Abstract:

The fastest imaging technique on the market. Combining high-speed ASOPS and efficient THz generation antenna allows for spectroscopic imaging at 10 kpixels / second acquisition speed, with an excellent signal to noise ratio. Being able to measure the phase and amplitude information at this high speed is unmatched by any other device on the market.

Terahertz (THz) imaging has a strong potential for industrial and scientific applications. Many molecules have unique fingerprint spectra in this frequency region making the radiation useful, for example, biomedical imaging or gas sensing. The sub-millimetre radiation also provides valuable contrast information (e.g. air bubbles) for application in quality control and is much more suitable than Gigahertz (GHz) waves due to superior spatial resolution.

A multitude of different Terahertz spectroscopy techniques have been well established in the past. Due to the rapid development in thermoelectric devices fast scan imaging techniques in the 100s of GHz are possible nowadays, with imaging rates as high as 1000 pixel per second. However, in these measurements light is captured using thermoelectric cameras or an array of microwave antennas so that only the intensity contrast information can be gathered. In addition, the resolution is confined by the limited pixel matrix size of the detection camera or the limited number of antennas in an array. On the other hand, there exist high resolution THz spectrometers that can gather the full spectral information of a sample but with limited frame rates, about 10s of pixel or even less, so that the total acquisition time when being used in a real-world applications is as high as several hours until an image is formed.

THz spectroscopy based on asynchronous optical sampling (ASOPS) overcomes these obstacles and provides a unique combination of extreme high data acquisition rates, as well as allowing access to amplitude and phase information at the same time. Enabling low noise, high precision THz spectroscopy with GHz frequency resolution [1].

The extremely high scan rate is specifically enabled by employing ASOPS with high repetition rate lasers running at 1 GHz repetition rate and which are locked together in a master-slave configuration with a slight offset $\Delta f_R$. When $\Delta f_R = 10$ kHz, a 1 ns THz transient can be acquired within 100 $\mu$s of integration time. Figure 1 shows an example measurement of a THz transient illustrating an excellent signal to noise ratio of more than 100.
THz spectroscopic imaging at kHz pixel rates

in the time domain - even at these high scan rates without averaging. Since the pulse energies of high repetition rate lasers is on the nJ range, it is crucial to employ highly efficient photoconductive antennas [2] for producing sufficiently large THz electric fields so that averaging is not required.

THz spectroscopic imaging with spectral coverage around 1 THz is typically limited to a spatial resolution of approximately 500 µm per pixel due to fundamental wave limits if no near-field techniques are employed. In combination with the presented high-speed THz spectrometer it is, thus, possible to perform one dimensional line scan measurements of a moving sample, even when the sample is moving as fast as 5 m/s or larger while maintaining the fundamental pixel resolution. This speed has so far only been shown with 100 GHz line scan technique where the spatial resolution is of order 3 mm and the image is formed solely by intensity contrast [3].

To demonstrate high speed imaging of a two-dimensional sample we employed a combination of a rotational and translation movement as indicated in Figure 2. The sample under investigation is the backside of a metal coin, of diameter 2.4 cm, which is placed in the THz focal plane. The rotation speed is chosen to be $\omega = 10$ Hz, while the translational movement is $\nu = 1.5$ mm/s. While the sample is moving, the THz spectrometer continuously acquires data, so that the image is scanned in a spiral movement. When choosing $\omega$ and $\nu$ carefully, aliasing and under sampling of the final image can be avoided. A complete scan of the coin is shown in Figure 3 and is acquired within only 13 seconds. The final THz image contains 130 000 pixel with 500 µm spatial resolution and amplitude and phase information on every pixel. Note that the spatial resolution is limited by the THz fundamental properties and not by the measurement speed of the system. Each of the measured THz transient can be related to the pixel position since a second signal monitoring the rotational speed and angle position of the coin is simultaneously recorded, thus keeping the position error much smaller than the spatial resolution.

The experiment shown here has been performed by employing the THz antenna by the CNRS [2] and the ASOPS Engine from Laser Quantum (Figure 4).

References: