A novel multiplexed THz spatial modulator for fast, sub-wavelength imaging and spectroscopy

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Abstract: We report on the current state of the development of a sub-wavelength THz spatial modulator array – a multi-pixel THz imaging device. The modulator allows fast image acquisition and spectroscopy with greatly improved spatial resolution.
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1. Introduction – THz spatial modulator for imaging and spectroscopy

Current THz sub-wavelength imaging techniques require mechanical (raster, point-by-point) scanning of a THz imaging complex over the sample area for image composition. This results in long acquisition times. Therefore, in order to increase the speed of acquisition, a THz imaging device consisting of multiple sub-wavelength apertures (an imaging array) for THz radiation was developed. The need for X-Y mechanical scanning of the apertures across the sample is minimized depending on the pixel array dimensions (number of sub-wavelength apertures) with respect to the sample area. The THz spatial modulator concept was first proposed by Rutt et al in [1]. In this paper we report on the design and characterization of a fully functional THz spatial modulator.

The transmission factor of each of the sub-wavelength apertures can be varied (modulated) electronically at a given modulation frequency. Thus, each of the apertures can perform independent amplitude modulation of the THz radiation. These apertures are then multiplexed in the frequency domain. The received signal – a bundle of frequency components – is processed which permits the photodetector system to differentiate between the adjacent holes. This is done by transforming the received signal (modulated optical signal, time signal) into the frequency domain by virtue of the FFT. The amplitude modulation is revealed in the output spectrum as a row of uniformly spaced modulation peaks separated by a fixed frequency interval. This is schematically depicted in figure 1. The position of a modulation peak on the frequency axis corresponds to the aperture's modulation frequency. If the amplitude modulation depth factor is constant and known for each of the apertures, the amplitude of a single modulation peak yields information about the sample's THz attenuation – THz absorption image.

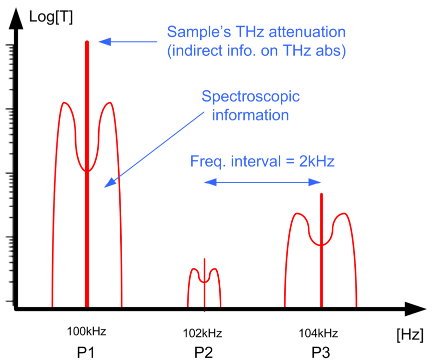

Figure 1 - Frequency spectrum of the THz modulator signal

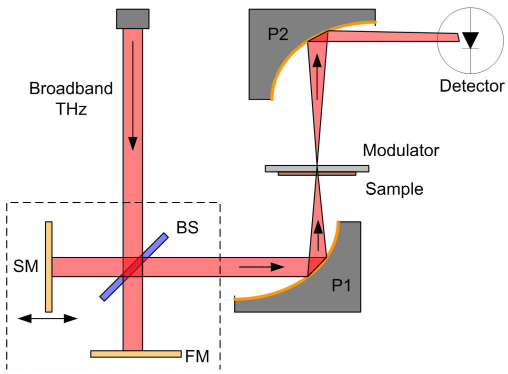

Figure 2 - THz modulator for FTIR spectroscopy

Additionally, if combined with a broadband, coherently enhanced synchrotron radiation source and scanning Fabry-Perot interferometer, the modulator can be used for THz Fourier Transform Spectroscopy. A complete THz imaging microscope for THz micro-spectroscopy of samples is shown in figure 2. The spectroscopic information – collected over the area imaged through a particular sub-wavelength aperture – is contained within the modulation peaks' side-bands, as depicted in figure 1.

2. Modulator electronic design and principle of operation

As seen in figure 3, in its current form, the device consists of an array of sixteen THz transmission windows (pixels) of sub-wavelength diameter. The complete array of sixteen pixels can be frequency multiplexed. Several variants of the device with varying pixel diameters – 5, 10, 15 and 20µm – were already fabricated, tested and characterized.

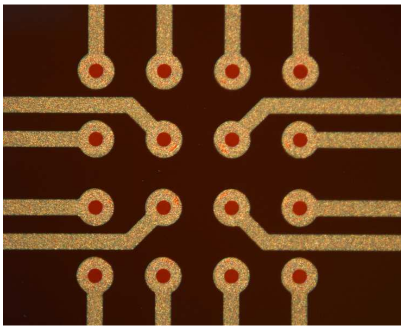

Figure 3 – THz modulator – P+ side pixel contacts

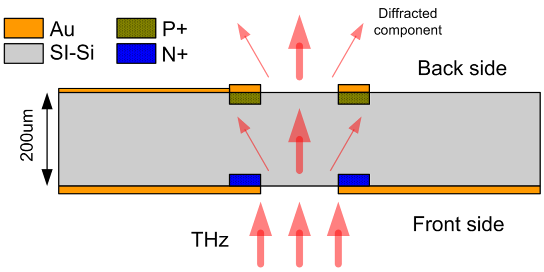

Figure 4 – THz modulator design (pixel lateral cross section)

The increase in image acquisition speed is achieved since the modulator can deliver a 4x4 pixel image within a single integration time of a THz photodetector. In addition to that, the array can be mechanically scanned over the sample, yielding an improvement factor of 16 in the speed of image acquisition in comparison to a single aperture, sub-wavelength scanning imaging techniques.

As seen from figure 4 the modulator pixel is effectively a P-i-N diode, where the electric contacts form the transmission apertures. Free carrier absorption is exploited for the amplitude modulation of the THz radiation. By injecting additional electric carriers into the P-i-N diode (aperture) area, the increase in the free carrier absorption is achieved.

3. Experimental results

Figure 5 presents the THz radiation amplitude modulation depth [%] of a single aperture obtained on the basis of the measurements of the THz modulator. The device is capable of AM modulation of THz radiation.

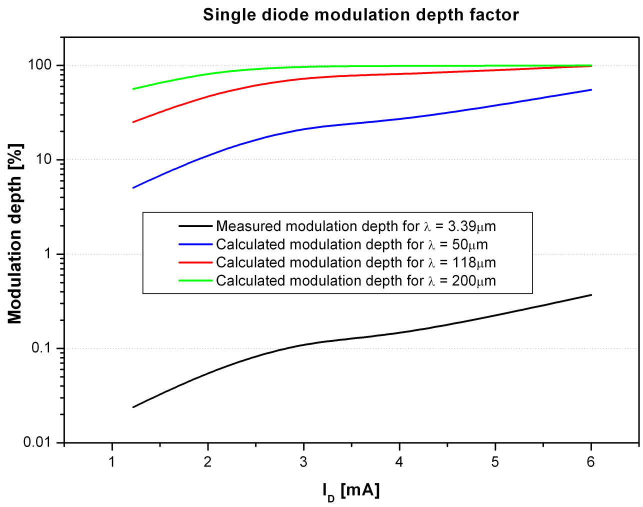

Figure 5 – THz modulator amplitude modulation depth.

4. References

[1] Harvey Rutt and Mohammad M Al Hakim – "A proposed novel multiplexed near field Terahertz microscope" - University of Southampton e-prints, ORC Colloquium, 5th of April 2006.