Novel Optical Design for Terahertz Imaging Applications

John Loughran[1], J. Anthony Murphy[1], William Lanigan[1], Eoin Cartwright[1], Robert May[1], Tomás Ward[2], Kenneth Humphreys[2] and Charles Markham[3]

Terahertz Optics Group, Departments of [1]Experimental Physics, [2]Electronic Engineering and [3]Computer Science, National University of Ireland, Maynooth, Co. Kildare, Ireland. E-mail: john.p.loughran@may.ie

Abstract

We report on our investigations of a number of issues for terahertz medical imaging including optimisation of spatial resolution, characterisation of bio-medical tissues, efficient quasi-optical design and novel delivery systems. In tandem with our experimental approach we are developing effective computational models with which to analyse system performance.

Introduction

With frequencies ranging from 0.1 to 30 THz and wavelengths between 3 mm and 10 μm T-rays are finding new applications in areas as diverse as security and medical imaging. Due to the poor spatial resolution and low penetration through tissue of terahertz radiation, a recent review [3] indicates that the most common medical imaging applications explored to date are identification of basal cell carcinoma and of dental caries. Advantages of imaging at these wavelengths include good tissue differentiation reported by some researchers [2] for histopathology on animal tissues. T-rays are also safer than x-rays as they are non-ionizing.

Our research to date concentrates on characterising the gross optical properties of materials including biological tissues, in the design of quasi-optical imaging systems and in developing image processing techniques. Applying expertise in the area of the optics of Gaussian beams, we plan to develop novel optical techniques to extract detail from our targets in an efficient manner.

Absorbtion Measurements

We have concentrated on developing systems at 0.1 THz, for proof of concept purposes, and because of the ready availability of the necessary experimental components at a reasonable cost. A schematic diagram of one such system used to measure absorption is shown in figure 1(a). Initially we modelled the beam using a Gaussian beam mode approximation and verified this model experimentally. Measurements of beam width at various points in the optical path were found to agree closely with the theoretical predictions with an error of less than 5%. To measure absorption, the power loss as the beam traversed the sample was measured.

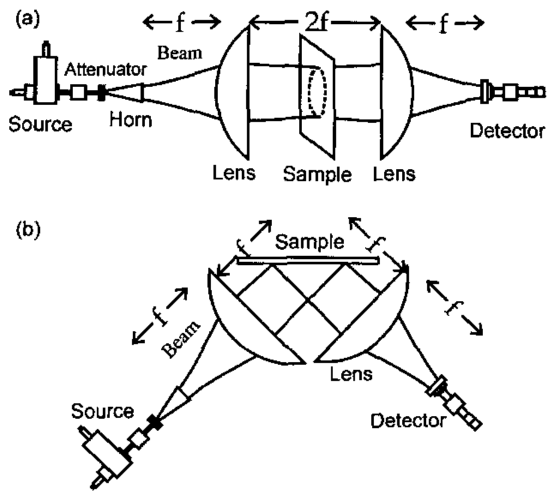

Figure 1: Set up to measure (a) absorption and (b) reflection

To ensure that most of the power loss was due to absorption rather than reflection from the sample holder, the sample was placed so that the angle of incidence of the beam was 56°. This is close to the Brewster angle for materials such as the plastics we tested. The source and detector were thus arranged so that the beam polarisation was in the plane of incidence. The results of our measurements of power loss though different materials are presented in table 1. Measurements of the reflectivity of some materials compared to that of aluminium, at an angle of incidence of 45°, were also made using the set up shown in figure 1(b). The results for reflection where the beam was polarised perpendicular to the plane of incidence are also presented table 1. Results for beam polarisation parallel to the incident plane confirmed that reflection was minimal, i.e. less than 1% in most cases, 6±1% for glass and 8±2% for water.

The measured absorption of T-rays by water here, of 19±4 dB/mm is in the same order of magnitude as measurements obtained by other researchers [1]. The absorption by the biological materials is, as expected, intermediate between water and various plastics. We used perspex as a liquid sample holder because of its

0-7803-8490-3/04/$20.00 ©2004 IEEE

Sample	Power loss (dB/mm)	Reflectivity* (%)
Aluminium		100±18
Water (distilled and tap)	18.8±4.0	60±9
Parma Ham	16.9±3.0	
Cheddar Cheese	7.4±0.5	
Wood	1.0±0.1	
Olive Oil	0.9±0.2	
Natural Rubber	0.8±0.1	
Flour	0.8±0.1	
Sugar	0.3±0.2	
Eccosorb	3.45±0.30	16±5
Glass	0.59±0.05	47±8
Polycarbonate	0.34±0.20	9±2
Polystyrene (solid)	0.33±0.20	32±6
Acrylic	0.28±0.20	27±5
Cardboard	0.28±0.05	33±6
Perspex	0.22±0.06	3.7±0.8
HDPE	0.14±0.02	24±5
ABS	0.14±0.06	3.1±0.6
White Cast Nylon	0.13±0.01	
Teflon	0.08±0.05	5.4±1.0
Polystyrene foam	0.01±0.10	0.4±0.1

Table 1: Power loss and Reflectivity (*angle of incidence 45°) of biological and man made materials at 100 GHz

low absorption and stiffness. Variations in the set up produced similar thus reproducible results on each occasion, within the limits of the errors indicated. In a separate experiment, the absorption by water was found to be proportional to the depth of the water along the optical path. This indicated that power loss was not dominated by reflection. No significant difference was measured in absorption or reflection between distilled water and tap water.

Imaging

The image obtained using a detector array or scanning system will require sophisticated image processing techniques to recover the clearest possible image of the original sample. Some preliminary studies in image processing are being explored. The result of convolution with a Gaussian filter is shown in figure 2.

A system to improve the structural detail obtained uses an optical filter as illustrated in figure 3. Using this system, radiation scattered by edges in the target is preferentially detected, while the main on-axis illuminating beam is blocked by the central obstruction of the spatial filter. This will use a detector array or the scanning system being developed in the new Biomedical Imaging Laboratory at NUI Maynooth.

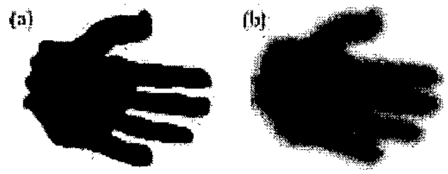

Figure 2: Drawn image of a hand (a) before and (b) after convolution with a Gaussian filter

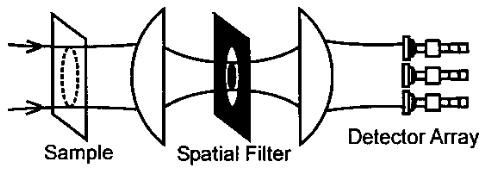

Figure 3: Using a Spatial Filter

Conclusions and Future Work

As human tissue contains on average 75% water we conclude that it is impractical to use terahertz radiation for transmission through more than a few millimeters of tissue. However the high absorption at these wavelengths may prove extremely useful in imaging thin histological samples. Another possible application is reflection imaging of surface features. So far research in this area has concentrated on imaging the skin or other objects in vitro. However, if compact delivery systems can be developed then endoscopic imaging may be feasible. It may be possible to image the uterine cervix in future, as an alternative to cervical smears. To this end we are investigating novel delivery and imaging systems, including flexible corrugated waveguide, axicons and binary elements. It will be possible to realistically model overall system performance computationally for purposes of optimisation of optical layout.

References

[1] C.D. Sudworth et al. Optical properties of human tissue at terahertz frequencies. In *Proc. SPIE, 5143, Progress in Biomedical Optics and Imaging 4(32)*, Munich, 24-25 June 2003.

[2] P. Knobloch et al. Medical thz imaging [of] histopathological samples. In *Proc. first intl. conf. on biomed. imaging & sensing apps. of THz technology, Phys. Med. Biol., 47, 3875-3884*, 7 Nov. 2002.

[3] K. Humphreys J.P. Loughran M. Gradziel W. Lanigan T. Ward J.A. Murphy, C. O'Sullivan. Medical terahertz imaging: Review of current technology and future potential. In *25th Annual International Conference IEEE Engineering in Medicine and Biology*, San Francisco, 1-5 Sept 2004.