantum-cascade lasers based on optical-phonons scattering extraction*, G. Scalari, N. Hoyler, M. Giovannini and J. Faist, *Appl. Phys. Lett.*, vol. **86**, pp. 181101–1–181101–3 (2005).

[49] *Imaging at 3.4 THz with a quantum-cascade laser*, D. Chamberlin, P. Robrish, W. Trutna, G. Scalari, M. Giovannini, L. Ajili and J. Faist, *Appl. Opt.*, vol. **44**, no. 1, pp. 121–125 (2005).

[50] *Time-resolved broadband analysis of slow-light propagation and superluminal transmission of electromagnetic waves in three-dimensional photonic crystals*, J. Gómez Rivas, A. Farré Benet, J. Niehusmann, P. Haring Bolívar, and H. Kurz, *Phys. Rev. B* **71** (15), 155110 (2005).

[51] *All-optical switching of the transmission of electromagnetic radiation through subwavelength apertures*, C. Janke, J. Gómez Rivas, P. Haring Bolívar and H. Kurz , *Opt. Lett*. **30** (18): 2357-2359 (2005).

[52] *Terahertz science, engineering and systems—from space to earth applications*, Encyclopedia of RF and Microwave Engineering, P. de Maagt, P. Haring Bolivar and C. Mann, Ed. by K. Chang, pp. 5175-5194 (John Wiley & Sons, Inc., 2005) ISBN 0-471-27053-9.

[53] *High-resolution gas phase spectroscopy with a distributed feedback terahertz quantum cascade laser*, H.-W. Hübers, S. G. Pavlov, H. Richter, A. D. Semenov, L. Mahler, A. Tredicucci, H. E. Beere, and D. A. Ritchie, *Appl. Phys. Lett.* **89**, 061115 (2006).

[54] *Heterodyne receiver at 2.5 THz with quantum cascade laser and hot electron bolometric mixer*, H.-W. Hübers, S.G. Pavlov, H. Richter, A.D. Semenov, L. Mahler, A. Tredicucci, H.E. Beere, and D.A. Ritchie, *Proceedings of SPIE* - Volume **6275** Millimeter and Submillimeter Detectors and Instrumentation for Astronomy III, Jonas Zmuidzinas, Wayne S. Holland, Stafford Withington, William D. Duncan, Editors, 62750H (2006).

[55] *Electron-lattice coupling in bound-to-continuum THz quantum-cascade lasers*, M. S. Vitiello, G. Scamarcio, V. Spagnolo, T. Losco, R. P. Green, A. Tredicucci, H. E. Beere, and D. A. Ritchie, *Appl. Phys. Lett*. **88**, 241109 (2006).

[56] *Surface plasmon photonic structures in terahertz quantum cascade lasers*, O. Demichel, L. Mahler, T. Losco, C. Mauro, R. Green, A. Tredicucci, J. Xu, F. Beltram, H. E. Beere, D. A. Ritchie, and V. Tamošinuas, *Opt. Express* **14**, 5335 (2006).

[57] *High-performance operation of single-mode terahertz quantum cascade lasers with metallic gratings*, L. Mahler, A. Tredicucci, R. Köhler, F. Beltram, H.E. Beere, E.H. Linfield, and D.A. Ritchie, *Appl. Phys. Lett*. **87**, 181101 (2005).

[58] *Continuous wave operation of a superlattice quantum cascade laser at 2 THz*, C. Worral, J. Alton, M. Houghton, S. Barbieri, H.E. Beere, D. Ritchie and C. Sirtori, *Opt. Express* **14**, 171 (2006).

[59] *Terahertz polarization imaging*. N.C.J. van der Valk. W. van der Marel, and P.C.M. Planken. *Opt. Lett*. **30**, 2802 (2005).

[60] *Buried waveguides in terahertz quantum cascade lasers based on two-dimensional surface plasmon modes*, J. Alton, S.S. Dhillon, C. Sirtori , S. Barbieri, A. de Rossi, M. Calligaro, H.E. Beere, and D.A. Ritchie, *Appl. Phys. Lett.*., **86**, 071109 (2005).

[61] *Buried heterostructure 2.9-THz quantum cascade lasers operating up to 77K in continuous wave*, J. Alton, S.S. Dhillon, C. Sirtori , S. Barbieri, A. de Rossi, M. Calligaro, H.E. Beere, and D.A. Ritchie, *Proc. SPIE Int. Soc. Opt. Eng.* **5738**, 159 (2005).

[62] *Ultra-low threshold current quantum cascade lasers based on double-metal buried strip waveguides*, S.S. Dhillon, J. Alton, S. Barbieri, C. Sirtori, A. de Rossi, M. Calligaro, H.E. Beere, and D.A. Ritchie, *Appl. Phys. Lett.*, **87**, 071107 (2005).

[63] *2.9 THz quantum cascade laser operating up to 70K in continuous wave*, S. Barbieri, J. Alton, H.E. Beere, J. Fowler, E.H. Linfield, and D.A. Ritchie, *Appl. Phys. Lett.* **85**, 1674 (2004).

[64] *Recent developments in people screening using terahertz technology – seeing the world through terahertz eyes'* M. C. Kemp, A. Glauser, and C. Baker, *SPIE*, **6212**, 2006.

[65] *Characterization of Crystalline Phase-Transformations in Theophylline by Time-Domain Terahertz Spectroscopy*. Upadhya, P.; Nguyen, K.L.; Shen, Y.C.; Obradovic, J.; Fukushige, K.; Griffiths, R.; Gladden, L.; Davies, AG; Linfield, E.H.; *Spectroscopy Letters* **39**. Taylor & Francis. pp. 215-224. 2006.

[66] *On-chip photoconductive excitation and detection of pulsed terahertz radiation at cryogenic temperatures*. Wood, C.D.; Cunningham, J.; Upadhya, P.; Linfield, E.H.; Hunter, I.C.; Davies, A.G.; Missous, M. *Applied Physics Letters* **88** (14, Article 142103). pp.142103, 2006.

[67] *Analysis of drugs-of-abuse and explosives using terahertz time-domain and Raman spectroscopy*. A. Burnett, W. Fan, P. Upadhya, J. Cunningham, E. Linfield, G. Davies, H. Edwards, T. Munshi, and A. O'Neil. *Proceedings of SPIE* Vol. **6120**, 61200M (March 7, 2006).

[68] *Guided-wave THz devices for sensing the properties of overlaid dielectric films*. C. Wood, J. Cunningham, A.G. Davies, I.C. Hunter, P. Tosch, and E.H. Linfield. *Proceedings of SPIE* Vol. **6120**, 61200P (March 7, 2006).

Period Three

[69] *THz Near-field Measurements of Metal Structures*, A.J.L. Adam, J.M. Brok, P.C.M. Planken, M.A. Seo, D.S. Kim, *Comptes Rendues Physique* **9** 161-168 (2007).

[70] *Measurement and Calculation of the Near-field of a Terahertz Apertureless Scanning Optical Microscope*, A.J.L. Adam, N.C.J. van der Valk, and P.C.M. Planken, *J. Opt. Soc. Am*. **B 24**, 1080 (2007).

[71] *Frequency-dependent Radiation Patterns Emitted by Terahertz Plasmons on Finite Length Cylindrical Metal Wires* J. A. Deibel, N. Berndsen, K. Wang, D.M. Mittleman, N.C.J. van der Valk, and P.C.M. Planken, *Opt. Express* **14**, 8772 (2006).

[72] *Shape Resonance Omni-directional Terahertz Filters with Near-unity Transmittance*. J. Lee, M. Seo, D. Park, D. Kim, S. Jeoung, Ch. Lienau, Q-Han Park, and P. Planken, *Opt. Express*. **14**, 1253 (2006).

teraNova
novel terahertz sensing & imaging systems

[73] *Propagation of Terahertz Radiation through Random Structures: A Novel Theoretical Approach and Experimental Validation*, J.R. Fletcher, G.P. Swift, De Chang Dai, J.A. Levitt and J.M. Chamberlain. *Journal of Applied Physics*. Vol **101** (1) 013102-11.

[74] *Molecular Spectroscopy with TeraHertz Quantum Cascade Lasers*, H.-W. Hübers, S.G. Pavlov, H. Richter, A. D. Semenov, L. Mahler, A. Tredicucci, H.E. Beere, and D.A. Ritchie, *J. Nanoelectron. Optoelectron*. **2**, 101 (2007).

[75] *Frequency Characterization of a Terahertz Quantum-cascade Laser*, N. Beverini, G. Carelli, A. De Michele, A. Moretti, L. Mahler, A. Tredicucci, H.E. Beere, and D.A. Ritchie, *IEEE Trans. Instrum. Meas.* **56**, 262 (2007).

[76] *Tuneable Terahertz Quantum Cascade Lasers with an External Cavity*, J. Xu, J.M. Hensley, D.B. Fenner, R.P. Green, L. Mahler, A. Tredicucci, M.G. Allen, F. Beltram, H.E. Beere, and D.A. Ritchie, *Appl. Phys. Lett., in Press.*

[77] *Amplification of THz Radiation in Quantum Cascade Structures*, C. Mauro, R.P. Green, A. Tredicucci, F. Beltram, H.E. Beere, and D.A. Ritchie, *J. Appl. Phys.***102** 063101 (2007).

[78] *THz Transfer Onto a Telecom Optical Carrier* S. Dhillon, C. Sirtori, J. Alton, S. Barbieri, A. de Rossi, H. Beere, and D. Ritchie, *Nature Photonics*, **1**:411, 2007.

[79] *13 GHz Direct Modulation of THz Quantum Cascade Lasers* Barbieri, W. Maineult, S. Dhillon, C. Sirtori, J. Alton, N. Breuil, H. Beere, and D. Ritchie. *Accepted for publication. Appl. Phys. Lett* **91,** 143510 (2007).

[80] *Thermal Properties of THz Quantum Cascade Lasers Based on Different Optical Waveguide Configuration*, M. Vitiello, G. Scamarcio, V. Spagnolo, J. Alton. S. Barbieri, C. Worrall, H. Beere, D. Ritchie, C. Sirtori, *Appl. Phys. Lett*. **89**, 021111 (2006).

[81] *Subband Electronic Temperatures and Electron-Lattice Relaxation in THz Quantum Cascade Lasers with Different Conduction Band Offsets*, M. Vitiello, G. Scamarcio, V. Spagnolo, C. Worrall, H. Beere, D. Ritchie, C. Sirtori, J. Alton, S. Barbieri, *Appl. Phys. Lett*. **89**, 131114 (2006).

[82] *Low Threshold THz QC Lasers With Thin Core Regions*, Y. Chassagneux, J. Palomo, R. Colombelli, S. Barbieri, Dhillon, C. Sirtori, H. Beere, J. Alton, and D. Ritchie, *Electron. Lett*. **43**, 205 (2007).

[83] *Metallic Slit Waveguide for Dispersion-Free Low-Loss Terahertz Signal Transmission*. M. Wächter, M. Nagel, H. Kurz, *Appl. Phys. Lett*. **90**, 061111 (2007).

[84] *Metallic Wave-Impedance Matching Layers for Broad-Band Optical Systems*, J. Kröll, J. Darmo and K. Unterrainer, *Optics Express*, **15** (2007), 67552-6560.

[85] *Terahertz Optical Activity of Sucrose Single Crystals*, J. Kröll, J. Darmo and K. Unterrainer, *Vibrational Spectroscopy*, **43** (2007), 324-329.

[86] *Longitudinal Spatial Hole Burning in Terahertz Quantum Cascade Lasers*, J. Kröll, J. Darmo, K. Unterrainer, S.S. Dhillon, C. Sirtori, X. Marcadet, and M. Calligaro, *Appl. Phys. Lett*. **90** (2007), 231116.

[87] *Terahertz Quantum-cascade Laser Dynamics in Time-Domain*, J. Kröll, J. Darmo, S. Dhillon, X. Marcadet, M. Calligaro, C. Sirtori, and K. Unterrainer, AIP Conference Proceedings 893,"28th International Conference on the Physics of Semiconductors", p. 1435.

[88] *Theoretical Aspects of Time-domain Spectroscopy of Semiconductor Terahertz Gain Medium* J. Darmo, J. Kröll, and K. Unterrainer, AIP Conference Proceedings **893**,"28th International Conference on the Physics of Semiconductors", p. 515.

[89] *Monolithic Integration of Low-Temperature-Grown GaAs with a Two-Dimensional Electron Gas*, Cunningham, J., Upadhya, P.C., Tiang, C.K., Lachab, M., Khanna, S., Linfield, E.H., and Davies, A.G., *Semiconductor Science and Technology* **22**, 811-813 (2007).

[90] *Excitation-Density-Dependent Generation Of Broadband Terahertz Radiation In An Asymmetrically Excited Photoconductive Antenna*, P.C. Upadhya, W. Fan, A. Burnett, J. Cunningham, A.G. Davies, E.H. Linfield, J. Lloyd-Hughes, E. Castro-Camus, M.B. Johnston, and H. Beere. *Optics Letters*, Vol. **32**, Issue 16, pp. 2297-2299.

[91] *Far-Infrared Spectroscopic Characterization of Explosives for Security Applications Using Broadband Terahertz Time-Domain Spectroscopy*, W.H. Fan, A. Burnett, P.C. Upadhya, J. Cunningham, E.H. Linfield, and A.G. Davies. *Applied Spectroscopy*, Volume **61**, Number 6, June 2007, pp. 638-643(6).

[92] *Advanced Optoelectronics in III-V Semiconductor Compounds,* M. Först, M. Nagel, M. Awad, M. Wächter, T. Dekorsy, and H. Kurz, *Phys. Stat. Sol*. (b) **244**, 2971-2987 (2007).

[93] *Horn Antennas for Terahertz Quantum Cascade Lasers*, M.I. Amanti, M. Fischer, C. Walther, G. Scalari, and J. Faist, *Electron. Lett*. **43**, 573.

[94] *Quantum Cascade Lasers Operating from 1.2 to 1.6 THz*, Christoph Walther, Milan Fischer, Giacomo Scalari, Romain Terazzi, Nicolas Hoyler, and Jérôme Faist, *Appl. Phys. Lett*. **91**, 131122 (2007).

[95] *Strong Confinement in Terahertz Intersubband Lasers by Intense Magnetic Fields*, G. Scalari, C. Walther, L. Sirigu, M. L. Sadowski, H. Beere, D. Ritchie, N. Hoyler, M. Giovannini, J. Faist, *Phys. Rev. B* **76**, 115305 (2007).

[96] *Population Inversion by Resonant Tunnelling in Quantum Wells*, G. Scalari, R. Terazzi, N. Hoyler, M. Giovannini, J. Faist, *Appl. Phys. Lett*., **91**, 032103 (2007).

[97] *Precise Ab-Initio Prediction of Terahertz Vibrational Modes in Crystalline Systems*, P. Uhd Jepsen and S. J. Clark, *Chem. Phys. Lett*. **442,** 275 (2007).

[98] *Investigation of Aqueous Alcohol Solutions with Reflection Terahertz Time-Domain Spectroscopy*, P. Uhd Jepsen, U. Møller, and H. Merbold, *Opt. Express* (*Accepted*, October 2007).

[99] *Phase-resolved Measurements of Stimulated Emission in a Laser,* Josef Kröll, Juraj Darmo, Sukhdeep S. Dhillon, Xavier Marcadet, Michel Calligaro, Carlo Sirtori & Karl Unterrainer, *Nature* **449**, 698-702 (2007).

[100] *Dual-Mode Microcavity THz Quantum-cascade Lasers,* G. Fasching, A. Benz, A. M. Andrews, R. Zobl, T. Roch, W. Schrenk, G. Strasser, V. Tamosiunas, K. Unterrainer, *AIP Conference Proceedings **893**, 28th International Conference on the Physics of Semiconductors*, p. 511 (2006).

[101] *Optimization of MBE Growth Parameters for GaAs-Based THz Quantum Cascade Lasers,* A. M. Andrews, T. Roch, A. Benz, G. Fasching, W. Schrenk, K. Unterrainer, and G. Strasser, *AIP Conference Proceedings **893**, 28th International Conference on the Physics of Semiconductors*, p. 51 (2006).

Period Four

[102] *Numerical sampling rules for paraxial regime pulse diffraction calculations*, D.P. Kelly, B.M. Hennelly, A. Grün, and K. Unterrainer, *J. Opt. Soc. Am*. A **25**, 2299-2308 (2008).

[103] *Ultrafast probing of light-matter interaction in a mid-infrared quantum cascade laser* , W. Parz, T. Müller, J. Darmo, K. Unterrainer, M. Austerer, G. Strasser, L.R. Wilson, J.W. Cockburn, A.B. Krysa, J.S. Roberts, *Applied Physics Letters*, **93,** 091105 (2008).

[104] *Doping dependence of LO-phonon depletion scheme THz quantum-cascade lasers*; A.M. Andrews, A. Benz, C. Deutsch, G. Fasching, K. Unterrainer, P. Klang, W. Schrenk, G. Strasser, *Materials Science and Engineering B*, **147**, S. 152 – 155 (2008).

[105] *Terahertz quantum cascade devices: from intersubband transition to microcavity laser,* K. Unterrainer, A. Benz, J. Darmo, Ch. Deutsch, G. Fasching, J. Kröll, D.P. Kelly, M. Martl, T. Müller, W. Parz, S.S. Dhillon, C. Sirtori, A.M. Andrews, W. Schrenk, G. Strasser, X. Marcadet, M. Calligaro, H.E. Beere, and D.A. Ritchie, *IEEE Journal of Selected Topics in Quantum, Electronics*, Vol. **14**, No. 2, 307 (2008).

[106] *Phase-resolved measurement of stimulated emission in a laser*, J. Kröll, J. Darmo, S.S. Dhillon, X. Marcadet, M. Calligaro, C. Sirtori and K. Unterrainer; *Nature*, **449**(7163), 698-701 (2007).

[107] *Subwavelength Microdisk and Microring Terahertz Quantum-Cascade Lasers,* G. Fasching, V. Tamosiunas, A. Benz, A. M. Andrews, K. Unterrainer, R. Zobl, T. Roch, W. Schrenk, G. Strasser, *IEEE Journal of Quantum Electronics*, Vol. **43**, No. 8, 687 (2007).

[108] *Longitudinal spatial hole burning in terahertz quantum cascade lasers*, J. Kröll, J. Darmo, K. Unterrainer, S.S. Dhillon, C. Sirtori, X. Marcadet and M. Calligaro, *Appl. Phys. Lett*., **91**, 161108 (2007).

[109] *Influence of doping on the performance of terahertz quantum-cascade lasers,* A. Benz, G. Fasching, A.M. Andrews, M. Martl, K. Unterrainer, T. Roch, W. Schrenk, S. Golka, G. Strasser, *Applied Physics Letters*, **90**, 101107 (2007).

[110] *Laser local oscillators for heterodyne receivers beyond 2 terahertz,* H.-W. Huebers, H. Richter, S. Pavlov, A. Semenov, A. Tredicucci, L. Mahler, H. E. Beere, D. A. Ritchie, *Frequenz* **62**, 111 (2008).

[111] *Terahertz quantum cascade lasers with quasi-periodic resonators,* Lukas Mahler, Alessandro Tredicucci, Richard P. Green, Fabio Beltram, Christoph Walther, Jérôme Faist, Harvey E. Beere, and David A. Ritchie, *Physica* E **40**, 2176 (2008).

[112] *THz quantum cascade designs for optimized injection* ,T. Losco, J.H. Xu, R.P. Green, A. Tredicucci, H.E. Beere, and D.A. Ritchie, *Physica* E **40**, 2207 (2008).

[113] *Line width enhancement factor of terahertz quantum cascade lasers,* R.P. Green, J-H. Xu, L. Mahler, A. Tredicucci, F. Beltram, G. Giuliani, H.E. Beere and D.A. Ritchie, *Appl. Phys. Lett*. **92**, 071106 (2008).

[114] *Tunable terahertz quantum cascade lasers with an external cavity,* J. Xu, J.M. Hensley, D.B. Fenner, R.P. Green, L. Mahler, A. Tredicucci, M.G. Allen, F. Beltram, H.E. Beere, and D.A. Ritchie, *Appl. Phys. Lett.* **91**, 121104 (2007).

[115] *Amplification of terahertz radiation in quantum cascade structures,* C. Mauro, R.P. Green, A. Tredicucci, F. Beltram, H.E. Beere, and D.A. Ritchie, *J. Appl. Phys.* **102**, 063101 (2007).

[116] *Pulsed THz Signal Reconstruction,* J.R. Fletcher, G.P. Swift, Dechang Dai, J.M. Chamberlain and P.C. Upadhya, *Journal of Applied Physics* **102**, 113105 (2007).

[117] *Characterization of low temperature GaAs antenna array terahertz emitters.* M. Awad, M. Nagel, H. Kurz, J. Herfort, and K. Ploog, *Appl. Phys. Lett.* **91**, 181124 (2007).

[118] *Advanced optoelectronics in III-V semiconductor compounds.* M. Först, M. Nagel, M. Awad, M. Wächter, T. Dekorsy, and H. Kurz, *Phys. Stat. Sol. (b)* **244**, 2971-2987 (2007).

[119] *Low-loss terahertz transmission through curved metallic slit waveguides fabricated by spark erosion.* M. Wächter, M. Nagel, and H. Kurz, *Appl. Phys. Lett.* **92**, 161102 (2008).

[120] Terahertz and sub-THz quantum cascade lasers, G. Scalari, C. Walther, M. Fischer, R. Terazzi, H. Beere, D. Ritchie, J. Faist, *Lasers and Photonics Reviews*, Published on line September (2008).

[121] Te*rahertz quantum cascade lasers based on two-dimensional photonic crystal resonators*, L. Sirigu, R. Terazzi, M.I. Amanti, M. Giovannini , J. Faist L. A. Dunbar, R. Houdré, *Optics Express*, **16**, 5206-5217, (2008).

[122] *A terahertz quantum cascade laser grown by low-pressure metalorganic vapor phase epitaxy*, L. Sirigu, A. Rudra, E. Kapon, M.I. Amanti, G. Scalari, J. Faist, *Appl. Phys. Lett.* **92** 181111 (2008).

[123] *Advances in Fiber Delivery of Femtosecond Laser Pulses*, T. Le, M. Hofer, Z, Cheng, and A. Stingl, J. Darmo, D.P. Kelly, K. Unterrainer, Laser 2008, San Jose, California, USA, *Proc. SPIE* Vol. **6871**, Solid State Lasers XVII: Technology and Devices.

[124] *Absorption-Sensitive Diffuse Reflection Imaging of Concealed Powders Using a Terahertz Quantum Cascade Laser.* P. Dean, M.U. Shaukat, S.P. Khanna, S. Chakraborty, M. Lachab, A.D. Burnett, A.G. Davies, and E.H. Linfield. *Optics Express* **16**, 5997 – 6007 (2008).

[125] *Terahertz Spectroscopy of Explosives and Drugs.* A.G. Davies, A.D. Burnett, W.H. Fan, E.H. Linfield, J. Cunningham. *Materials Today* **11**, 18 – 26 (2008).

[126] *Excitation-Density-Dependent Generation of Broadband Terahertz Radiation in an Asymmetrically Excited Photoconductive Antenna.* P.C. Upadhya, W.H. Fan, A.D. Burnett, J.E. Cunningham, A.G. Davies, E.H. Linfield, J. Lloyd-Hughes, E. Castro-Camus, M.B. Johnston, and H.E. Beere. O*ptics Letters* **32**, 2297 – 2299 (2007).

[127] *Far-Infrared Spectroscopic Characterization of Explosives for Security Applications Using Broadband Terahertz Time-Domain Spectroscopy.* W.H. Fan, A.D. Burnett, P.C. Upadhya, J.E. Cunningham, E.H. Linfield, and A.G. Davies. *Applied Spectroscopy* **61**, 638 – 643 (2007).

[128] *Advanced terahertz electric near-field measurements at sub-wavelength diameter metallic apertures*, A.J.L. Adam *et al.*, *Opt. Express* **16**, 7407 (2008).

[129] *THz near-field measurements of metal structures*, A.J.L. Adam, J.M. Brok, P.C.M. Planken, M.A. Seo, and D.S. Kim, C.R. *Physique* **9**, 161 (2008).

[130] *Fourier-transform terahertz near-field imaging of one-dimensional slit arrays: mapping of electric-field-, magnetic-field-, and Poynting vectors*, M.A. Seo, A.J.L. Adam, J.H. Kang, J.W. Lee, S.C. Jeoung, Q.H. Park, P.C.M. Planken, and D.S. Kim, *Opt. Express* **15**, 11781 (2007).

[131] *Measurement and calculation of the near-field of a terahertz apertureless scanning optical microscope*, A.J.L. Adam, N.C.J. van der Valk, and P.C.M. Planken, *J. Opt. Soc. Am*. **B 24**, 1080 (2007).

[132] *Frequency selective surfaces for high sensitivity terahertz sensing*, C. Debus, P. Haring Bolívar, *Applied Physics Letters*, Vol. **91**, no. 18, p. 184102 (2007).

[133] *Characterization of aqueous alcohol solutions in bottles with THz reflection spectroscopy*, P. Uhd Jepsen, J.K. Nielsen, and U. Møller, *Optics Express* **16**, 9318-9331 (2008).

[134] *Optical modulation of terahertz pulses in a parallel plate waveguide*, D.C. Cooke and P. Uhd Jepsen, *Optics Express* **16**, 15123-15129 (2008).

[135] *Routes to fiber delivery of ultra-short laser pulses in the 25 fs regime*_T. Le, G. Tempea, Z. Cheng, M. Hofer, and A. Stingl, *Optics. Express* **17**, 1240-1247 (2009)

CONTRIBUTIONS TO BOOKS

Martyn Chamberlain - Durham

Applied Terahertz Science: The Technology of the Future, and Always Will Be? In R.E. Miles, X-C Zhang, H. Eisele, A. Krotkus (Eds). Terahertz Frequency Detection of Materials and Objects, Springer, pp 11-176., 2007.

Giles Davies & Edmund Linfield - Leeds

Molecular and Organic Interactions. In R E Miles, X.-C Zhang, H Eisele, A. Krotkus (Ed) Terahertz Frequency Detection and Identification of Materials and Objects. Springer. pp. 91-104, 2007.

THz Spectroscopy and Imaging. Future trends in microelectronics. Wiley pp.359-368. 2007.

Peter Uhd Jepsen – COM-DTU
"*Nyt lys på ukendt land: Terahertz Teknologi*", in Optiske Horisonter, en rejse på kommunikationsteknologiens vinger (ISBN: 87-92062-01-6), pp. 67-91, COM•DTU, Odense (2007). Textbook for high-school students, distributed to all high-schools in Denmark.

Terahertz Time-Domain Spectroscopy of Crystalline and Aqueous Systems. NATO Security through Science Series: *Terahertz Frequency Detection and Identification of Materials and Objects:* pages 147-165.ISBN 978-1-4020-6502-

A. Tredicucci – SNS Pisa

Terahertz quantum cascade lasers, in Intersubband Transitions in Quantum Structures (McGraw-Hill, New York, 2006), p. 45-105.

Quantum cascade lasers, in Encyclopaedia of Condensed Matter Physics, Q-1 (2005).

Tailoring the emission of terahertz quantum cascade lasers, in Terahertz Frequency Detection and Identification of Materials and Objects (Springer, Dordrecht, 2007), p.41 – 54.

PATENTS

Laser Circolari A Semiconduttore Con Reticoli Per Emissione Verticale" Itpi/2008/0039
SNS, Pisa

Electromagnetic Wave Sensor with Terahertz Bandwidth US/2008/283752
Paris VII and Thales R & T

Integrated Sensing Probes etc, submitted as US patent 2006, EU patent app 2008
Siegen and RWTH Aachen

Monolithisch Integrierter Antennen- Und submitted as German patent 2008
Siegen and RWTH Aachen

Elektrooptische Kamera Mit Demodulierendem Detektorarray
Siegen and RWTH Aachen

Herstellungs-verfahren für einen Oberflächensensor, System und Verwendung eines Oberflächensensors DE 102008016294.9
Siegen and RWTH Aachen

Terahertz Pulse Reconstruction UK Patent GB0708491.6
Durham University

Determining concentration of a substance in aqueous solutions by self-referenced reflection THz spectroscopy, EU06116664.1 (and US provisional)
Danish Technical University

APPENDIX III

CONFERENCE TALKS AND PRESENTATIONS & PUBLIC UNDERSTANDING OF SCIENCE DISSEMINATION

Invited Talks 176

Aurele Adam - TU Delft

'Apertureless Wide Band Terahertz Near-field Microscopy', NFO-9 (Ninth international conference on near-field optics, nanophotonics and related techniques), 10-15 September 2006, Lausanne Switzerland.

'Terahertz Near-field Optics and Microscopy', Materials Research Society Spring Meeting 2006, San Francisco, 17-21 April 2006.

Sub-Wavelength Measurements of the Near-Field of a Metal Aperture, 29th Conference on Lasers and Electro Optics (CLEO 2008) San Francisco, California, USA, May 2008.

Terahertz Near-Field Measurements of Small Metal Structures, The International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz), Pasadena, California, USA, September 2008.

Debra Barnes – Durham University / Merops Consulting Ltd, UK

Terahertz – Emerging Markets, Terahertz Photonics 2007, Weetwood Hall, Leeds, 29-30 October, 2007.

Exploitation of THz, "Mind the Gap" – Millimetre Wave and THz Conference organised by Electronics Knowledge Transfer Networks (UK Technology Strategy Board), London, 24th January 2008.

S Barbieri – TeraView/ Paris VII

'Terahertz Quantum Cascade Lasers'. S. Barbieri, J. Alton, C. Worrall, M. Houghton, O. Marshall, S. Dhillon, A. de Rossi, M. Calligaro, C. Sirtori, H. E. Beere, and D. Ritchie, The 8th International Conference on Intersubband Transitions in Quantum Wells, Cape Cod, MA, USA, September 11th – 16th, 2005.

'Progress on Terahertz Quantum Cascade Lasers'. S. Barbieri, J. Alton, C. Worrall, M. Houghton, O. Marshall, S. Dhillon, A. de Rossi, M. Calligaro, C. Sirtori, H. E. Beere, and D. Ritchie, 2006 Materials Research Society Spring Meeting, San Francisco, California, USA, April 17th – 21st, 2006.

'THz Generation and Frequency Mixing in Quantum Cascade Structures', Advanced Optical Material and Devices (AOMD-5), Vilnius, Lithuania, 2006.

'Terahertz Quantum Cascade Lasers', Nanosciences and Nanotechnologies – 3rd Russian-French Workshop, St. Petersburg, Russia, June 2006.

Beam Shaping and Ultrafast modulation of THz Quantum Cascade Lasers, THz workshop. EUMW2007: European Microwave Week 2007. October 10, 2007, Munich, Germany.

Andrew Burnett – Leeds
Can Science Secure Our Skies? Presentation at Dana Centre Event, July 10th 2007.

Broadband Terahertz Time-Domain and Raman Spectroscopy and Their Use in the Analysis of Compounds of Security Relevance, A.D. Burnett, W.H. Fan, P.C. Upadhya, J.E. Cunningham, H.G.M. Edwards, J. Kendrick, T. Munshi, M. Hargreaves, E.H. Linfield and A.G. Davies, Terahertz Photonics 2007, Weetwood Hall, Leeds, 29-30 October, 2007.

Martyn Chamberlain -Durham

Between Radar and the Light Bulb: Terahertz Photonics for the 21st Century, Defence Technology Centre (MoD) Meeting, Edinburgh, September 2004.

Developments in PMMW and Terahertz Imaging, European Symposium on Optics and Photonics for Defence & Security, London, October 2004.

Between Radio and Light: European Terahertz Activities in Biology, Medicine, Security and Process Monitoring: UK/Japan Nanotechnology Symposium, The University of Tokyo, Japan, March 2005.

Functional Component Developments in the TeraNova Project for Terahertz Sensing & Imaging, Optro 2005, Paris, May 2005.

TeraNova - European Research into Novel Terahertz Sensing and Imaging Systems, Southern Universities Research Association, Washington DC, June 2005.

The Background to Terahertz Frequency Biomedical Imaging & Sensing. International School of Solid State Physics, Erice, Sicily. 35th Workshop: Physics and Technology of THz Photonics, July 2005.

The Applicable Physics of the Terahertz Frequency Band, LOI Action Group Disruptive Technology Workshop on THz Technology, 22nd September 2005, Edinburgh, UK.

'Novel Terahertz Sensing & Imaging Systems for Biotechnology, Healthcare, Security & Process Control'. SPIE Conference on Terahertz and Gigahertz Electronics and Photonics, Bruges, Belgium, September 2005.

'TeraNova and Other European Activities in THz Technology', HMGCC (Her Majesty's Government Communications Centre), Workshop on THz Sources and Systems for Security Use, Durham University, UK, 28-30th September 2005.

'Overview of European Terahertz Activities, Anglo-Japanese Meeting on Terahertz Science', British Embassy, Tokyo, November 2005.

'Advances in THz Functional Components, Applications & Basic Science in the TeraNova Programme'. Teratech 2005, Osaka, Japan, November 2005.

'Sensing, Imaging and Other Applications of Terahertz Radiation: Challenges, and (Some) Solutions, from the TeraNova Project'. IEEE Lecture at University College, Dublin, Ireland, April 2006.

'TeraNova: Sensing, Imaging and Other Applications of Terahertz Radiation'. Essex University, UK, May 2006.

'Applied Terahertz Science: The Technology of the Future, and Always Will Be', NATO Advanced Study Institute on THz Systems for Sensing and Imaging, Spiez, Switzerland, J *Scattering of Terahertz Radiation from Random Structures*, 31st Joint International Conference of Infrared and Millimetre Waves and the 14th IEEE Terahertz Electronics Conference, Shanghai, September 2006.

Detection of Separation of Laminated Materials by Reflected THz Pulses, ECNDT, Berlin, September 2006.

THz Pulse Reconstruction, Joint 32nd Infrared and Millimetre Waves and 15th IEEE International Terahertz Electronics Conference, Cardiff, September 2007.

Background to the Development of Terahertz Frequency Systems, Terahertz Photonics 2007, Weetwood Hall, Leeds, 29-30 October, 2007.

The TeraNova Integrated Project, Terahertz Photonics 2007, Weetwood Hall, Leeds, 29-30 October, 2007.

Overview of Terahertz Technology, Terahertz Systems and Industrial Applications, Royal Society, London, February 25th 2009.

J. Darmo – TU Wien

Terahertz time domain spectroscopy: technique and applications, Institut of Physics, Mountain University Leoben, Austria, 20.1.2005. *THz Photonics'*, J. Darmo, J. Kroell, K. Unterrainer, International Laser Centre at Slovak University of Technology, Bratislava, January 12, 2006.

Gain and Loss in Terahertz Quantum Cascade Structures: Time-domain study, The 15th International Conference on Non-equilibrium Carrier Dynamics in Semiconductors HCIS15, Tokyo, Japan, 23-27 July 2007.

Terahertz Semiconductor Gain Medium: Static Properties and Dynamic Behaviour, J. Darmo, J. Kröll, M. Martl, D. Dietze, S. Barbieri, C. Sirtori, and K. Unterrainer, CLEO/QELS and PhAST 2008, San Jose, California, USA, 4.05.2008 - 09.05.2008.

Quantum Cascade Laser: between device physics and quantum optics, J. Darmo, J. Kröll, M. Martl, D. Dietze, K. Unterrainer, S. Barbieri, C. Sirtori, 15th International Winter School on New Developments in Solid-State Physics, 18.-22.2.2008, Bad Hofgastein, Austria.

THz Quantum Cascade Lasers: THz time-domain spectroscopy study, J. Darmo, J. Kröll, K. Unterrainer, S.S. Dhillon, C. Sirtori, X. Marcadet, M. Calligaro; Conference ITQW 2007, 9-14 Sep. 2007, Ambleside, UK.

Phase-resolved study of lasing in THz quantum cascade lasers, J. Darmo, J. Kröll, M. Martl, D. Dietze, W. Parz, S. Barbieri, C. Sirtori, K. Unterrainer, Plenary talk, European Optical Society Annual Meeting 2008, Paris, 29.Sept.-2.Oct. 2008.

Time Domain Spectroscopy of Gain,Loss and Coherence in Quantum Cascade Lasers J. Darmo, J. Kröll, M. Martl, W. Parz, D. Dietze, S. Barbieri, C. Sirtori, K. Unterrainer, International Quantum Cascade Lasers School & Workshop, Monte Verita (Acsona), Switzerland, 14.-19. Sept. 2008.

Phase and amplitude resolved time domain study of terahertz quantum cascade lasers, J. Darmo, J. Kröll, M. Martl, W. Parz, D. Dietze, K. Unterrainer, S. Barbieri, C. Sirtori, "", Wilhelm und Else Heraeus-Seminar "Novel Light Sources and Applications", 3.-9.2.2008, Obergurgl, Austria.

Time resolved THz QCL measurements for THz amplification J. Darmo, J. Kröll, M. Martl, S. S. Dhillon, X. Marcadet, M. Calligaro, C. Sirtori, K. Unterrainer, THz Photonics, 29.-30.Oct. 2007, Leeds, UK.

THz Quantum Cascade Lasers: THz time-domain spectroscopy study, J. Darmo, J. Kröll, K. Unterrainer, S.S. Dhillon, C. Sirtori, X. Marcadet, M. Calligaro, Conference ITQW 2007, 9-14 Sep. 2007, Ambleside, UK.

Giles Davies – Leeds

"Squeezing more out of the electromagnetic spectrum: terahertz frequency science and technology, "Physics 2005, A Century after Einstein", Warwick UK, 10-14 April 2005.

Terahertz quantum cascade lasers: realization and recent progress. Defence Technology Centre (MoD) Meeting, Edinburgh, September 2004.

Quantum Cascade Lasers, LOI Action Group Disruptive Technology Workshop on THz Technology, 22nd September, Edinburgh, UK.

'*Spectroscopy of explosives and drugs-of-abuse*', HMGCC (Her Majesty's Government Communications Centre), Workshop on THz Sources and Systems for Security Use, Durham University, UK, 28-30th September 2005.

'*TeraNova: A European Integrated Project on 'Novel Terahertz Sensing and Imaging Systems'*, Photonics West (January 2006).

'Molecular and Organic Interactions', NATO Advanced Research Workshop 'Terahertz Frequency Detection of Materials and Objects' (Switzerland, June 2006).

'*Broadband Terahertz Sources*'. 18th Annual Meeting of the IEEE Lasers and Electro-Optics Society (LEOS), Sydney, Australia, 23–27 October 2005.

'*Solid State Terahertz Sources from an Optical Perspective*'. Japanese European Seminar on Terahertz Technology. British Embassy, Tokyo, Japan, 21st November 2005.

'*Broadband Pulsed Terahertz Sources*'. Materials Research Society 2006 Spring Meeting, San Francisco, USA, 17–21 April 2006.

'*Broadband THz Technology for Security Applications*'. SPIE Europe Conference Optics/Photonics in Security and Defence, Stockholm, Sweden, 11–14 September 2006.

'*Broadband THz Technology*'. SPIE Optics East, Boston, MA, USA, 1–4 October 2006.

Terahertz time Domain Spectroscopy - Present and Future Modalities, Cunningham, J., Wood, C., Burnett, A., Upadhya, P. C., Fan, W. H., Linfield, E. H. and Davies, A. G., Proc. IEEE International Microwave Symposium, 1697-1699 (2007).

Terahertz Research at the University of Leeds – from Quantum Cascade Lasers to Pulsed Broadband Spectroscopy, Edmund H Linfield and a Giles Davies, GDR-E THz school/ Bordeaux- Bombanes June 1-2, 2007.

Recent Developments in Quantum Cascade Lasers, Edmund Linfield and Giles Davies, 13th International Symposium on Ultrafast Phenomena in Semiconductors (Vilnius, Lithuania), 26-29 August, 2007.

The MBE Growth and Fabrication of Terahertz Quantum Cascade Lasers, Edmund Linfield, *2nd International Workshop on Quantum Cascade Lasers* (Brindisi, Italy), September 6-8, 2006.

S. Dhillon – Thales R & T, France

THz generation and mixing in Quantum Cascade Lasers, 12th international Conference on Narrow Bandgap Semiconductors (NGS12), Toulouse, France, June 2005. *'THz Generation and Non-linear Mixing in Quantum Cascade Lasers'*, Mid-Infrared Coherent Sources (MICS), Barcelona, Spain, Nov 2005.

'THz Generation and Non-linear Mixing in Quantum Cascade Lasers', International Conference on Superlattices, Nanostructures and Nanodevices (ICSNN) 2006, Istanbul, Turkey, Aug 2006.

Daniel Dolfi – Thales R&T, France

Continuous Wave THz Generation Based on a Dual-frequency Laser and a LTG - InGaAs Photomixer, R. Czarny, M. Alouini, X. Marcadet, S. Bansropun, J.L. Doualan, R. Moncorgé, J.F. Lampin, M. Krakowski & Daniel Dolfi, Terahertz Photonics 2007, Weetwood Hall, Leeds, 29-30 October, 2007.

Jerome Faist - ETH Zurich, Switzerland

Quantum Cascade laser at subterahertz frequencies, International Conference on the physics of Semiconductors, Rio de Janeiro, Brazil, July 27th-August 1st, 2008.

Terahertz quantum cascade lasers, CLEO, Conference on Lasers and Electro-Optics, San José, CA, May 4-9, 2008.

Peter Haring Bolívar- Siegen

Photonic Terahertz Technology, Course at WS EuMC02 Workshop Terahertz Technology for Space and Earth Applications, 7th European Microwave Week, Amsterdam, NL, 11-15 October 2004.

THz biomolecular sensing, Seminar of the Observatoire des Micro et Nanotechnologies THz technologies: state of the art, challenges and applications, Institute Curie, Paris, F, 19 October 2004.

Integrated terahertz sensors for label-free analysis of genes, SPIE Conference Photonics West 2005, San Jose, January 22-28, 2005.

Biomolecular Sensing with Integrated THz Systems, OSA Topical Meeting on Optical Terahertz Science and Technology, Orlando, USA, March 14-16, 2005

Time-domain characterization techniques applied to THz metamaterial analysis, Workshop on Metamaterials for Microwave and Optical Technologies, San Sebastián, Spain, July 18-20, 2005.

DNA and protein diagnostics, 35th Workshop: Physics and Technology of THz Photonics, Erice, Italy, July 20 -26, 2005 (Tutorial).

THz biomolecular sensing, Biophotonics and Bioelectronics Workshop, Ottawa, Canada, 15 August 2005. *Integrated terahertz sensing arrays for label-free biomolecular sensing*, 230th ACS National Meeting, in Washington, DC, Aug 28-Sept 1, 2005. *'Integrated Terahertz Sensing Arrays for Label-free Biomolecular Sensing'*, 230th ACS National Meeting, in Washington, DC, Aug 28-Sept 1, 2005.

'Terahertz Technology and Its Biosensing Potential', Life is Matter – Life Matter, 1st Annual Symposium *Conversations in Bionanotechnology*, Göteborg, Oct 25-27, 2005.

'THz Biomolecular Sensing', Forum for Terahertz Spectroscopy and Imaging, Kaiserslautern, Germany, March 1-2, 2006.

New Concepts for THz Biomolecular Sensing Systems, C. Debus, F. Voltolina and P. Haring Bolívar, 4ièmes Journées THz, Bombannes, F, 29-31st may (2007).

Towards Cost-Efficient THz Biochip Technologies, C. Debus, F. Voltolina and P. Haring Bolívar, 2007 IEEE Antennas and Propagation Society Meeting, Honolulu, Hawaii, June 10-15, 2007.

Perspectives for High Sensitivity THz Biosensing, P. Haring Bolivar, Academy Colloquium, Royal Dutch Society of Science and Arts, Amsterdam, 1-16 June 2007.
New Approaches for High-sensitivity THz Biosensing Systems, C. Debus, F. Voltolina, D. Surawicz and P. Haring Bolivar, International Symposium Topical Problems of Biophotonics, Nizhny Novgorod – Moscow – Nizhny Novgorod, Russia, 4-11 August, 2007.

Biological Applications of THz Sensing, P. Haring Bolívar, Infrared and Millimetre Wave Conference, Cardiff, 3-7 September 2007.

Terahertz biosensors based on double split ring arrays, C. Debus, P. Haring Bolívar, Photonics Europe, SPIE, Strasbourg, 9 April (2008).

Peter Uhd Jepsen- Danish Technical University

Chemical recognition with broadband THz spectroscopy and its applications in the defence and security sectors, DSTO workshop on Terahertz for Defence and Security, December 16-17 2005, Adelaide, Australia (presented by B. M. Fischer)

Terahertz molecular spectroscopy, Workshop on THz Photonics, July 20-26 2005, Erice, Italy

Quantitative terahertz time-domain spectroscopy and analysis in chemistry and biology, 230th ACS National Meeting, 29-31 August 2005, Washington, D.C. *Quantitative Terahertz Time-domain Spectroscopy and Analysis in Chemistry and Biology'*, ACS Fall Meeting, Washington, USA, August 30th, 2005.

'*New Light on the Metal-insulator Phase Transition in VO_2: A THz Perspective*', TeraTech 2005, November 2005, Osaka, Japan, (invited).

'Chemical and Biochemical Sensing with THz Radiation', Japanese-European THz seminar on Terahertz Technology, November 21st 2005, Tokyo, Japan (invited).

'Terahertz Time-domain Spectroscopy', NATO Advanced Research Workshop, Spiez, Switzerland, 6-11 July 2006 (invited).

Ingredients Analysis of Aqueous Solutions and Food Products with THz Reflection Spectroscopy, FiO/LS XXIII (OSA Annual Meeting), San Jose, September 2007.

Terahertz Time-domain Spectroscopy of Crystalline and Aqueous Systems, Annual Meeting of the Danish Physical Society, June 2007.

Terahertz Time-domain Spectroscopy of Crystalline and Aqueous Systems, KNAW Meeting on Terahertz Science, Amsterdam, 14-16 June 2007.

Terahertz Activities in Denmark, Réunion du GDR Européen, Bombannes, France, 1-2 June 2007.

Terahertz Time-domain Spectroscopy of Crystalline and Aqueous Systems, French THz Days, Bombannes, France, 29-31 May 2007.

Terahertz Time-domain Spectroscopy of Crystalline and Aqueous Systems, CLEO, Baltimore, May 2007.

Drugs & Alcohol: Prediction of Solid-state Vibrational Modes and Analysis of Aqueous Solutions with THz Spectroscopy, International Bunsen Discussion Meeting, Bad Honnef, 1-4 April 2007.

Determination of Alcohol Concentration in Aqueous Solutions and Food Analysis using Reflection Terahertz Time-Domain Spectroscopy, OTST 2007, Orlando, Florida, March 14-16 2007 (contributed talk, given by Uffe Møller)

Ab-initio Prediction of Terahertz Vibrational Modes in Crystalline Systems, SPIE Optics East, Boston, Massachusetts, October 2006.

The Physical Principles of Chemical Recognition in Terahertz Spectral Imaging, MICCAI 2006, Copenhagen, October 2006.

Ingredients analysis of aqueous solutions and food products with THz reflection spectroscopy, Frontiers in Optics/Laser Science 2007, San Jose, California, 19-23 September 2007.

Terahertz Time-domain Spectroscopy - Sensing Applications, Terahertz Photonics 2007, Weetwood Hall, Leeds, 29-30 October, 2007.

Ab-initio investigation of terahertz vibrational modes in molecular crystals, Ohio State University 63rd International Symposium on Molecular Spectroscopy, Columbus, Ohio, 15-18 June, 2008.

Drugs & Alcohol: THz time-domain investigations of solids and liquids, Physics Colloquium, University of Alberta, 7 March 2008.

Reflection THz-TDS for characterization of bottled liquids, ICOOPMA 2008, Edmonton, Alberta, Canada, 2025 July 2008.

Optical Terahertz Science and Technology, 18th Jyvaskyla Summer School, Jyvaskyla, Finland, 6-22 August 2008.

Terahertz Time-Domain Spectroscopy, European Optical Society Annual Meeting, Paris, France, 29 September – 2 November 2008.

M. Kemp-Teraview

TeraNova - European Research into Novel Terahertz Sensing and Imaging Systems, Southern Universities Research Association, Washington DC, June 2005. [Joint with M. Chamberlain]

Explosives Detection Using Terahertz Technology', by M. C. Kemp, Combating Terrorism Technology Support Office - Technical Support Working Group (TSWG) - Explosives Detection Conference, Miami, Florida, USA. June 12-16 2006.

E.H. Linfield- Leeds

Solid State Sources and Components. International School of Solid State Physics, 35th Workshop: Physics and Technology of THz Photonics Erice, Italy, July 20-26, 2005 (Tutorial).
Terahertz spectroscopy for in-process analysis. Plenary talk at the 2005 Annual Conference of the British Association for Crystal Growth,4th-6th September 2005, Sheffield, UK.

From quantum cascade lasers to broadband sources – the development and applications of terahertz systems, Quantum Electronics and Photonics 16, 6th-9th September 2004, Glasgow, UK.

Pulsed optical approaches to THz, LOI Action Group Disruptive Technology Workshop on THz Technology, 22nd September, Edinburgh, UK.

'Quantum Cascade Laser', HMGCC (Her Majesty's Government Communications Centre), Workshop on THz Sources and Systems for Security Use, Durham University, UK, 28-30th September 2005.

'Solid-state Sources and Components for THz Applications', 2nd Workshop on Terahertz Technology (Kaiserslautern, March 2006).

'Terahertz Spectroscopy and Imaging', Future Trends in Microelectronics workshop (Crete, June 2006).

'Terahertz Quantum Cascade Lasers', Seminar, University of Lancaster, UK (Lancaster, June 2006).

The RCUK Terahertz Basic Technology Research Project/The ISIS Network of Excellence, Terahertz Photonics 2007, Weetwood Hall, Leeds, 29-30 October, 2007.

Terahertz Background & Overview, E.H. Linfield and J.M. Chamberlain, "Mind the Gap" – Millimetre Wave and THz Conference organised by Electronics Knowledge Transfer Networks (UK Technology Strategy Board), London, 24th January 2008.

Recent developments in terahertz quantum cascade lasers, E.H. Linfield and A.G. Davies, ICOOPMA 2008 conference, 20 - 25 July 2008, Edmonton Canada.

Terahertz quantum cascade laser, E.H. Linfield and A.G. Davies, Quantum Electronics and Photonics-18 Conference, 25-29 August 2008, Edinburgh.

The generation and applications of terahertz frequency radiation, E.H. Linfield, A.G. Davies & J.E Cunningham, Nanoelectronics Days 2008 (http://www.cni-juelich.de/index.php?index=126), May13-16 2008, Aachen.

Growth, fabrication and measurement of terahertz quantum cascade laser, E.H. Linfield and A.G Davies, IRMMW, Cardiff, 2007.

Michael Nagel- RWTH Aachen

Characterization of Wire Pair Negative Index Metamaterials at Terahertz Frequencies. IRMMW/THz2007, Cardiff, Wales, 02-07 September 2007

Terahertz Photoconductive Antenna Arrays, H.F. Tiedje, D. Saeedkia, M. Nagel, H.K. Haugen, Optical Scanning Techniques for Characterization of, IRMMW/THz2008, Pasadena (2008).

P.C M. Planken –TU Delft

Terahertz near-field optics and microscopy, LEOS 2004, Puerto Rico, 7-11 November 2004.

Terahertz near-field microscopy, CLEO/QELS 2005 Baltimore USA, 22-27 May 2005.

Terahertz imaging, URSI 2005, Eindhoven, The Netherlands, 27 April 2005.

Terahertz near-field optics and microscopy, "Physics 2005, A Century after Einstein", Warwick UK, 10-14 April 2005 *Near-field THz Microscopy'*, NATO Advanced Research Workshop, 7-11 July 2006, Spiez, Switzerland.

'THz Microscopy', HMGCC (Her Majesty's Government Communications Centre), Workshop on THz Sources and Systems for Security Use, Durham University, UK, 28-30th September 2005.

'Terahertz Near-field Microscopy', CLEO/QELS 2005 Baltimore USA, 22-27 May 2005.

'*Terahertz Imaging'*, URSI 2005, Eindhoven, 27 April 2005.

'Terahertz Near-field Optics and Microscopy', 'Physics 2005, A Century after Einstein', Warwick UK, 10-14 April 2005.

THz Near-Field Measurements on Metal Structures, Symposium on "Prospects on High Resolution Imaging", 3 November 2006, Delft, The Netherlands.

Apertureless Wide Band Terahertz Near-Field Microscopy (invited, talk given by A. Adam), NFO-9 (Ninth international conference on near-field optics, nanophotonics and related techniques), 10-15 September 2006, Lausanne Switzerland.

Terahertz Near-Field Measurements on Metal Objects with Sub-Wavelength Spatial Resolution (invited, talk given by A. Adam) 4ème journées TeraHertz, 29 -31 May, 2007, Bombannes, France.

Near-Field Microscopy of THz Fields Near Metal Structures, Optical Terahertz Science and Technology conference, 2007, Orlando, Florida USA.

Masterclass on "*Terahertz Near-Field Measurements*", KNAW (Royal Academy of Sciences) Colloquium, Amsterdam, June 14-16, 2007.

Terahertz Near Field Techniques for Field Enhancements Measurements and Near Field Imaging , A.J.L. Adam, Academy Colloquium "TeraHertz Science", 14-16 June 2007, Amsterdam, The Netherlands.

Course on THz Emitters, A.J.L. Adam. European Summer School on New Trends in Terahertz Imaging, NTTI 2007, 9-13 July 2007, Paris Observatory, France.

Terahertz near-field measurements, "Master class", KNAW Workshop on Terahertz Science, Amsterdam, June 2007.

Near-field microscopy on metal structures, Congress on THz science and applications, Bordeaux, France, 29 May- 2 June, 2007.

Near-Field Microscopy of THz Fields near Metal Structures, Optical Terahertz Science and Technology conference, 2007, Orlando, Florida USA.

Giacomo Scalari – ETH Zurich

Recent Progress on Long Wavelength Quantum Cascade Lasers between 1-2 THz, LEOS 2007, 21-25 October 2007. Lake Buena Vista, Florida.

Terahertz Quantum Cascade Lasers Based on Intra-well Optical Transitions, 2nd Int. Workshop on Quantum Cascade Lasers, Bari, Italy, 6-9th Sept. 2006.

Magnetic confinement on THZ quantum cascade structures, International Quantum Cascade School and Workshop, MonteVerità, Switzerland, September 14-19, 2008.

C. Sirtori – Unversité Paris VII

'THz Generation and Mixing in Quantum Cascade Lasers', Photonics West 2006, San Jose, USA, Jan 2006.

'Terahertz Generation and Frequency Mixing in Quantum Cascade Structures', International Conference of the Physics of Semiconductors (ICPS) 2006, Vienna, Austria, Jul 2006.

'Quantum Cascade Laser-Applications', NATO Advanced Research Workshop: Terahertz Frequency Detection and Identification of Materials and Objects, Spiez, Switzerland, Jul 2006.

THz Frequency Shifting Using Quantum Cascade Lasers, Journées Scientifiques de l' ONERA: "Sources Optiques Paramétriques Pour L'Infrarouge" February 5-6, 2007, Clamart, France.

Andreas Stingl- Femtolasers

Contactless Semiconductor Wafer Scanner, Terahertz Photonics 2007, Weetwood.

G.P. Swift-Durham

Processing of Terahertz Pulses, Using a Reconstruction Method, Terahertz Photonics 2007, Weetwood Hall, Leeds, 29-30 October, 2007.

A. Tredicucci – SNS Pisa

Advances in THz quantum cascade lasers: fulfilling the application potential Photonics West – Optoelectronics '05 San Jose, USA, January 22-27, 2005.

THz Quantum Cascade Lasers: Developing New Operating Concepts and Advancing Application Technologies Optical Terahertz Science and Technology (OSA topical meeting) Orlando, USA, March 14-16, 2005.

Quantum cascade lasers International School of Solid State Physics, 35th Workshop: Physics and Technology of THz Photonics Erice, Italy, July 20-26, 2005*'THz Photonics and Quantum Cascade Sources'* (tutorial), POISE Summer School 2006, Cortona, Italy; June 25 – 30, 2006.

'Controlling the Emission of THz Quantum Cascade Lasers', NanoItaly 2006 – 3rd National Conference on Nanoscience and Nanotechnology, Trieste, Italy; May 22 – 24, 2006.

'Surface Plasmon Photonic Structures for THz Quantum Cascade Lasers', WOCSDICE 2006 – 30th Workshop on Compound Semiconductor Devices and Integrated Circuits held in Europe, Fiskebäckskil, Sweden; May 14 – 17, 2006.

'Designing the Emission of THz Quantum Cascade Lasers with Surface Plasmon Photonic Structures', 21st General Conference of the EPS Condensed Matter Division, Dresden, Germany; March 27 – 31, 2006.

'Designing the Emission of THz Quantum Cascade Lasers with Surface Plasmon Photonic Structure', 2006 March meeting of the American Physical Society, Baltimore, USA; March 13 – 17, 2006.

'Controlling Surface Plasmon Modes in Terahertz Quantum Cascade Laser', 2005 Fall Meeting of the Materials Research Society (MRS), Boston, USA; November 28 – December 2, 2005.

'Manipulating Surface Plasmons in THz Quantum Cascade Lasers', Teratech '05 – International Workshop on Terahertz Technology, Osaka, Japan; November 16 – 18, 2005.

'THz Quantum Cascade Lasers: Developing New Operating Concepts and Advancing Application Technologies', XCI Congresso Nazionale della Società Italiana di Fisica, Catania, Italy; September 26 – October 1, 2005.

'Tailoring the Emission of THz QCL', NATO Advanced Research Workshop on THz frequency detection and identification of materials and objects, Spiez, Switzerland, July 2006.

'Terahertz Quantum Cascade Laser', Photonics West 2006, San Jose, US, January 2006.

Controlling the Emission of THz Quantum Cascade Lasers, 2nd International Workshop on Quantum Cascade Lasers", Marina di Ostuni, Italy; September 6 – 9, 2006.

Frequency Tuning of THz Quantum Cascade Lasers, The 7th Pacific Rim Conference on Lasers and Electro-Optics (CLEO / Pacific Rim 2007), Seoul, Korea; August 26 – 31, 2007.

Frequency Tuning of THz Quantum Cascade Lasers, Workshop of the GDR-E "Semiconductor sources and detectors of THz radiation", Bombannes, France; June 1 – 2, 2007.

Emission Properties of THz Quantum Cascade Lasers, Photonics West 2007, San Jose, USA; January 20 – 25, 2007.

Il Laser a Cascata Quantica: da un Cristallo Artificiale Progettato a Tavolino, la Sorgente per la Fotonica nel Medio e Lontano Infrarosso, Nanoforum 2006, Milano, Italy; September 27 – 28, 2006.

Controlling the Emission of THz Quantum Cascade Lasers, 2nd EPS-QEOD Europhoton Conference, Pisa, Italy; September 10 – 15. 2006.

Recent advances and future prospects of THz quantum cascade lasers, The joint 32nd International Conference on Infrared and Millimetre Waves and 15th International Conference on THz Electronics (IRMMW-THz 2007), Cardiff, United Kingdom; September 2 – 7, 2007.

THz Photonics and Quantum Cascade Sources, Elettroottica 2008, Milan, Italy; June 10 – 12, 2008.

Engineering photonic structures for THz devices, 5th Regensburg Workshop on Quantum Heterostructures and THz Electronics, Regensburg, Germany; January 24, 2008.

Advancing technology of THz Quantum Cascade Lasers, Terahertz Photonics 2007, Leeds, UK; October 29 – 30, 2007.

K. Unterrainer T.U.Wien

Few-cycle THz spectroscopy: A tool for spectro-imaging, Gordon Research Conference, "Chemical Sensors and Interfacial Design", The Queens' College, Oxford, Great Britain, August 28 - September 2, 2005.

Few-cycle THz spectroscopy of intersubband dynamics, 3ème Journées Terahertz, Aussois, France, 10.-13.3.2005

THz Carrier Dynamics', K. Unterrainer, Int. Conf. on Superlattices, Nano-structures, and Nano-devices, ICSNN 2006, Istanbul, 31.7 - 4.8.2006.

'Generation and Application of THz Radiation in Semiconductor Nanostructures'. T. Müller, F. Schrey, G. Fasching, J. Darmo, J. Kröll, W. Parz, K. Unterrainer, M. Andrews, T. Roch, W. Schrenk, G. Strasser, E-MRS Spring Meeting, Nice,France, 29.5.- 2.6.2006.

'Ultra-broadband THz Generation and Nanostructure Spectroscopy', K. Unterrainer, International Workshop on Terahertz Technology (TeraTech 05), Osaka, Japan, 16-18 November 2005.

'Ultrawide Band THz Spectroscopy Applied to Semiconductor Nanostructures', T. Müller, F. Schrey, G. Fasching, J. Darmo, J. Kröll, W. Parz, M. Andrews, T. Roch, W. Schrenk, G. Strasser, K. Unterrainer, MICS 05, NATO Advanced Research Workshop "Mid-Infrared Coherent Sources", Barcelona, Spain, 6. -11. November 2005.

Phase-resolved Stimulated Emission from THz Quantum Cascade Lasers, 2nd Int. Workshop on Quantum Cascade Lasers, Bari, Italy, 6-9th Sept. 2006.

A THz Study of Relaxation and Dephasing. International Workshop on Terahertz Sensing and Security Applications, Thessalonika, Greece, 10-13th, Sept. 2006.

THz Time-Domain Spectroscopy of THz Quantum Cascade Laser: Phase and Amplitude Resolved Stimulated Emission, International Bunsen Discussion Meeting: Exploring THz spectroscopy, Bad Honnef, Deutschland, 1.4 - 4.4.2007.

Terahertz Quantum-Cascade Lasers: Micro Cavity Effects, Doping Dependence and Loss, Réunion du GDR-E "Semiconductor Sources and Detectors of Terahertz radiation", Bombannes, Bordeaux, France, 1.-3. 6. 2007.

THz Quantum Cascade Lasers: Microcavities and Photonic Crystal Devices, G. Fasching, A. Benz, Ch. Deutsch, W. Parz, A.M. Andrews, W. Schrenk, G. Strasser, K. Unterrainer, 15th Int. Conf. on Superlattices, Nanostructures and Nanodevices (ICSNN-15), 3.-8. Aug. 2008, Natal, Brazil.

Understanding intersublevel dynamics for device applications, K. Unterrainer, First SANDiE Workshop on Intersublevel studies in self-assembled semiconductor quantum dots, Paris, France, 2 - 3 April, 2008.

THz time-domain spectroscopy of THz quantum cascade lasers, K. Unterrainer, Workshop on Quantum Heterostructures and THz Electronics, Regensburg, 24.1.2008.

Time resolved THz QCL measurements for THz amplification, J. Darmo, J. Kröll, M. Martl, S. S. Dhillon, X. Marcadet, M. Calligaro, C. Sirtori, K. Unterrainer, THz Photonics, Leeds, UK, 29.-30.Oct., 2007.

From few-cycle THz pulses to Terahertz Quantum Cascade Lasers, G. Fasching, A. Benz, J. Kröll, J. Darmo, Ch. Deutsch, A.M. Andrews, W. Schrenk, G. Strasser, K. Unterrainer, ICECOM 2007, 19th Int. Conference on Applied Electromagnetics and Communications, 24-26 Sep. 2007, Dubrovnik, Croatia.

THz time-domain spectroscopy of THz quantum cascade lasers, J. Darmo, J. Kröll, M. Martl, S. S. Dhillon, X. Marcadet, M. Calligaro, C. Sirtori, K. Unterrainer, , IRMMW THz 2007, 2-7 Sep. 2007, Cardiff, UK.
Markus Wächter – RWTH Aachen

Propagation Dynamics of Guided THz Signals in Straight and Bended Metallic Slit Waveguides, IRMMW/THz2007, Cardiff, Wales, 02-07 September 2007.

Other Conference Talks and Contributions

1. *Optical control processes in terahertz quantum-cascade laser waveguide*, J. Darmo, K. Kröll, V. Tamousiunas, G. Fashing, K. Unterrainer, G. Strasser, M. Beck, M, Giovannini, J. Faist, CLEO/QELS 2005 Conference, May 22-27, 2005, Baltimore, Md. USA.

2. *Active photonics Structures for terahertz frequencies*,. Darmo, K. Kröll, G. Fashing, A. Benz, K. Unterrainer, M. Andrews, T. Roch, W. Shrenk, G. Strasser, 11th International Workshop on Applied Physics of Condensed Matter, June 15-17, 2005, Mala Lucivna, Slovakia.

3. *Optical processes in terahertz quantum-cascade laser waveguides* J. Kroell, J. Darmo, G. Fasching, G. Strasser, and K. Unterrainer, International School of Solid-State Physics – 35th Workshop: Physics & Technology of THz Photonics, July 20 – 26 , 2005, Erice, Italy.

4. *THz spectroscopy of semiconductor nanostructures and applications* T. Müller, F. Schrey, G. Fasching, J. Darmo, J. Kröll, W. Parz, M. Andrews, T. Roch, W. Schrenk, G. Strasser, K. Unterrainer, International School of Solid State Physics - 35th Workshop: Physics and Technology of THz Photonics", Erice, Italy.

5. *Phase matched frequency mixing between telecom wavelengths and THz radiation in a quantum cascade laser*, S. S. Dhillon, C. Sirtori, S. Barbieri, A. de Rossi, M. Calligaro, H. E. Beere and D. A. Ritchie, Intersubband Transitions in Quantum Wells (ITQW) 2005, Cape Cod, USA.

6. *Low Threshold (I_{th}< 20mA) Buried THz Quantum Cascade Lasers Using a Double Metal Scheme*, S. S. Dhillon, C. Sirtori, J. Alton, S. Barbieri, A. de Rossi, M. Calligaro, H. E. Beere, E. H. Linfield and D. A. Ritchie, Conference on Lasers and Electro-Optics (CLEO) 2005, Baltimore, USA.

7. *Buried waveguides in THz quantum cascade lasers based on two-dimensional surface plasmon modes*, S. S. Dhillon, J. Alton, A. de Rossi, M. Calligaro, H. E. Beere, S. Barbieri, E. H. Linfield, D. A. Ritchie and C. Sirtori, OPTRO 2005, Paris, France.

8. *Buried heterostructure 2.9 THz quantum cascade lasers operating up to 77K in continuous wave*, J. Alton, S. Dhillon, S. Barbieri, H. E. Beere, E. H. Linfield, D. A. Ritchie, M. Calligaro, A. De Rossi and C. Sirtori, Photonics West 2005, San Jose, USA.

9. *Buried waveguides in THz quantum cascade lasers based on two-dimensional surface plasmon modes*, S. S. Dhillon, J. Alton, A. de Rossi, M. Calligaro, H. E. Beere, S. Barbieri, E. H. Linfield, D. A. Ritchie and C. Sirtori, Laser and Electro-Optics Society (LEOS) conference, 2004, Puerto Rico, USA.

10. *Continuous-wave THz generation through photomixing using a dual-frequency Yb3+:KGd(WO4)2 laser*, R. Czarny, M. Alouini, C. Larat, S. Dhillon, M. Krakowsky, S. Bansropun, V. Ortiz, X. Marcadet, C. Sirtori, B. Gerard and D. Dolfi, 3emes Journées Térahertz, 13-16 March, 2005.

11. *Terahertz near-field microscopy*, Paul Planken, First Optical Terahertz Science and Technology conference Orlando USA, 14-16 March, 2005.

12. *High-speed characterization of integrated resonant THz biosensors using asynchronous optical sampling.* C. Janke, M. Nagel, M. Först, and H. Kurz, Optical Terahertz Science and Technology Conference 2005, Orlando, USA (2005).
13. *Asynchronous optical sampling for high-speed characterization of integrated THz resonator arrays.* C. Janke, M. Först ,M. Nagel, A. Bartels and H. Kurz, CLEO/QELS 2005 Conference, May 22-27, 2005, Baltimore, Md. USA
14. *Cost-efficient THz-resonators for label-free detection of DNA hybridization.* M. Nagel and H. Kurz, European Conferences on Biomedical Optics, June 12 – 16, 2005, Munich, Germany.

15. *Controlling surface plasmon modes in THz quantum cascade lasers* Richard Green et al MMD Meeting, Genova, Italy, June 22-25, 2005.

16. *Controlling surface plasmon modes in THz quantum cascade lasers* Richard Green et al. 8th International Conference on Intersubband Transitions in Quantum Wells – ITQW 2005 North Falmouth, USA, September 11-16, 2005.

17. *Terahertz spectroscopy in otorhinolaryngology: investigation of native mucosa tissue samples*, K. Schramm, C. Jahnke, D. Surawicz, P. Haring Bolivar, J.F.R. Ilgner, M. Westhofen, SPIE Conference Photonics West 2005, San Jose, January 22-28, 2005.

18. *Terahertz pulse transmission of surface plasmon polaritons through semiconductor gratings*, J. Gómez Rivas, M. Kuttge, P. Haring Bolivar, and H. Kurz, CLEO Europe, Munich, Germany, 12-16 June 2005.

19. *Enhanced emission and detection techniques for terahertz time-domain spectroscopy*, J. Kröll, J. Darmo, and K. Unterrainer, Optical Terahertz Science and Technology 2005, Orlando, USA.

20. *Ultra-thin metallic layers studied by broadband terahertz time-domain spectroscopy*, J. Kröll, J. Darmo, and K. Unterrainer, OPTRO 2005, Paris, France.

21. *RNA spot imaging*, M. Hoffmann, B. M. Fischer, H. Helm, and P. Uhd Jepsen, OSA Topical Meeting, Optical Terahertz Science and Technology, March 16-18 2005, Orlando, Florida.

22. *Sommerfeld Wires at Terahertz Frequencies'*, M. Wächter, M. Nagel, and H. Kurz, IEEE International Microwave Symposium (IMS), June 12 – 16, 2006, San Francisco, USA.

23. *'LT-GaAs Based Photoconductive Antenna Arrays For Pulsed and CW Operation'*, M. Awad, M. Nagel and H. Kurz, IRMMW/THz2006, September 18 – 22, Shanghai, China.

24. *'Low-Index Discontinuity THz Waveguides'*, M. Nagel, A. Marchewka, and H. Kurz, IRMMW/THz2006, September 18 – 22, Shanghai, China.

25. *'Investigation of THz Sommerfeld Wires for Cavity Applications', M. Wächter, M. Nagel, and H. Kurz*, IRMMW/THz2006, September 18 – 22, Shanghai, China.

26. *'High Power Superlattice Quantum Cascade Laser Emitting at 2THz'.* By C. Worrall, J. Alton, M. Houghton, O. Marshall, C. Sirtori, S. Barbieri, H. E. Beere, and D. Ritchie, Photonics West 2006, San Jose Convention Centre, San Jose, California, USA, 21st – 26th January 2006.

27. *'Recent Developments in People Screening Using Terahertz Technology – Seeing the World Through Terahertz Eyes'*, M. C. Kemp, A. Glauser, and C. Baker, SPIE Defense and Security Symposium, Orlando, Florida USA, April 2006.

28. *'Phase Matched Frequency Mixing Between Telecom Wavelengths and THz Radiation in A Quantum Cascade Laser'*, S. S. Dhillon, C. Sirtori, J. Alton, S. Barbieri, A. de Rossi, M. Calligaro, H. E. Beere, D. A. Ritchie, Photonics West 2006, San Jose, USA, Jan 2006.

29. *'Phase Matched Frequency Mixing Between Telecom Wavelengths and THz Radiation in A Quantum Cascade Laser'*, S.S. Dhillon, C. Sirtori, J. Alton, S. Barbieri, A. de Rossi, M. Calligaro, H.E. Beere, D.A. Ritchie, 17th International Symposium on Space Terahertz Technology (ISSTT), Paris, France, May 2006.

30. *'Continuous Wave THz Generation Based on a Dual-frequency Laser and a LTG - InGaAs Photomixer'*. R. Czarny, M. Alouini, X. Marcadet, S. Bansropun, J. L. Doualan, R. Moncorgé, J.F. Lampin, M. Krakowski, D. Dolfi, IEEE International Conference on Microwave Photonics (MWP 06), Oct. 06, Grenoble.

31. *'Optical Control in Active Terahertz Waveguide'*, J. Darmo, J. Kröll, K. Unterrainer, S.S. Dhillon, C. Sirtori, X. Marcadet and M. Calligaro, Joint 30th International Conference on Infrared and Millimeter Waves and 13th International Conference on Terahertz Electronics, Williamsburg, USA, September 19-23, 2005.

32. *'Optical Processes in Terahertz Quantum-Cascade Laser Waveguides'*, J. Kröll, J. Darmo, K. Unterrainer, S.S. Dhillon, C. Sirtori 14th International Winter School on New Developments in Solid State Physics, Mauterndorf, Austria, February 13-17, 2006.

33. *'Quantum Cascade Laser Dynamics Probed by Broad-band Terahertz Pulses'*, J. Kröll, J. Darmo, K. Unterrainer, S.S. Dhillon, C. Sirtori, X. Marcadet and M. Calligaro Junior Scientist Conference 2006, Vienna, Austria, April 19-21, 2006.

34. *'Terahertz Time-domain Spectroscopy of a Quantum Cascade Laser'*, J. Kröll, J. Darmo, K. Unterrainer, S.S. Dhillon, C. Sirtori, X. Marcadet and M. Calligaro, CLEO/QELS 2006 Conference, Long Beach, USA, May 21-26, 2006.

35. *'Semiconductor Terahertz Lasers: Optical Assessments and Control'*, J. Kröll, J. Darmo, K. Unterrainer, S.S. Dhillon, C. Sirtori, X. Marcadet and M. Calligaro G. Fasching, W. Schrenk, T. Roch, M. Andrews, G. Strasser, IEEE/LEOS Semiconductor Laser Workshop 2006, Long Beach, USA, May 26, 2006.

36. *'Optical Control of Terahertz Quantum Cascade Lasers'*, J. Kröll, J. Darmo, K. Unterrainer, S.S. Dhillon, C. Sirtori, X. Marcadet and M. Calligaro 11th International Workshop on Applied Physics of Condensed Matter, Mala Lucivna, Slovakia, June 21-23, 2006.

37. *'Terahertz Quantum-Cascade Laser Dynamics in Time-domain'*, J. Kröll, J. Darmo, K. Unterrainer, S.S. Dhillon, C. Sirtori, X. Marcadet and M. Calligaro 28th International Conference on the Physics of Semiconductors, Vienna, Austria, July 24 – 28, 2006.

38. *'Theoretical and Experimental Aspects o Time-domain Spectroscopy Applied to Semiconductor Terahertz Gain Medium'*, J. Darmo, J. Kröll, K. Unterrainer, S.S. Dhillon, C. Sirtori, X. Marcadet and M. Calligaro. 8th International Conference on the Physics of Semiconductors, Vienna, Austria, July 24 – 28, 2006.

39. *'Advanced Device Architectures for THz QCLs'* (Oral), A. Tredicucci, ICPS-28, Vienna, July 2006.

40. *'New Device Structures for THz QCLs* '(Oral), A. Tredicucci, POISE Summer School, Cortona, Italy, June 2006.

41. *'Controlling Surface Plasmon Modes in Terahertz Quantum Cascade Lasers'* (Oral), A. Tredicucci, Intersubband '*Transitions in Quantum Wells'* (ITQW 2005), Cape Cod, US, September 2005.

42. *'Towards Tunable THz QCLs'* (Poster), A. Tredicucci, POISE Summer School, Cortona, Italy, June 2006.

43. *'Analysis of Drugs-of-abuse and Explosives Using Terahertz Time-domain and Raman Spectroscopy'*, A. Burnett, W. Fan, J.E. Cunningham, P. Upadhya, A.G. Davies, E. Linfield, and R. Miles, Photonics West (San Jose, January 2006).

44. *'Ultra-broadband Coherent Terahertz Spectroscopy Using Asymmetric Excitation of Photoconductive Structures'*, P.C. Upadhya, W. Fan, A. Burnett, Y.C. Shen, A.G. Davies, E.H. Linfield, Infrared and millimetre wave conference (IRMMW) 2005, (Virginia, September 2005).

45. *Terahertz Near-Field Measurements of Field Enhancement Near Metal Objects* (A. Adam), Joint 31st International Conference on Infrared and Millimetre Waves and 14th International Conference on Terahertz Electronics September 18-22, 2006, Shanghai, China*:*

46. *LT-GaAs Based Photoconductive Antenna Arrays for Pulsed and CW Operation*, M. Awad, M. Nagel and H. Kurz, Joint 31st International Conference on Infrared and Millimetre Waves and 14th International Conference on Terahertz Electronics September 18-22, 2006, Shanghai, China.

47. *Low-Index Discontinuity THz Waveguides*, M. Nagel, A. Marchewka, and H. Kurz, Joint 31st International Conference on Infrared and Millimetre Waves and 14th International Conference on Terahertz Electronics September 18-22, 2006, Shanghai ,China.

48. *Investigation of THz Sommerfeld Wires for Cavity Applications, M. Wächter, M. Nagel, and H. Kurz*, Joint 31st International Conference on Infrared and Millimetre Waves and 14th International Conference on Terahertz Electronics September 18-22, 2006, Shanghai ,China.

49. *Terahertz Quantum Cascade Lasers: Novel Resonators and Line-width Properties*, (L. Mahler), CLEO 2007, Baltimore, USA; May 6 – 11, 2007.

50. *Line-width Enhancement Factor of a THz Quantum Cascade Laser,* (R.P. Green), WOCSDICE 2007, Venice, Italy; May 20 – 23, 2007.

51. *Controlling the Emission of THz Quantum Cascade Lasers*, (J. Xu), Joint 31st International Conference on Infrared and Millimetre Waves and 14th International Conference on Terahertz Electronics September 18-22, 2006, Shanghai, China.

52. *Designing THz Quantum Cascade Lasers for High Current Injection,* (J. Xu), MSS 13, Genova, Italy; July 15 – 20, 2007.

53. *Terahertz Quantum Cascade Lasers With Quasi-Periodic Resonators,* (L. Mahler), MSS 13, Genova, Italy; July 15 – 20, 2007.

54. *Terahertz Transfer onto a Telecom Optical Carrier*, (S. Dhillon), CLEO 2007, Baltimore, USA; May 6 – 11, 2007.

55. *Integrated Horn Antenna for Microstrip Waveguide THz Quantum Cascade Lasers,* (S Barbieri), Baltimore, USA; May 6 – 11, 2007.

56. *Dispersion-free and Low-Loss Propagation of THz Signals in a Metallic Slit Waveguide*, M. Wächter, M. Nagel, H. Kurz, Cleo Europe/EQUEC 2007, 17-22 June, Munich, Germany.

57. *Wire Pair Negative-Index Material at Terahertz Frequencies.* M. Awad, H. Kurz, M. Nagel, Cleo Europe 2007, 17-22 June, Munich, Germany.

58. *Enhanced Photoconductive Terahertz Antenna Array Devices*, M. Awad, M. Nagel, H. Kurz, IRMMW/THz2007, Cardiff, Wales, 02-07 September 2007.
59. *Electromagnetic Modelling of the DNA Monolayer in THz Bio-chips.* M. Neshat, D. Saeedkia, M. Nagel, S. Safavi-Naeini, IRMMW/THz2007, Cardiff, Wales, 02-07 September 2007.
60. *GHz Modulation of THz Quantum Cascade Lasers*, Stefano Barbieri, ITQW 2007. September 2007, Ambleside (UK).

61. *THz Sensing of Doping Concentration in Epitaxial Semi-Conductors and 2-D Electron Gases: Theory and Experiment*. D.P. Kelly, J. Darmo, K. Unterrainer, CLEO-Europe Conference, Munich, Germany 18.06.2007 – 22.06.2007.

62. *Gain and Loss in Terahertz Quantum Cascade Laser*, J. Kröll, J. Darmo, K. Unterrainer, S.S. Dhillon, C. Sirtori. X. Marcadet, M. Calligaro, CLEO-Europe Conference, Munich, Germany 18.06.2007 – 22.06.2007.

63. *Thermally Activated Absorption Features in Terahertz Semiconductor Heterostructures*, J. Kröll, J. Darmo, K. Unterrainer, S.S. Dhillon, C. Sirtori. X. Marcadet, M. Calligaro, CLEO/QELS Conference, Baltimore, USA 06.05.2007 – 11.05.2007.

64. *Design Limitations in THz-QCLs Caused by Thermally Activated Absorption Losses*, J. Kröll, J. Darmo, K. Unterrainer, S. S. Dhillon, C. Sirtori, X. Marcadet and M. Calligaro, Conference: Optical terahertz science and technology, Orlando, USA, 18-21 March 2007.

65. *Broadband Terahertz Time-Domain and Raman Spectroscopy and Their Use in The Analysis of Compounds of Security Relevance*, A.D. Burnett, W. Fan, P. Upadhya, J.E. Cunningham, H.G.M. Edwards, J. Kendrick, T. Munshi, M. Hargreaves, E.H. Linfield, A.G. Davies. ICVAS 4 2007, June 10 -15 2007, Corfu, Greece.

66. *Broadband Terahertz Time-Domain and Raman Spectroscopy of Explosives,* A.D. Burnett, W. Fan, P. Upadhya, J.E. Cunningham, H.G.M. Edwards, J. Kendrick, T. Munshi, M. Hargreaves, E.H. Linfield, A.G. Davies. SPIE Vol. 6549, 65490D [6549-04] (April 9, 2007).

67. *Complementary Spectroscopic Studies of Materials of Security Interest*, A. Burnett, W. Fan, P. Upadhya, J. Cunningham, H. Edwards, T. Munshi, M. Hargreaves, E. Linfield, and G. Davies. Proc. SPIE Vol. 6402, 64020B (Sep. 28, 2006).

68. *Temperature-Dependent Far-Infrared Spectra of Explosives and Drugs Measured by Terahertz Time-Domain Spectroscopy,* W.H. Fan, A. Burnett, P.C. Upadhya, J. Cunningham, E.H. Linfield and A.G. Davies. IRMMW-THz 2006, 18-22 September 2006, Shanghai, China.

69. *Cryogenic Excitation and Detection of Terahertz Radiation in Microstrip Circuits,* Cunningham, J., Wood, C., Upadhya, P.C., Linfield, E.H., and Davies, A.G., Proc. IRMMW-THz 2006, 232 (2006).

70. *Broadband THz Spectroscopy and its Security Applications*, A. Burnett, W. Fan, P. Upadhya, J. Cunningham, H. Edwards, T. Munshi, M. Hargreaves, E. Linfield, and G. Davies. Terahertz sensing and security applications, September 10 - 13 2006, Thessaloniki, Greece.

71. *Long Wavelength Terahertz Quantum Cascade Lasers Emitting Down to 1.2 THz*, C. Walther, M. Fischer, G. Scalari, R. Terazzi, N. Hoyler, J. Faist, ITQW 2007, September 2007, Ambleside (UK).

72. *Study and Improvement of THz Quantum Cascade Laser Beam-pattern for Different Waveguides Configurations.*, M.I. Amanti, C. Walther, M. Fischer, N. Hoyler, L. Sirigu, G. Scalari, J. Faist, ITQW 2007. September 2007, Ambleside (UK).

73. *Surface Plasmon Polariton-based Coaxial Probe for Terahertz Near-field Microscopy*, D. Surawicz, P. Haring Bolívar, H.-J. Shin and B. Mizaikoff, *Conference on Lasers and Electro-optics* and *Quantum Electronics and Laser Science Conference* ´07, OSA Technical Digest Series, Baltimore, USA, Mai 6-11 (2007).

74. *Frequency Selective Surfaces for High-Sensitivity Terahertz Sensors*, C. Debus and P. Haring Bolivar, *Conference on Lasers and Electro-optics* and *Quantum Electronics and Laser Science Conference* ´07, OSA Technical Digest Series, Baltimore, USA, Mai 6-11 (2007).

75. *Terahertz Time-Domain Spectroscopy: A New Way to Determine Alcohol Concentrations in Aqueous Solutions*, Annual Meeting of the Danish Physical Society, June 2007 (contributed talk, given by Uffe Møller).

76. *Precise Ab-initio Calculation of Terahertz-frequency Vibrational Modes in Molecular Crystals*, OTST 2007, Orlando, 14-16 March 2007 (contributed talk).

77. *Dual-Colour, Power-Scalable DFB Fibre Laser system for kHz-line-width Terahertz Generation*, OTST 2007, Orlando, Florida, March 14-16 2007 (Finn Eichhorn).

78. *Ultrafast Spectroscopy as a Probe of Light-Matter interaction in a mid-infrared Quantum Cascade Laser"*, W. Parz, T. Müller, J. Darmo, M. Austerer, G. Strasser, K. Unterrainer, L.R. Wilson, J.W. Cockburn, A.B. Krysa, and J.S. Roberts: International Conference on the Physics of Semiconductors (ICPS) 2008, Rio de Janeiro, Brazil, 27.07.2008 – 01.08.2008.

79. *Microcavity quantum-cascade lasers: Confinement and coupling in the terahertz spectral range*, G. Fasching, A. Benz, Ch. Deutsch, A.M. Andrews, R. Zobl, P. Klang, W. Schrenk, V. Tamosiunas, and K. Unterrainer: Institute for Quantum and Complex Dynamics, University of California Santa Barbara, USA; 02.05.2008.

80. *Current and gain in terahertz quantum cascade lasers,* A. Benz, G. Fasching, Ch. Deutsch, A.M. Andrews, K. Unterrainer, P. Klang, W. Schrenk, G. Strasser, T. Kubis, P. Vogl; 15th International Winter School on New Developments in Solid State Physics, Bad Hofgastein, Austria, 18.2.08 – 22.2.08.

81. *"Single-mode" whispering-gallery Terahertz quantum-cascade lasers with controlled degeneracy;* G. Fasching, V. Tamosiunas, A. Benz, A.M. Andrews, C. Deutsch, R. Zobl, W. Schrenk, G. Strasser, K. Unterrainer, Poster: 2007 9th International Conference on Transparent Optical Networks, Rome, Italy; 01.07.2007 - 05.07.2007.

82. *Effects of doping on terahertz quantum-cascade lasers,* A. Benz, G. Fasching, C. Deutsch, A.M. Andrews, K. Unterrainer, P. Klang, W. Schrenk; IRMMW-THz 2007, Cardiff, UK; 03.09.2007 - 07.09.2007.

83. *Time-resolved photocurrent measurements of terahertz QCLs,* R. P. Green, A. Tredicucci, N. Q. Vinh, B. Murdin, C. Pidgeon, H. E. Beere, D. A. Ritchie, ITQW 2007, Ambleside, UK; September 9-14, 2007.

84. *Vertically emitting microdisk lasers,* L. Mahler, A. Tredicucci, R. P. Green, F. Beltram, C. Walther, Jerôme Faist, H. E. Beere, D. A. Ritchie, CLEO/QELS 2008, San Jose, USA; May 4-9, 2008.

85. *Tunable THz Quantum Cascade Lasers with external cavity"* J. Xu, L. Mahler, R. Green, C. Mauro, T. Losco, A. Tredicucci, F. Beltram, H.E. Beere, D.A. Ritchie, SPIE Europe Security & Defense 2007, Florence, Italy; September 17-20, 2007.

86. *Terahertz quantum cascade lasers with quasi-periodic resonators* (Poster), L. Mahler, A. Tredicucci, R.P. Green, F. Beltram, H.E. Beere, D.A. Ritchie, ITQW 2007 Ambleside, UK; September 9-14, 2007.

87. *Frequency selective surface sensor for terahertz bio-sensing applications,*M. Nagel, G. Klatt, M. Awad, H. Kurz, A. Bartels and T. Dekorsy Ultrafast Phenomena (2008).

88. *Frequency Selective Surfaces and stretched DNA investigated by Time-Domain THz Spectroscopy based on ASOPS.* G. Klatt, M. Nagel, T. Fischer, T. Gisler, A. Bartels, G. Maret and T. Dekorsy, EOS Conference 2008, Paris (2008).

89. *Frequency Selective Surfaces for High-Sensitivity Terahertz Sensors*, C. Debus and P. Haring Bolivar, Conference on Lasers and Electrooptics and Quantum Electronics and Laser Science Conference ´07, OSA Technical Digest Series, Baltimore, USA, Mai 6-11 (2007).

90. *Low Cost Thermopile Detectors for THz Imaging and Sensing*, IRMMW-THz 2008, F. Voltolina, A. Tredicucci, P. Haring Bolivar, Pasadena, USA, September 15-19 (2008).

91. *Broadband Terahertz Time-Domain Spectroscopy of Drugs-of-Abuse Mixtures and 'Street' Samples.* A.D. Burnett, W. Fan, P. Upadhya, J.E. Cunningham, H.G.M. Edwards, T. Munshi, M. Hargreaves, E.H. Linfield, A.G. Davies. IRMMW-THz 2008, September 15–19, 2008, Pasadena, USA.

92. *Broadband Terahertz Time-Domain and Raman Spectroscopy for the Analysis of Compounds of Security Relevance.* A.D. Burnett, W. Fan, P. Upadhya, J.E. Cunningham, H.G.M. Edwards, J. Kendrick, T. Munshi, M. Hargreaves, E.H. Linfield, A.G. Davies, Forensic Analysis 2007, September 2nd – 4th 2007, Lincoln, UK.

93. *Broadband THz Spectroscopy and its Security Applications,* A.D. Burnett, W.H. Fan, P.C. Upadhya, J.E. Cunningham, H.G.M. Edwards, T. Munshi, M. Hargreaves, E.H. Linfield, and A.G. Davies. Terahertz sensing and security applications 2006, September 10th – 13th 2006, Thessaloniki, Greece.

94. *Terahertz time-domain spectroscopy of a two-dimensional electron gas in GaAs/AlGaAs Heterostructures*, D. Dietze, J. Darmo and K. Unterrainer: Poster: 58. Jahrestagung der Österreichischen Physikalischen Gesellschaft, Leoben, Austria; 22.09.2008 – 26.09.2008.

95. *Terahertz time-domain spectroscopy of a two-dimensional electron gas in GaAs/AlGaAs heterostructures* D. Dietze, J. Darmo and K. Unterrainer; Poster: EOS Annual Meeting 2008, Paris-Nord Villepinte, France; 29.09.2008 - 02.10.2008.

96. *THz Ellipsometry in Theory and Experiment* D. Dietze, D. Kelly, J. Darmo and K. Unterrainer: Poster: 33rd International Conference on Infrared, Millimeter and Terahertz Waves, Pasadena, California, USA; 15.09.2008 – 19.09.2008.

97. *Großflächige Terahertz-Emitter mit verschränkten Elektroden* , A. Grün, J. Darmo, K. Unterrainer,THz-Frischlinge Meeting, Freiburg, Germany 01.04.2007 – 04.04.2007.

98. *THz evanescent field spectroscopy*, J. Darmo, J. Kröll, K. Unterrainer, , The Joint 30th International Conference on Infrared and Millimeter Waves & 13th International Conference on Terahertz Electronics, Willimsburg, Virginia, USA; 19.09.2005 - 23.09.2005.

APPENDIX IV

A. EXTERNAL TRAINING AND DISSEMINATION EVENTS ORGANISED BY TERANOVA

- *International School of Solid State Physics: Physics and Technology of THz Photonics*, Erice, Italy, July 2005.
- *.Japanese European Seminar on Terahertz Technology*. British Embassy, Tokyo, Japan, 21st November 2005.
- *Physics of Intersubband Semiconductor Emitter'" (POISE) Summer School*, Palazzone di Cortona, Italy, June 2006.
- *Advanced Research Workshop on Identification of Materials: Terahertz Frequency Detection and Identification of Materials and Objects,* Spiez, Switzerland, July 2006.
- *Topical Meeting on Optical Terahertz Science and Technology (OTST 2007)* Orlando, Florida, June 2007).
- The *Ninth International Conference on Intersubband Transitions in Quantum Wells*, ITQW 2007, Ambleside, UK; September 9-14, 2007.
- *Terahertz Photonics 2007*, Weetwood Hall, Leeds, UK, 29th-30th October 2007.
- *Mind the Gap – Millimetre Wave and THz Conference* organised by Electronics Knowledge Transfer Networks (UK Technology Strategy Board), London, 24th January 2008.
- First topical meeting of the *European Focus Group on THz Science and Technology*, under the auspices of the European Optical Society, Paris, 29th September 29 to 1st October, 2008.
- *Terahertz and Industry*, Royal Society, London, UK, February 2009.

In addition to these events, internal training workshops have been held at Partner Assemblies. Details of these have been provided to the Commission annually.

B. EXHIBITIONS AND TRADE FAIRS

TeraNova was represented at the following:

- *Laser 2005*, Messe Muenchen, June 2005 (Femtolasers)
- *Photonics Korea 05*, Korea, 5th-9th September 2005 (Femtolasers)
- *OSA, Tucson,* USA, 16th-20th October 2005 (Femtolasers)
- *TeraTech 05*, Osaka, Japan, 16th-18th November 2005 (Femtolasers)
- *BIOS/Photonics West*, San Jose, USA, 19th-28th January 2006 (Femtolasers)
- *Laser 2006*, Shanghai, China, 21st-23rd March 2006 (Femtolasers)
- *CLEO 2006*, Long Beach, CA, USA, 22nd-25th May 2006 (Femtolasers)
- *SURA Terahertz Application Symposium*, Washington DC, USA, 31st May – 6th June 2006 (Femtolasers)
- *Laser 2007 - World of Photonics*, Messe Muenchen, 15-18 June 2007 (Femtolasers)
- *Iberian Nanotechnology Institute* in Braga, Portugal (21st-22nd November, 2007)
- *ICT Exhibition*, held in Lyon, France (25th – 27th November 2008)

There was also an exhibition at the Terahertz Systems and Industrial Applications meeting, Royal Society, London, 25th February 2009 at which partners *Femtolasers, Alpes Lasers* and *TeraView* all exhibited equipment.

C. PUBLIC AWARENESS OF SCIENCE & TECHNOLOGY

Book Chapters, Published Articles & Press Interviews

Martyn Chamberlain, Durham University

The terahertz gap: into the dead zone. Chemistry World, March 2007. [Published by the Royal Society of Chemistry]

Opening up the last part of the spectrum.
http://cordis.europa.eu/ictresults/index.cfm/section/news/tpl/article/BrowsingType/Features/ID/90252/highlights/teranova

Giles Davies, Leeds University

Publication in *The House Magazine*, Special Science Issue.
[This publication is circulated in the European Parliament]

Publication in *The Parliament* Magazine.
[This publication is circulated in the UK Parliament]

Peter Uhd Jepsen, Danish Technical University

Nyt lys på ukendt land: Terahertz Teknologi, D. Cooke, D. Turchinovich, U. Møller, F. Eichhorn, P. Uhd Jepsen, in Optiske Horisonter, en rejse på kommunikationsteknologiens vinger (ISBN: 87-92062-01-6), pp. 67-91, COM DTU, Odense (2007).
[Textbook for high-school students, distributed to all high-schools in Denmark]

Paul Planken, TU Delft

Interview with Dutch national newspaper *Volkskrant*, published July 16, 2005.

Terahertz Spectroscopie, *De Ingenieur*, p44-47, 10 February 2006, nr 2, Jaargang 118.

Terahertzgolven maken doorzichtig', *NRC handelsblad*, 29-11 2005 (Paul Planken, Delft).

Alessandro Tredicucci, SNS Pisa

Newspaper articles:
- Il sole 24ore, 7/9/2006
- Il Secolo XIX, 19/7/2007
- La Stampa, 18/7/2007

Broadcasts (Radio, Television and Internet)

Paul Planken, TU Delft

Interview with Noorderlicht (Web-site of the science programme from VPRO radio/tv) at http://noorderlicht.vpro.nl/artikelen/20009058/.

'Verkenningen in het duister: Terahertz Technologie opent de ogen', *Website of the Dutch Science programme Noorderlicht 2005*: http://noorderlicht.vpro.nl/artikelen/20009058/ (Paul Planken, Delft).

.

TELEAC/NOT "School TV" series on THz Medical Imaging. November 16, 2006 on 09.30 hr.

Alessandro Tredicucci, SNS, Pisa

Radio Interview: AGR Circuit, July 16, 2007.

Karl Unterrainer, TU Wien

Austrian Public Radio: ORF OE1 Dimensionen "Terahertz-Strahlung".

Peter Haring Bolivar, Siegen

TV spot (5 Min) by Univ. Siegen on WDR3 (German TV) to inform the general public, 13th July 2006 (Peter Haring, Siegen).

Radio programme WDR5 by Univ. Siegen, Frankfurt and Braunschweig to inform the general public on THz technology, 10th October 2006.

Popular Lectures & Presentations

Martyn Chamberlain, Durham University

'Between Radio and the Light Bulb: Physics and Applications of Terahertz Frequency Waves', British Physics Olympiad (lecture to High School Students), Royal Society, London, April 2006.

Edmund Linfield, Leeds University

'*The Development and Applications of Terahertz Imaging and Spectroscopy Systems*', Student Open Day of the Institute of Physics CMMP Conference, Exeter, April 2006.

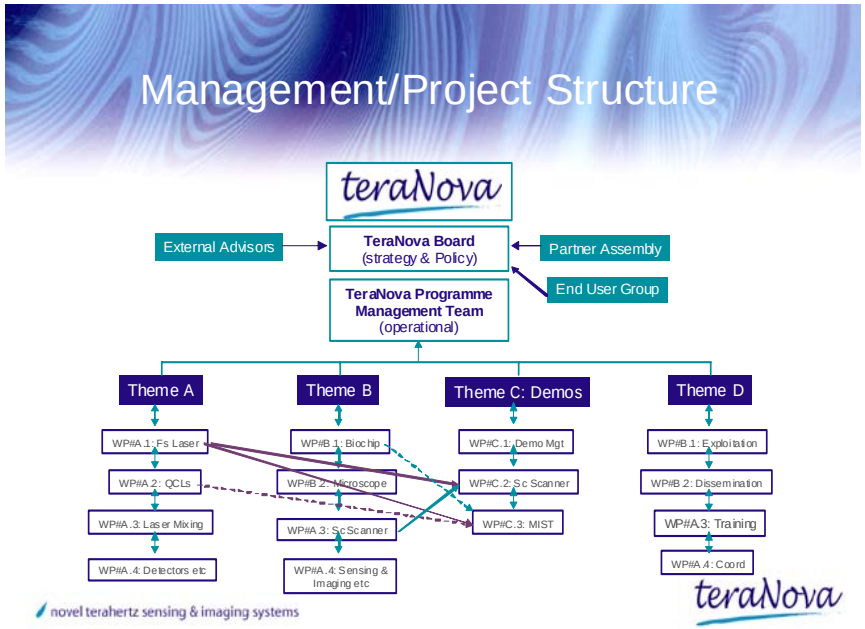
Karen Steenson, Leeds University

The Importance of Dissemination in Framework Projects – TeraNova, EC Project Manager's Association (ECPMA), St James' Hospital, Leeds, UK, 9th May and 25th July 2008.

Peter Swift, Durham University

Presentation at the House of Commons, London, November 2007, for MPs on the work of Young UK Scientists.

APPENDIX V



The *TeraNova* programme has been organised thematically (A, B, C, D), with further subdivision into Workpackages. Strategy and Policy was determined by the *TeraNova Board*, initially chaired by the distinguished UK industrialist, Christopher Snowden (CEO, Filtronic PLC) and subsequently by Tom Brazil, Professor of Electrical Engineering at University College, Dublin. The Board membership also included: the *TeraNova* Scientific Coordinator (Martyn Chamberlain, Durham University); the four Theme Leaders; a representative of large-scale industry (Daniel Dolfi, Thales); and a representative of small-medium enterprise (Andreas Stingl, Femtolasers). Panels of End Users and other Advisers were drawn from across Europe and beyond to advise the Board , for example in the matter of determining which Demonstrator bids should be selected for full development within Theme C. Additional advisers were retained for ethical and gender issues.

The Partner Assembly was made up of one representative of every member organisation of the Consortium. It met twice per annum to present the work of the partners and to discuss matters of common interest. It advised the Board of any matters of concern on the progress of the Programme, and had appropriate voting rights on the Board.

The Scientific and Technical aspects of the Programme were coordinated by Professor Martyn Chamberlain (*University of Durham*). The administrative, management and financial activities were coordinated by Dr Karen Steenson (*University of Leeds*). The Scientific Coordinator and Administrative Coordinator constituted the *Programme Management Team* and were responsible for day-to-day coordination of the project. The Exploitation Management of the

Programme was in the hands of Durham University, but contracted to a dedicated Professional (Dr Debra Barnes, Merops Ltd.)

During the course of the Project, the Management Team were responsible for: setting budgets; writing reports (technical, financial and management); organising and maintaining a website; arranging for *TeraNova* representation at events; ensuring that legal and IP issues were addressed; liaising with Brussels; responding to partners' changing needs; managing Deliverables; dealing with external agencies and enquiries; and ensuring that strategic decisions were taken by the Board on time and in accordance with best practice.

Report and Appendices compiled by:

Dr Karen Steenson,
TeraNova Administrative Co-ordinator,
Leeds University, United Kingdom.

Professor Martyn Chamberlain
TeraNova Scientific Co-ordinator
Durham University, United Kingdom.