

Video Rate THz imaging based on frequency upconversion using a near-IR CMOS camera

Patrick Tekavec, Dylan Fast, Ian Mcnee and Vladimir Kozlov

Microtech Instruments, 858 W. Park St. Eugene, OR 97405, USA

Email: tekavec@mtinstruments.com

Yun-Shik Lee

Department of Physics, Oregon State University, Corvallis, OR 97331, USA

Konstantin Vodopyanov

CREOL, College of Optics and Photonics, Univ. Cent. Florida, Orlando, FL 32816

Abstract: We demonstrate a video-rate THz-imaging system based on upconversion of THz pulses into the infrared. Sideband generation by mixing high-power, narrowband THz pulses with picosecond pulses at 1064 nm in QPM-GaAs provide high contrast imaging.

OCIS codes: (110.6795) Terahertz imaging; (300.6495) Spectroscopy, terahertz; (190.7220) Upconversion

1. Introduction

The development of techniques that can rapidly acquire THz images has applications in biomedicine, non-destructive evaluation of materials, and security imaging. Previous work in this field has focused on the detection of broadband THz pulses through electro-optic detection [1]. Here we demonstrate the detection of narrowband THz pulses by frequency upconversion in QPM-GaAs.

2. Experiment

The source for the imaging system is a fiber laser that delivers up to 7.5 W of average power at 80 MHz repetition rate, with 8 ps pulses centered at 1064 nm. The generation of THz is accomplished by intracavity difference frequency generation (DFG) in gallium arsenide [2]. A portion of the fiber laser output is used to synchronously pump a double resonant optical parametric oscillator with gain crystal of periodically poled lithium niobate crystal (PPLN), cut for type II phase matching. Orthogonally polarized signal and idler pulses near degeneracy (2.1 μm) are resonated in a ring cavity configuration, generating up to 100 W of intracavity IR power. THz pulses are created through difference frequency generation in QPM-GaAs sample placed at a second focus in the cavity. When the difference between signal and idler frequencies is tuned to fulfil the phase matching condition, THz pulses are generated with up to 1.4 mW of average THz power (measured with a calibrated Golay cell) at 1.5 THz with bandwidth less than 80 GHz. An off-axis parabolic mirror with a 3 mm hole allows the cavity beam to pass through unaffected, while the THz beam collimated and coupled out of the cavity.

For the upconversion detection, half wave plate and polarizing beamsplitter is used to partition the amount of pump light used for generation and detection of THz. We adopt an imaging geometry similar to that used for IR upconversion imaging [3]. The THz beam is incident on an object placed a one focal length away from lens f_1 . This lens forms the spatial Fourier transform of the object on a QPM-GaAs sample placed f_1 away from the lens ($f_1 = 75$ mm). The spatial frequencies are upconverted to the IR after interacting with the portion of the pump beam used for upconversion. In order to efficiently upconvert the higher spatial frequencies, the pump beam is expanded to a diameter of 8 mm measured at the QPM-GaAs sample position. A combination of long pass filter and polarizer is used to remove the strong background at 1064 nm from the upconverted signal. A lens of focal length $f_2 = 250$ mm performs the inverse transform, forming an image on a CMOS camera placed a distance f_2 from the lens. For spectral measurements the camera is replaced with a spectrometer.

3. Results

Measurements of the upconverted spectrum are shown in Fig. 1. On the left, a notch filter is used to attenuate the background at 1064 nm. Sidebands corresponding to $\omega_{\text{pump}} + \omega_{\text{THz}}$ (at 1058 nm) and $\omega_{\text{pump}} - \omega_{\text{THz}}$ (at 1070 nm) are observed. On the right, a spectrum where the notch filter is replaced by a long pass is shown. The pump (and also the shorter wavelength sideband) is almost completely removed, leaving the sideband at 1070 nm.

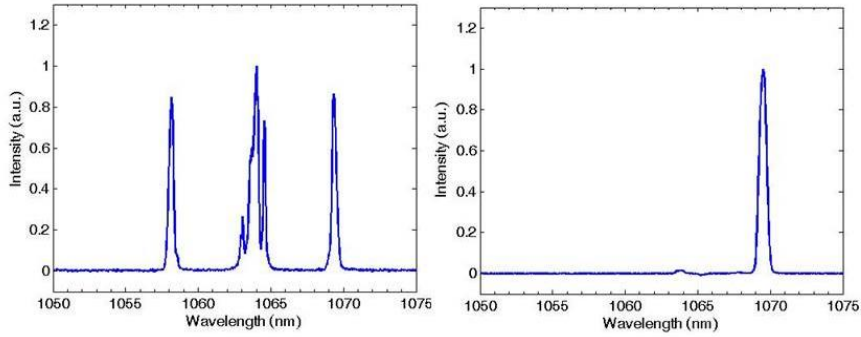


Fig. 1. Spectra of upconverted signal. Left panel: a notch filter is used to attenuate the pump at 1064 nm. Right panel: a long pass filter is used to remove the pump at 1064 nm.

Images taken with the system are shown in Fig. 2. The ratio of pump beam sent to the OPO and used for upconversion was adjusted to give maximum contrast between the upconverted image and the background. This produced 440 μW of 1.5 THz and 940 mW of 1064 nm at the Fourier plane. Images shown are frames from a movie taken at 10 frames/sec (100 ms integration time). The image formed on the camera is de-magnified by a factor of $(\lambda_{\text{up}}/\lambda_{\text{THz}}) \times (f_2/f_1)$, the ratio of the upconverted wavelength to the THz wavelength multiplied by the ratio of the inverse transform lens to the transform lens. To demonstrate the imaging capabilities, a leaf is placed in the THz beam. On the left is the image recorded on the CMOS camera with no image processing. By taking a separate image of the beam without the object, the image can be normalized to take into account the inhomogeneity of the THz beam incident on the object. This is shown in the center panel, where the image of the object is divided by the image of the beam. The last panel shows a digital photograph of the object. The shape of the leaf can be clearly seen through the tape, as well as the contrast showing the veins in the leaf.

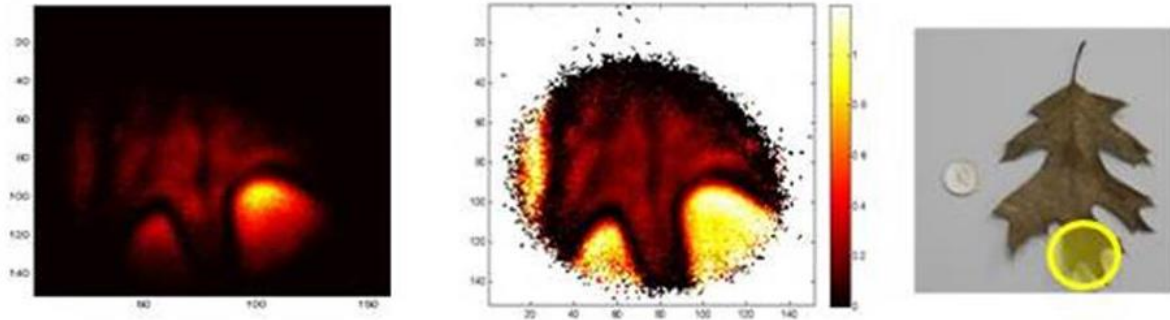


Fig 2. Images. Left panel: raw image. Center panel: normalized image obtained by dividing raw image by the THz beam image. Right panel: photograph of the object with approximate region imaged highlighted in yellow..

The images shown demonstrate the feasibility of taking narrowband, real time THz images. The image quality can be improved by increasing the diameter of the pump beam to upconvert higher spatial frequencies at the cost of lower overall intensity. As the overall intensity increases linearly with both the THz power and pump power incident on the QPM-GaAs crystal, an increase in overall signal intensity can be achieved through the use of a higher power pump laser and AR coating the crystal.

4. References

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