Total Internal Reflection Terahertz Imaging

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***Abstract*— We present a new Terahertz imaging scheme based on total internal reflection that allows the study of aqueous samples while improving the longitudinal resolution. We were able to image a frog neuron using the spectral phase of the THz pulses using this technique.**

I. Introduction And Background

TIME-RESOLVED Terahertz (THz) imaging has been successfully applied using different schemes, such as transmission, reflection or partial reflection. However, when it comes to image samples made of polar liquids (water, notably), transmission imaging suffers from high loss (100µm-thick sample absorbs half of the incident intensity), leading to a poor signal-to-noise ratio. Besides, reflection imaging is impeded by the presence of echoes, irregularities of the surface and the need of a surface referencing in some case.

Total Internal Reflection (TIR), that appears above the critical angle ($\theta_c = \text{asin}(n_2/n_1)$) at a $n_1>n_2$ index interface has been successfully used in THz spectroscopy[1]. It has also been used to study the optical tunneling of THz wave and some properties of evanescent waves[2]. High-Resistivity silicon (HR-Si) is a highly valuable material in THz optics, thanks to its low absorption coefficient, and its high and quasi-constant refractive index in the THz range. This latter property makes it suitable for THz-TIR, since indices of polar liquids are generally much smaller.

In conventional optics, Total Internal Reflection Microscopy is a tool well-suited to study the properties of cell membranes[3] for instance.

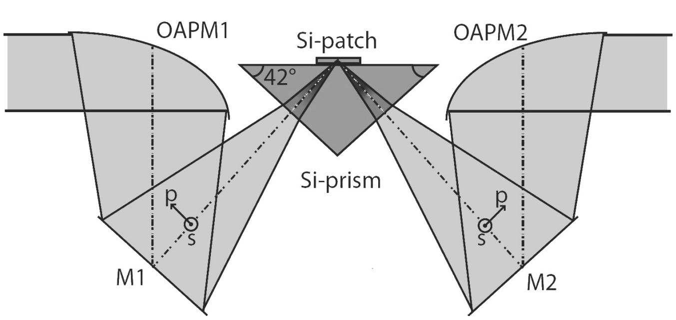

Fig 1. principle of terahertz total internal reflection imaging using a silicon prism and a mobile silicon patch.

At TIR interface, the evanescent wave properties depend upon the optical properties of the outer medium. This is a factor of contrast that can be used to image the small index changes such as those related to the ion concentration in water[4]. The evanescent wave skin-depth is sub-wavelength, allowing sub-wavelength longitudinal resolution, while absorption losses due to the presence of water that generally impedes the imaging of biological compound are much less severe thanks to reduced interaction length. Moreover, the interface is always flat, so that it can be used as a reference surface, and the sample holds by gravity and surface tension. The loss of time-delay information retrieved in transmission microscopy is compensated by the phase-shift of the wave that occurs upon TIR.

II. Results

This We used a classical terahertz time domain spectroscopy system. Our THz source is a photoconductive antenna triggered by 12fs, 76MHz, 120mW average power Ti:Sa laser, and the detection is achieved by the mean of two orthogonal photo-switch antennas triggered by the same laser, with the use of a delay line and a thick HR-Si used as a beam-splitter. We used a 42 degrees isosceles HR-silicon prism to provide coupling of the THz wave into a 3mm-thick patch of HR-silicon (Fig.1), which can be moved in X-Y direction, thus providing the scanning ability required for imaging.

We recorded the temporal waveform of the signal for several x-y position of the sample over an area of 4x4mm². As a first biologic sample, we used a frog neuron of about 1 mm diameter bathed in a physiological solution. The spectral phase contrast between the neuron and the solution is sensible, achieving much better contrast than with temporal or spectral amplitude. We are thus capable of spatially resolving a section of the neuron with a resolution in the order of 1mm (Fig. 2).

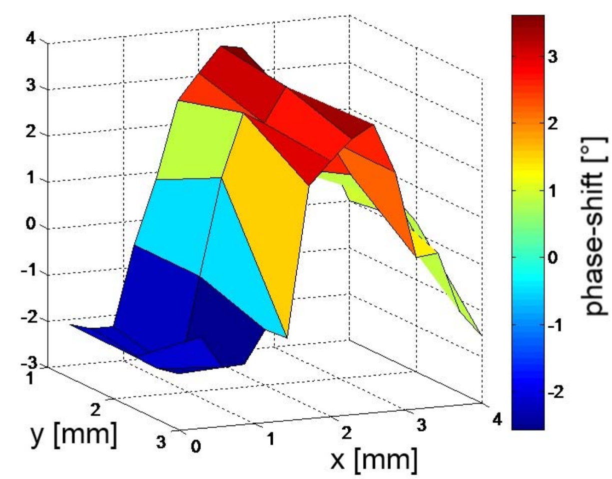

Fig. 2 : image of the spectral phase at 1THz of a frog sciatic nerve using total internal reflection THz imaging.

Among the advantage of this technique is the lower sensitivity of the phase to noise over long acquisition time, for fluctuations of phase are less severe than those of the rest of the setup.

We assessed the longitudinal resolution of the system by placing an aluminum mirror on top of the patch and by changing the spacing between them. When the mirror is close to the surface, the reflection is metallic (*i.e.* no phase change occurs) while when it is placed further apart, the reflection of the Thz pulse is accompanied by a phase shift while the power spectral density remains constant (Fig. 3).

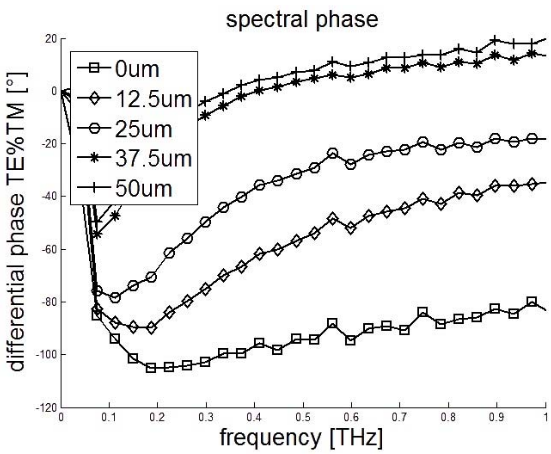

Fig. 3 : effect of the spacing between a metal mirror and the reflection interface on the phase-shift (0° is taken as the TIR reference)

When the spacing is more than 40µm, the influence of the mirror becomes negligible, consistent with the calculated skin-depth of the evanescent wave (23µm at 1THz). This effect has recently been used to study the hydration of lipid membrane[5].

III. CONCLUSION

A technique based on total internal reflection phase-shift has been shown to be suitable for the imaging of a biologic object in a physiological solution with good lateral resolution and sub-wavelength longitudinal resolution. It could be used for the study of membranes and single layers of cells.

REFERENCES

[1] H. Hirori et al., “Attenuated Total Reflection Spectroscopy in Time Domain Using Terahertz Coherent Pulses”, *Japanese Journal of Applied Physics*, **43**, 10A, 1287, 2004

[2] M.T. Reiten et al., “Optical tunneling of single-cycle terahertz bandwidth pulses”, *Physical review E*, **64**, 3, 2001

[3] D. Axelrod, “Total internal reflection fluorescence microscopy in cell biology”, *Traffic*, **2**,764, 2001

[4] J. Masson et al., “Ionic contrast terahertz near-field imaging of axonal water fluxes”, *Proceedings of the National Academy of Science*, **103**, 13, 2006

[5] H. Hishida et al., “Long-Range Hydration Effect of Lipid Membrane Studied by Terahertz Time-Domain Spectroscopy”, *Physical Review Letters*, **106**, 15 (2011)