TPO-1500 Application Notes:
THz Upconversion Imaging

The terahertz region of the electromagnetic spectrum (1-10 THz) is a relatively unexplored area. One of the properties of THz light is that it can pass through cloth, ceramic, plastics, and many common packaging materials making it attractive for nondestructive evaluation in defense, security and industrial processes. THz is also non-hazardous to biological tissue, making it an option for biological and medical imaging. However, lack of high power sources and inefficient detectors in the THz region have limited the practical applications.

For a practical THz imaging system, a combination of higher power source and high efficiency detection is needed. There are two ways to detect THz: direct detection, which uses a detector that is capable of sensing THz wavelengths, and active dectection, where the THz beam is mixed with an optical frequency field and the resultant field is detected. Direct detectors tend to be slow and lack sensitivity, making them cumbersome for imaging applications. Active detection relies on a nonlinear process, where the THz beam is converted to an optical signal. THz radiation can be nonlinearly mixed with visible or near IR light to produce an "up-converted" signal which can be detected with highly sensitive, fast, and relatively inexpensive CCD or CMOS cameras. The conversion efficiency of THz to optical depends on the peak powers used, thus short pulses are desirable. Since the near IR light used is typically many orders of magnitude more powerful than the upconverted light, the image quality is increased by maximizing the upconversion light and removing as much background as possible.

The TPO terahertz parametric oscillator is an ideal source for THz upconversion imaging:

- Synchronized pulses of THz and IR radiation.
- High repetition gives a high average power in the up-converted signal, which is readily detected with a CCD or CMOS camera.
- Narrow bandwidth pulses produce a spectrally separated up-conversion signal which can be isolated from the strong pump beam by use of chromatic filters.
- Short pulses efficiently drive the nonlinear upconversion process

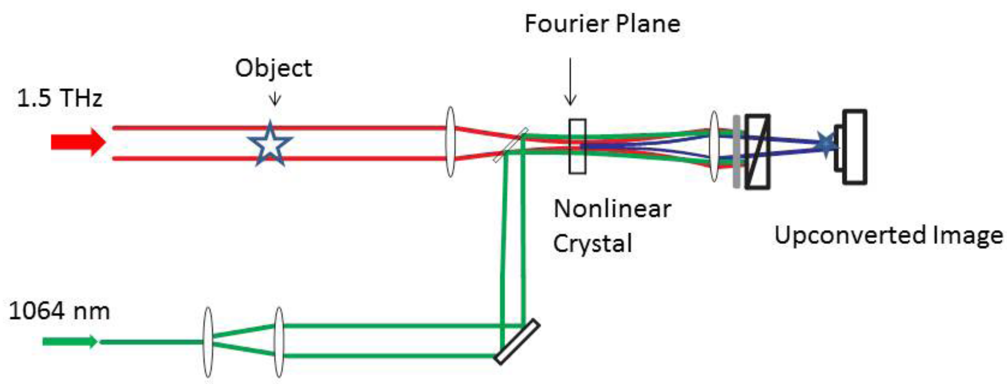

Fig. 1. Experimental diagram showing the setup for THz nonlinear imaging. THz radiation is incident on an object ("object" beam in red), and then focused into a nonlinear crystal placed at the Fourier Transform plane. IR light at 1064nm is over-lapped with the THz light in the crystal, up-converting spatial frequencies of the THz image to the mid-IR. A lens is used to inverse transform the upconverted light, forming an image on CCD or CMOS camera. A polarizer and longpass filter is used to remove the residual 1064 nm light, leaving only the upconverted light at 1070 nm.

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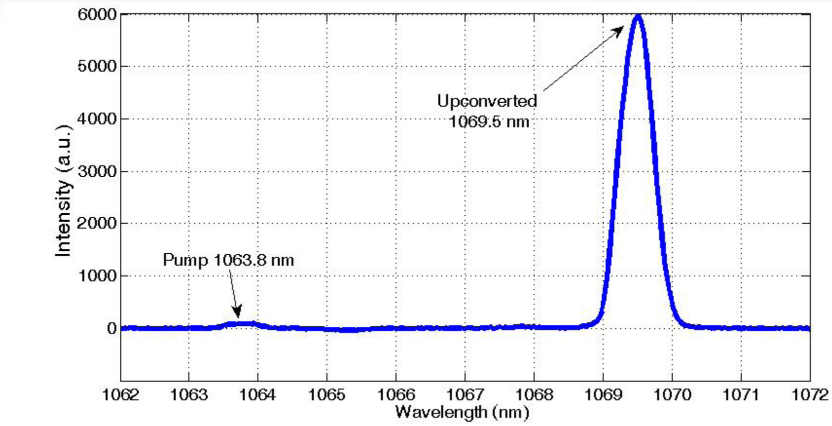

Fig. 2. Spectrum of upconveted light. A small amount of residual pump light is evident at 1063.8 nm, while a strong peak is present at 1069.5 nm, corresponding to the difference between the pump and THz frequencies (1.5 THz).

As with any nonlinear interaction, the efficiency of the up-conversion process increases with peak power. For this reason shorter pulses offer the advantage of higher signal powers. By keeping the bandwidth narrow, the spectrum of the up-converted signal can be well separated from the strong IR light (figure 2), which enables spectral filtering of the background.

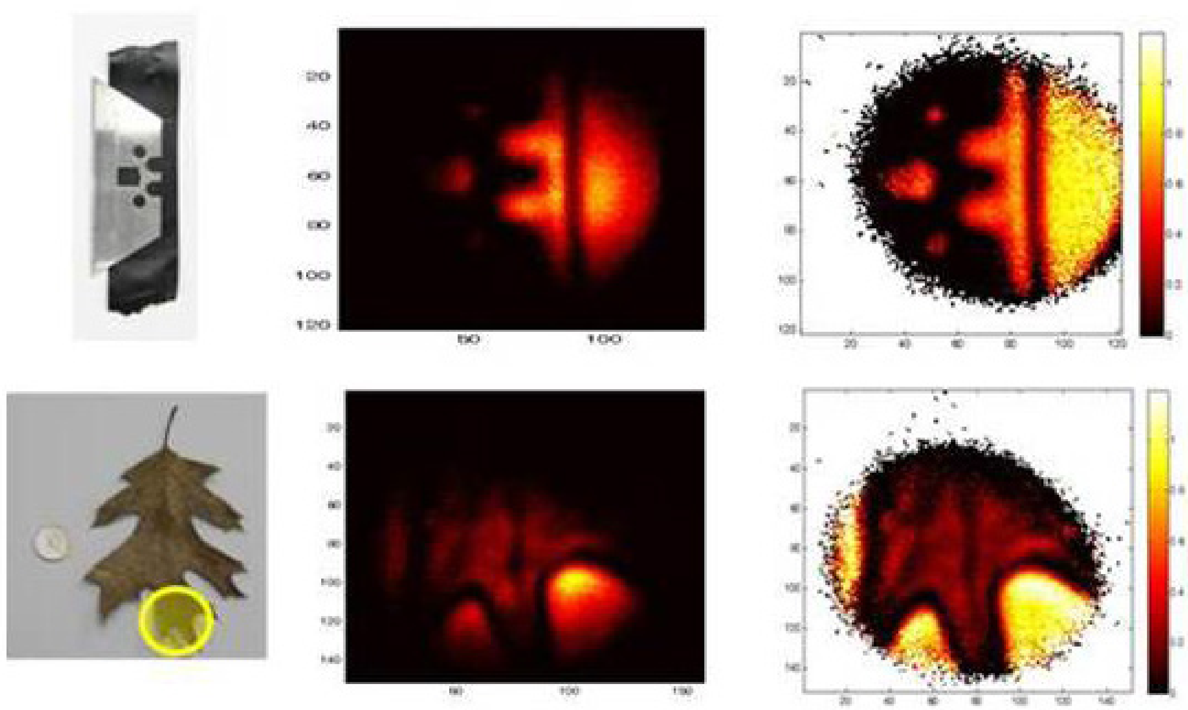

Fig. 3. Frames from video taken at 8 frames/second. Middle column is unprocessed image, and the right column shows the result of the image noramlized to the reference beam.

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The ability to spectrally separate the pump beam from the upconverted beam is a key aspect of this method as it enables video rate imaging with little or no image processing. Real time images can be taken by simply placing an object in the THz beam. If a reference image of the beam is taken before the object is inserted, the image can be normalized and the relative transmission across the entire field of view can be measured in real time. Figure 3 highlights the real time imaging capabilities of the system. The left column is a picture of the object and the center column shows a frame of a video taken at 8 frames/second with no image processing. In the right column, the image has been divided by a reference image of the beam which was taken prior to the video. The top row shows a razorblade concealed in electrical tape, which clearly shows the ability to penetrate the tape to reveal the metal blade. The second row is a transmission image of a leaf, showing the detail in the vein structure. (To view the movie visit: ***http://www.mtinstruments.com/downloads/Leaf5.avi***)

The output frequency of 1.5 THz is ideal for propagation through the atmospheric transmission window, and at wavelength of 200 μm it is sufficient to resolve small features in the wide-field imaging arrangement. The modulation transfer function (MTF) for the imaging system was measured using a slant edge method, with image shown in figure 4a. The results of the MTF calculation in figure 4b shows a value of 0.4 at 0.5 line pairs/mm, providing sufficient contrast for imaging at the millimeter level.

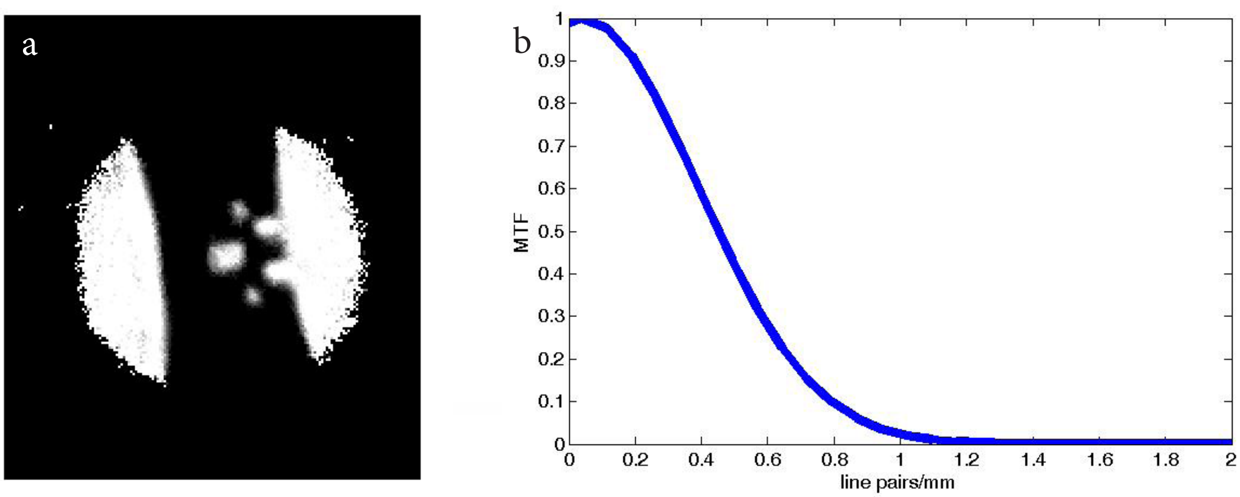

Fig. 4. The knife edge image (a) used to obtain the modulation transfer function (b).

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