Boosting terahertz radiation in THz-TDS using continuous-wave laser

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A method to enhance terahertz radiation by mixing a continuous-wave (CW) laser with a femtosecond pump laser beam in terahertz time-domain spectroscopy (THz-TDS) is presented. Experiment results show that the peak-to-peak amplitude of THz radiation is enhanced by 17% when a CW laser of 15 mW is employed. THz radiation increases as the power of the CW laser grows.

Introduction: Terahertz (THz) spectroscopy [1, 2] promises stand-off detection of various chemical or biological agents of interest through the identification of their unique spectral absorption patterns. However, the measurement range with the power and efficiency of currently available THz radiation sources and detectors is limited owing to strong attenuation in the atmosphere caused mainly by water vapour. Therefore, a high-power THz radiation source is imperative for remote detection of materials in practical environments. THz radiation strength in THz-TDS tends to grow as the power of the femtosecond laser increases [3]. A femtosecond laser source is expensive and the price increases in proportion to the power. This Letter demonstrates that use of an inexpensive CW laser, mixed with a femtosecond pump laser beam, helps to increase the power of THz radiation in THz-TDS. It has been observed that THz radiation increases as CW laser power grows. THz radiation shows uniform increase in a wide range of bias voltage and frequency when a CW laser of 15 mW is used.

Experiment design: Our THz-TDS system consists of a femtosecond laser, a photoconductive THz wave emitter, and an electro-optic (EO) detector [4]. The femtosecond laser source is a compact modelocked fibre laser (IMRA femtolite 780) that emits approximately 100 fs pulses with a centre wavelength of 780 nm, 50 MHz repetition rate, and a nominal power of 20 mW. The THz emitter is a photoconductive switch fabricated on a low temperature grown GaAs chip and modulated by the amplified reference signal of a lock-in amplifier. A linearly polarised laser beam from a low-cost CW laser source (World Star Tech, TECIRL-15G-780) with a centre wavelength of 780 nm and a nominal power of 15 mW is added to the femtosecond laser beam through a beam splitter. Fig. 1 shows the configuration of a THz spectrometer generating THz radiation through mixing of the CW laser with a pump beam from the femtosecond laser. The two beams travel together through the same path from beam splitter to THz emitter. The polarisation angle of the CW laser is adjusted to *p* polarisation so full power of the CW laser beam passes through the beam splitter. The polarisation angle between the two beams is perpendicular since the pump beam and CW laser beam are *s*- and *p*-polarised beams, respectively, after the beam splitter.

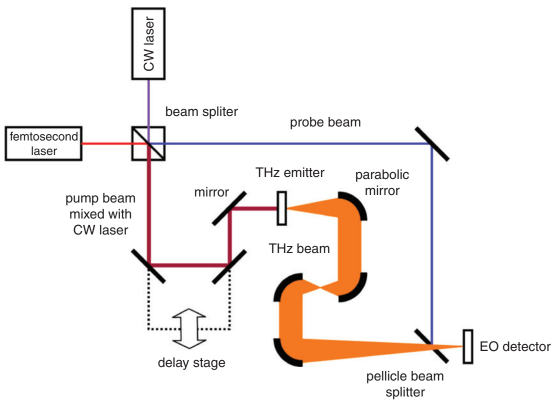

Fig. 1 *THz-TDS with CW laser mixed with femtosecond pump laser beam*

Results: We measured THz signals generated 10 times each for with and without the CW laser for the bias signal to the THz emitter of 10 kHz and 80 V rms. By adding a CW laser, average peak-to-peak amplitude of THz signals increases from 11.2 to 13.17 nA, which gives a 1.98 nA (17.16%) increase on average. Fig. 2 shows the Fourier magnitude spectrum of THz radiation with and without the CW laser in an open-air environment. Up to 2.5 THz, no frequency shift greater than 0.0029 THz is observed from the THz spectrum with a CW laser mixed with a femtosecond laser. The strength of THz radiation generated depends on the bias voltage and frequency as well as pump laser power [3, 5]. We increased the bias voltage from 40 to 100 V in 4 V steps at a fixed frequency of 10.9 kHz. As bias voltage increases, the peak-to-peak amplitude of THz radiation also increases linearly with the CW laser (Fig. 3). Fig. 4 shows that a CW laser uniformly enhances THz radiation for the frequency range of 10 to 11.5 kHz in 0.1 kHz steps for bias voltage of 80 V. A proportional relationship is observed between the CW laser power and the improvement in THz radiation strength as the power of the CW laser changes from 1 to 15.2 mW (Fig. 5). The curve fitting shows that the peak-to-peak amplitude of THz radiation increases monotonically beyond the CW laser input of 15.2 mW, which is the highest input power used in the experiment.

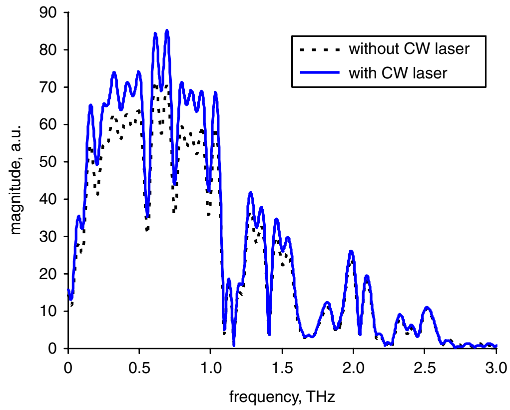

Fig. 2 *Fourier magnitude spectrum of THz signal in open-air condition*

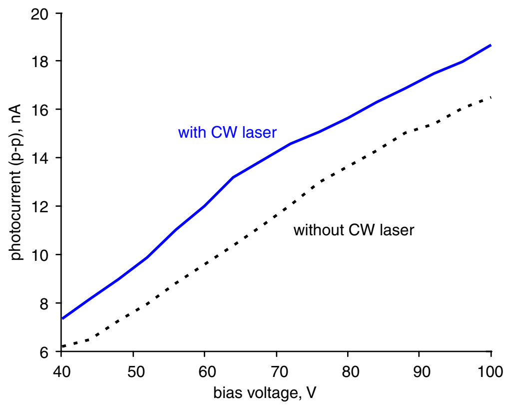

Fig. 3 *Increase in THz radiation as bias voltage changes*

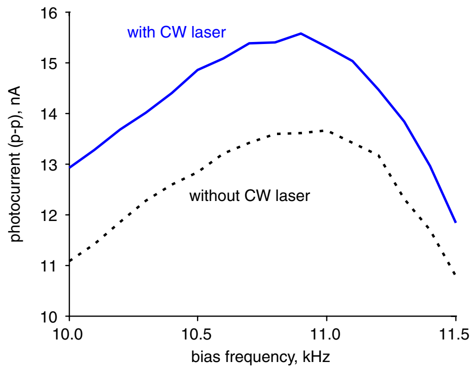

Fig. 4 *Increase in THz radiation as bias frequency changes*

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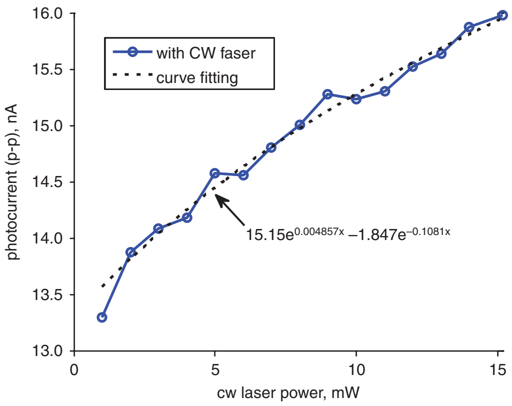

Fig. 5 *THz radiation power improvement against CW laser power*

Conclusion: The use of a inexpensive, linearly polarised CW laser, mixed with a femtosecond pump laser beam, helps to increase the power of THz radiation in THz-TDS. Experiment results show that the peak-to-peak amplitude of THz radiation increases uniformly as the power of the CW laser grows, which gives 17% improvement for a CW laser power of 15 mW. THz radiation demonstrates a uniform increase in a wide range of bias voltage and frequency at a fixed CW laser power.

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One or more of the Figures in this Letter are available in colour online.

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References

1 Ferguson, B., and Zhang, X.-C.: 'Materials for terahertz science and technology', *Nature Mater.*, 2002, **1**, pp. 26–33
2 Tonouchi, M.: 'Cutting-edge terahertz technology', *Nature Photonics*, 2007, **1**, pp. 97–105
3 Lee, Y.-S.: 'Principals of terahertz science and technology' (Springer, 2009)
4 Kong, S.G., and Wu, D.H.: 'Signal restoration from atmospheric degradation in terahertz spectroscopy', *J. Appl. Phys.*, 2008, **103**, p. 113105
5 Tani, M., Matsuura, S., Sakai, K., and Nakashima, S.-I.: 'Emission characteristics of photoconductive antennas based on low-temperature-grown GaAs and semi-insulating GaAs', *Appl. Opt.*, 1997, **36**, (30), pp. 7853–7859