SEVENTH FRAMEWORK PROGRAMME

THEME
[ICT-2007.3.5 Photonic components and subsystems]

Grant agreement for: < Small or medium-scale focused research project (STREP)>

OPTHER

Project no.: 224356

Project acronym: ***OPTHER***

Project title: **Op**tically Driven **T**era**h**ertz Amplifi**er**s

WP0 - Management

Deliverable D0.6 : Awareness and wider society implications

Due date of deliverable: 30.09.2011
Actual submission date: 14.02.2012

Start date of project: 01.04.2008

Duration: 42 months

Organisation name of lead contractor for this deliverable: TED

Revision - 1

Project Co-funded by the European Commission within the Seventh Framework Programme		
Dissemination level		
PU	**Public**	**X**
PP	**Restricted to other programme participants (including Commission Services)**	
RE	**Restricted to a group specified by the consortium (including the Commission Services)**	
CO	**Confidential, only for members of the consortium (including the Commission Services)**	

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Abstract

The aim of this deliverable D0.6 titled "Awareness and wider society implications" is to make a synthesis of all the societal benefits expected by the THz amplifiers to be issued from the OPTHER research project.

These are very wide as they address :

- some key professionnal groups, such as industrial production or maintenance companies, and security/defence entities;
- all individual people during their dayly life by the use of high throughput data links at home or at the office, and also through some specific healthcare capacities.

A general analysis of these topics has been reported in Deliverable D5.3. In the following, only the elements that characterize the subject of this deliverable have been highlighted.

1 Introduction

The Optically driven Terahertz amplifiers are the most challenging research components for the three THz scientific capacities which are :

- THz imaging
- THz spectroscopy
- THz communication

Beside these three scientific capacities, there are five main categories of applications :

- Non Destructive Testing for the quality control along the production chain
- Industrial Preventive Maintenance
- Security and Defence
- Telecommunications
- Biology and biomedical

The following chapters will detail each of these categories of applications, both in terms of THz imaging and THz spectroscopy, except the particular case of Telecommunications which is of course related to communication only.

The section 4.1 upon airport security has been written by Thales Services/ThereSIS (Thales European Research centre for eGov, Security and Information Systems).

The section 4.2 upon Defence is issued from a working group of the European Defence Agency CAPTECH IAP01 titled IEEMT (Information Exchange & Evaluation in Millimeter wave and Terahertz technologies), initially led by Thales Electron Devices SA and FOI, and currently led by Thales Research Technology France.

The other chapters refer to the French book "Optoelectronique térathertz" edited by EDP Sciences in 2008, written by professors and researchers from several French Universities in cooperation with Thales Airborne Systems.

2 Non destructive testing for the quality control along the production chain

THz systems present a major interest versus optical systems as they can check the integrity through non transparent non metallic materials.

As the cost of a stopped production chain is very important, such THz imaging systems might present real benefits, especially when there is a high need of real time imaging along the production chain.

Moreover THz spectroscopy can be used to detect noxious substances.

For example the automotive industry has used several THz systems for its high accuracy quality control without any contact:

- thickness of paint
- duration of drying
- dry/wet transition phase
- surfacic micro-defects on sheet steel

Another example is the use of THz spectroscopy to measure the in situ refractive index of several polymer materials (e.g. polyethylen, polypropylen, polyamide) in order to control the percentage of additive within these polymer materials.

Even in the case of very high temperatures, such as when controlling the purity of steel in fusion, THz systems can be used very fruitfully in real time with much more performance results than optical systems.

The detection of defects in electronic circuits is also very interesting with THz systems.

Last but not least are the domains of pharmaceutics and food processing, to control the integrity of the medicines (e.g. pills), to control the humidity level within the food packaging and to identify harmful substances within child food.

Actually, THz (versus ultrasound) can achieve measurements without any contact and are quite complementary to X-ray techniques, while being non ionizing.

3 Industrial preventive maintenance

Here, the THz capacity to go through non metallic materials, can be used to detect hidden objects or substances, by means of a volume analysis without any contact.

In this case, the target is to exploit the THz "drawbacks" in a useful way, i.e. the metallic reflection and the water absorption.

This can be achieved with a portable THz system for industrial preventive maintenance in situ.

Some interesting examples can be the following :

- Aeronautics (to detect defects under paint layer)
- building and public works sector (to detect defect under coat layer)
- agriculture (to evaluate the age of a tree or to measure the water contained inside leaves or plants)
- food processing (to measure the water contained inside vacuum-packed food)

4 Security and defence

4.1 Airport security

It is well known that, in people screening market, the need for explosives detection is highly increasing especially in the airport security domain. Solutions based on millimeter-wave (mmW) technologies (from 30 to 300 GHz) have proved their ability to detect objects concealed under clothes. Several products are already on the market and were tested in many European airports.

However, the output of these pilot tests showed that these products are far from addressing the whole expectations of people screening in terms of performances and also can raise some issues with privacy and safety, especially for active systems. Moreover airport stakeholders are eager to improve people screening process speed taking into account the evolution of air traffic (expected x 2 in the next 15 years).

While mmW systems penetrate better through some barrier materials compared to THz systems, there are two important considerations that favour THz scanning for security applications: (a) spatial resolution and (b) spectroscopic signatures. Terahertz detection inherently has a roughly ten times better spatial resolution compared to mmW systems simply because the electromagnetic wavelength of THz radiation is roughly ten times shorter than mmW radiation. Consequently, images of suspicious objects such as concealed metallic or plastic knives are much sharper and more readily identified when imaged with THz scanners. A second important consideration is specificity. Through known characteristic THz spectra of explosives, biological and chemical agents and illegal drugs, a THz image can be spectroscopically analysed to identify concealed contents and potential threats. THz techniques can identify materials via the spectrum of their absorbance by low frequency molecular motions, similar to infrared absorption methods. In fact, the spectral domain from 0.1 to 10 THz hosts low frequency vibrations (phonon modes), hydrogen-bonding stretches, and other intermolecular vibrations of molecules in many chemical and biological materials, including explosives and related compounds (ERCs), drugs and other biomolecules. Comparable spectroscopic 'fingerprint' spectra of these threats are not present in the mmW range.

The absorption peaks of the main ERCs are presented in the next table.

Explosive & Related Compound	Measured Absorption Peak Position (THz)
TNT	1.66, 2.20, 3.69, 4.71, 5.52, 8.28, 9.12, 9.78, 10.65, 11.01,13.86, 15.15, 16.95, 17.37, 19.17, 19.89
RDX	0.82, 1.05, 1.50, 1.96, 2.20, 3.08, 6.73, 10.35, 11.34, 12.33, 13.86, 14.52, 17.74, 18.12, 20.13
HMX	1.78, 2.51, 2.82, 5.31, 6.06, 11.28, 12.00, 12.54, 12.96, 13.74, 14.55, 18.15, 18.60, 19.38
PETN	2.0, 2.84
Tetryl	5.97, 10.11, 11.28, 14.67, 16.14, 18.36
2-amino-4, 6-DNT	0.96, 1.43, 1.87, 3.96, 5.07, 6.27, 8.49, 9.87, 10.77, 12.15, 13.44, 16.68
4-amino-2, 6-DNT	0.52, 1.24, 2.64, 3.96, 5.04, 5.82, 7.53, 9.30, 10.20, 11.13, 13.86, 14.97, 17.70
4-Nitrotoluene	1.20, 1.37, 1.86, 6.75, 8.85, 10.83, 14.04, 15.66, 18.51
1,3,5-TNB	4.17, 4.62, 10.05, 11.19, 13.80, 15.75, 19.05
1,3-DNB	0.94, 1.19, 2.37, 10.56, 12.18, 15.33, 17.13
1,4-DNB	3.24, 3.96, 5.55, 10.38, 12.45, 13.29, 15.21, 15.54
2,4-DNT	0.45, 0.66, 1.08, 2.52, 4.98, 8.88, 10.56, 11.58, 12.81, 14.34, 15.69, 19.05, 20.04
2,6-DNT	1.10, 1.35, 1.56, 2.50, 5.61, 6.75, 9.78, 11.43, 13.32, 13.89, 15.39, 17.25
3,5-dinitro aniline	0.96, 1.20, 3.18, 4.62, 5.04, 5.91, 7.44, 10.62, 10.98, 14.46, 16.41, 18.18
2-nitro diphenyl anine	2.19, 2.58, 2.88, 3.45, 5.13, 6.18, 7.56, 10.08, 12.33, 13.05, 15.00, 15.60, 16.29, 17.34, 18.51, 19.32

Fig. 1 THz peaks of Explosives and Related Compounds[1]

Limitations due to atmospheric attenuation (see figure below) prevent long-distance standoff spectroscopy techniques, although detection of explosives has been demonstrated up to 30 meters away. Some of the main limitations for long-distance standoff applications, however, relate back to the available THz power generated by the emitter and the sensitivity of the

[1] **Terahertz Spectroscopy and Imaging for Defense and Security Applications**, Hai-Bo Liu, Hua Zhong, Nicholas Karpowicz, Yunqing Chen, and Xi-Cheng Zhang - Proceedings of the IEEE | Vol. 95, No. 8, August 2007

detector. Hence, this frequency region is largely underutilized and is referred to as the "terahertz gap" of the electromagnetic spectrum because compact moderate power amplifiers are not available. Increased power output and increased detection sensitivity, which will come with improvements to technology, will aid the ability of THz technology to overcome long-distance standoff technical hurdles.

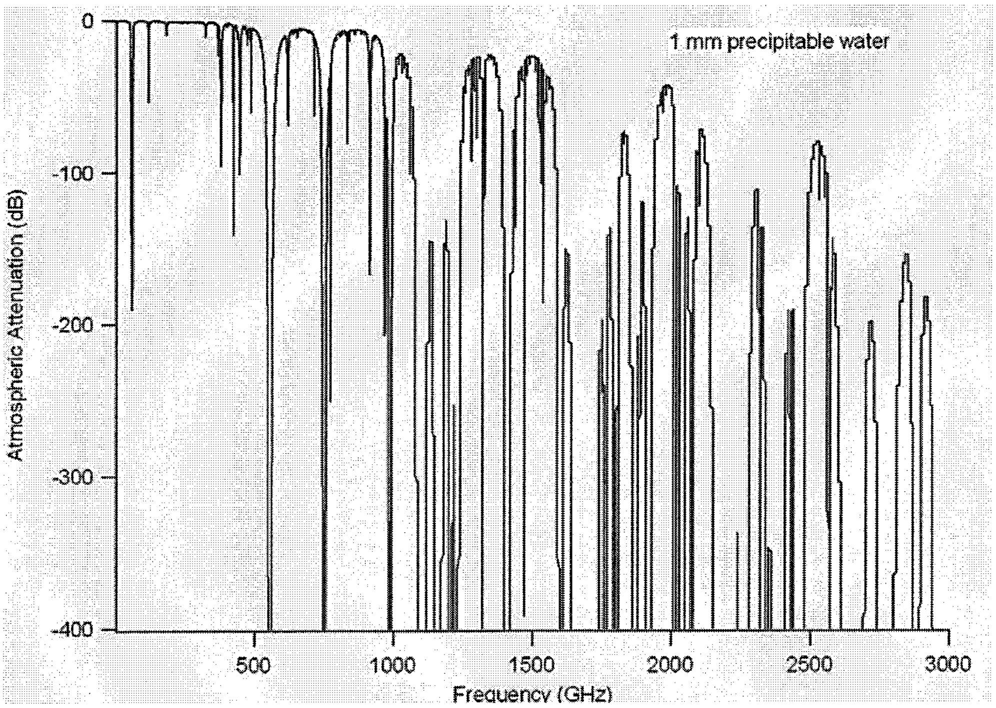

Fig. 2 Atmospheric attenuation of THz

The development of a **compact, cheap, powerful and efficient THz amplifier** will provide the opportunity for unique spectroscopic investigations and sensing modalities that contribute to the overall problem space facing explosives detection and more generally airport security[2].

4.2 Defence

Terahertz defence applications are currently studied through a working group at European Defence Agency (EDA), as a sub-group of IAP 01, created in 2008, named IEEMT (Information Exchange & Evaluation in Millimeter wave and Terahertz technologies), currently led by THALES RESEARCH TECHNOLOGY FRANCE, with the following main objectives, in order to come to a common and thorough understanding of the potential of these technologies for Defence applications:

- share results from existing & incoming national programmes
- perform round-Robin experiments
- build a joint data base
- perform joint functional evaluations
- share ideas about system design
- perform joint modelling & simulations developments
- prepare the construction of joint development projects

The focus is on scientific and pre-competitive low TRL (1-3) activities.

On the other side the EDA "DISCOTECH" roadmap study has led to the following trends :

[2] **THz imaging and sensing for security applications—explosives, weapons and drugs,** John F. Federici and al., Semicond. Sci. Technol. 20 (2005)

- In THz, Defence investment is needed to develop in a short term horizon under 1 THz, stand-off imaging sources and detectors. The military applications for such imaging are detection of IED (improvised explosives devices), protection of military sites and convoys, identification of the hidden face morphology, at farer ranges, with higher resolution, allowing an acceptable reaction time, in case of emergency.
- For above 1 THz stand-off imaging and spectroscopic point to point detection, the system concepts are being studied in detail, in order to analyse the future operational impact, while novel promising technologies are emerging.

5 Telecommunications

Today the short range telecommunications are ensured by Bluetooth and WIFI technologies, but the is a trend to get saturation within these frequency bands, due to the growth of multimedia computers and domotics applications.

THz frequencies could play an interesting role in the data throughput increasing challenge to connect computers at home or at the office.

The increase of the carrier frequency is currently the most used way to allow the access to more and more people to the high throughput. So in a longer term, THz frequencies could be a solution to establish high throughput telecommunications between fixed points.

Another aspect of THz use can be related to signal processing in telecommunications.

The throughput increase creates more and more information to be processed, hence there is a need to develop new electronic components in THz, and the THz amplifier is the most challenging one.

The THz waves cannot propagate well in the atmosphere because of the attenuation due to the water vapour absorption : this drawback can be fruitfully exploited to ensure confidentiality of communications within a given area.

Last but not least an advantage of THz waves in telecommunications could be an improved electromagnetic compatibility on board, for example for the In flight Entertainment within airplanes.

6 Biology and Biomedical

In the case of medical diagnosis, the THz water absorption will obviously limit the penetration depth. That is why THz is especially interesting for surfacic applications, such as dental and skin analysis.

THz can also provide interesting information upon the water content within the tissues

The biomedical THz imaging applications are mostly concerned with skin cancers, dental caries, burn diagnosis.

With an endoscopic system, THz could also be quite useful to detect cancers of oesophagus or intestines.

A great advantage of THz is its capacity to image and evaluate the burn cicatrization through the bandage, without needing to remove it.

THz spectroscopy can also address the spectroscopy of biological molecules, especially within DNA.

THz spectroscopy could also be exploited to detect glucose or uric acid.

7 Conclusion

The awareness and wider society implications of THz amplifiers has been described in five main categories of applications :

- Non Destructive Testing for the quality control along the production chain
- Industrial Preventive Maintenance
- Security and Defence
- Telecommunications
- Biology and biomedical

The THz amplifiers are the most challenging components research, but the applicative needs clearly request for strong involvement of industrial research, to go beyond the laboratory research and prepare the future step which will be the mass market, the last and final step to allow low cost production and real achievement in the wider society.

The OPTHER project is a key research milestone of this great adventure of Far Infrared that is based on the huge potential of THz optoelectronics. This conclusion is also supported by the decision of the IEEE Microwave Theory and Techniques Society (MTT) which has lunched in September 2011 a new journal specifically aimed at the frequency range between 300 GHz and 10 THz (http://www.thz.ieee.org): IEEE Transactions on Terahertz Science and Technology -

"Expanding the use of the Electromagnetic Spectrum". The transactions covers a wide range of activities and developments in terahertz science and applications, while at the same time, helping to bridge the technology gap between the RF and photonics communities.