2008

Terahertz Emission from Mercury Cadmium Telluride

M. L. Smith
University of Wollongong

Rajind Mendis
University of Wollongong, rajind@uow.edu.au

R. E. M. Vickers
University of Wollongong, rv@uow.edu.au

R. A. Lewis
University of Wollongong, roger@uow.edu.au

Terahertz Emission from Mercury Cadmium Telluride

M. L. Smith, R. Mendis, R. E. M. Vickers and R. A. Lewis

Institute for Superconducting and Electronic Materials, University of Wollongong, Wollongong, NSW 2522, Australia

THz-frequency electromagnetic radiation may be generated by illuminating a suitable target with short pulses of near-infrared radiation. We present results of experiments employing pulses of < 12 fs irradiating a HgCdTe thin film. The resulting THz emission was detected using a liquid-He–cooled bolometer. Strong azimuthal angle dependence on the generated THz power is observed. The THz power varies quadratically with the pump power.

1. Introduction

The "THz gap" refers to the lack of efficient sources and detectors of electromagnetic radiation in the frequency region between visible light and microwaves. Although many diverse sources of THz-frequency electromagnetic radiation are known (blackbody thermal radiators, far-infrared lasers, synchrotrons, quantum cascade lasers...) they each suffer drawbacks (low power, limited tunability, large size/cost, need for cryogens...). One especially attractive scheme for THz experimentation is time-domain spectroscopy (TDS), which has the advantage over other methods that both the amplitude and the phase of the THz signal are simultaneously recorded; in other words, both the real and imaginary optical constants may be obtained in a single measurement. TDS is realised through a pump-probe arrangement wherein an ultrashort pulse is split to both produce and detect the THz radiation. Consequently there is much interest in developing efficient emitters of THz radiation under illumination by ultrashort pulses.

A very wide range of targets has been investigated as THz emitters under ultrashort pulse illumination. These include metals (which vaporise), superconductors — even air. By far the most widely-employed emitters are semiconductors, such as ZnTe, which operates by the mechanism of optical rectification, and GaAs, which is used as a photoconductor.

Mercury Cadmium Telluride (Merc-Cad-Tell, MCT) is an appealing candidate material for THz generation as the bandgap is tunable via changing the fraction, x, of Cd in the alloy $Hg_{1-x}Cd_xTe$. Previous reports have discussed THz emission in alloys with fraction $x = 0$, 0.2 and 0.3 [1-4]. Laser pulses of duration 150 fs, repetition rate 76 MHz and centre wavelength 800 [2], 810 [3,4] or 820 [1] nm were directed onto the samples at near the Brewster angle. Radiation at the reflection angle, collected by a high-resistivity Si hemispherical lens [1,3,4] or a pair of off-axis paraboloidal mirrors [2], was detected using a 5-µm gap photoconductive antenna fabricated on low-temperature–grown GaAs of electron-trapping time 200 [1,3,4] or 500 [2] fs. The THz peak field showed little variation with Cd fraction and was about one third to one half of that from *p*- [1,2] or *n*- [3,4] InAs under similar conditions. The THz signal did not vary appreciably as the samples were rotated around the surface normal. This lack of azimuthal-angle dependence was taken to rule out optical rectification as a mechanism of THz generation. The mechanism was thought to be a linear current surge. Further evidence supporting this was the change in THz intensity induced by an in-plane magnetic field, presumed to rotate the radiating dipole. Two origins of a current surge were considered: acceleration of electrons/holes in the surface-depletion layer and the photo-Dember effect (differential diffusion of electrons/holes). The former was judged to be weak in $Hg_{1-x}Cd_xTe$ in view of the small band gap and so the latter considered to be the main mechanism of THz generation. The laser photons have sufficient energy to excite electrons from the light-hole (Γ_6), heavy-hole (Γ_8) and split-off (Γ_7) valence bands into the conduction band (Γ_6); from the lack of x dependence on the observed power it was concluded that the pumping is mainly from the split-off band [1,2].

2. Experimental details

The sample used in this investigation was in the form of a HgCdTe thin film grown on a CdZnTe substrate. Details of the sample parameters appear in Table 1.

The general features of the experimental set up, including data for the production of THz radiation from ZnTe (due to optical rectification), have been presented elsewhere [5]. A mode-locked Ti:sapphire laser of centre wavelength 790 nm, pulse width <12 fs and repetition rate 80 MHz [6] was used to produce the pump pulses. Detection was by means of a liquid-helium–cooled Si bolometer. The angle of incidence of the pump beam was 45°. The THz radiation was measured in the direction of specular reflection. The experimental arrangement is shown in Fig. 1.

Table 1. Sample parameters

Parameter	Value
Cd fraction, x	0.21
Thickness, t	19 μm
Carrier concentration, n (77 K)	3.8×10^{14} cm^{-3}
Mobility, μ (77 K)	1.3×10^{5} cm^2/Vs

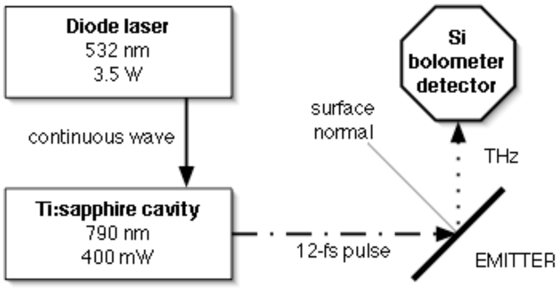

Fig. 1. Experimental configuration.

3. Results

The dependence of the detected THz power on angle of rotation of the sample around the surface normal is given in Fig. 2. The dependence of the THz power on the power of the near-infrared pumping radiation is given in Fig. 3.

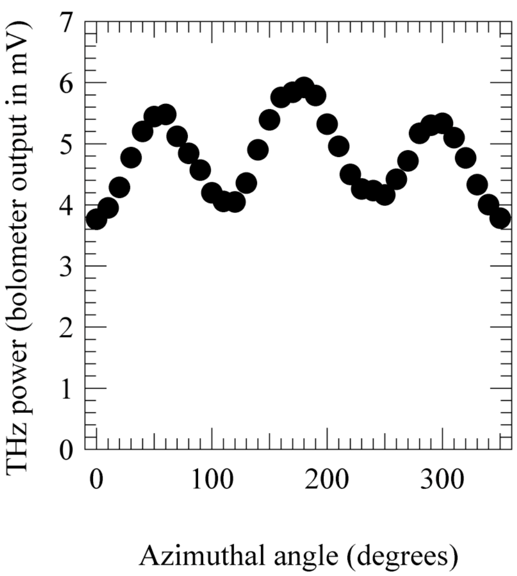

Fig. 2. Azimuthal-angle dependence of THz emission from sample.

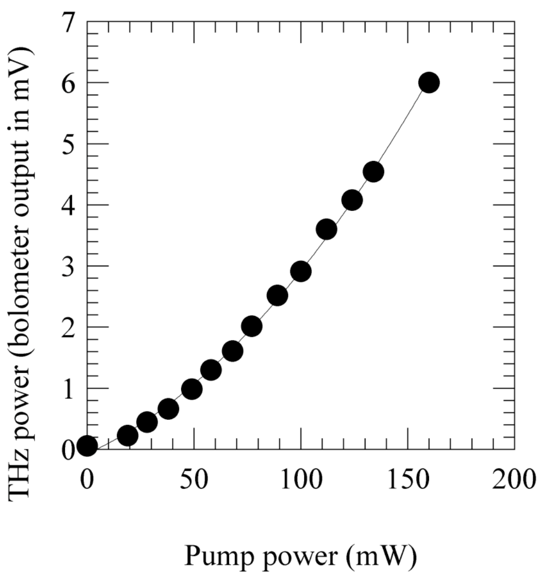

Fig. 3. Pump-power dependence of THz emission from sample. A quadratic fit to the data is shown.

4. Discussion

We may compare our results to the previous work [1-4]. In agreement with the previous work, we have found that the magnitude of the THz signal is less than that from *p*-InAs under similar illumination conditions [1,2], but comparable to the signal from the commonly-used unbiased emitter, ZnTe. To our knowledge, *p*-InAs is the unbiased material that is the strongest emitter of THz radiation under pulsed laser illumination identified to date [7]. In contrast to the previous work, we find a marked azimuthal-angle dependence on the magnitude of the THz signal. This suggests a strong contribution by the mechanism of optical rectification to the THz generated. This observation does not rule out a simultaneous contribution due to linear current surge, suggested as the prime mechanism of THz generation from HgCdTe in the previous work [1-4]. It might be noted that the lack of azimuthal angle dependence in the previous work was for (100) HgCdTe samples; this was compared with the strong cos(3θ) azimuthal dependence observed for (111) InAs; but (100) InAs shows only a weak azimuthal-angle dependence [7]; so the comparison is not an entirely fair one. In addition to the previous work, we have measured the dependence of the emitted THz power on the near-infrared pump power and found a quadratic relation. This observation is also consistent with the generation of the THz radiation by the mechanism of optical rectification.

5. Conclusion

Our results give strong evidence that optical rectification is contributing significantly to the observed generation of THz radiation in a $Hg_{1-x}Cd_xTe$ thin film. This does not exclude a contribution arising from fast photocurrent as suggested by previous work [1-4]. Taken together, these experiments suggest that even higher levels of THz output may be obtained by designing suitable materials to optimise both mechanisms of THz radiation at once; further work in this area is expected therefore to be fruitful. Preliminary data on a range of other single and double-layer thin-film $Hg_{1-x}Cd_xTe$ samples investigated by TDS is given elsewhere [8].

Acknowledgments

We thank Prof. L. Faraone and the Microelectronics Research Group of the University of Western Australia for provision of the sample. This work was supported in part by the Australian Research Council and by the University of Wollongong.

References

[1] A. Krotkus, R. Adomavicius, G. Molis, A. Urbanowicz, H. Eusebe, *J. Appl. Phys.* **96**, 4006 (2004).

[2] A. Krotkus, G. Molis, E. Satkovskis, *J. Lumin.* **113**, 301 (2005).

[3] R. Adomavicius, A. Urbanowicz, G. Molis, A. Krotkus, *Microelect. Eng.* **81**, 238 (2005).

[4] R. Adomavicius, A. Urbanowicz, G. Molis, A. Krotkus, *Acta Physica Polonica A* **107**, 132 (2005).

[5] R. A. Lewis, R. E. M. Vickers, M. L. Smith, *Proceedings of 16th AIP Congress*, CMMSP PTU112 (2005).

[6] Femtolasers Produktions GmbH, Fernkorngasse 10, A - 1100 Vienna, Austria.

[7] R. Mendis, M. L. Smith, L. J. Bignell, R. E. M. Vickers, R. A. Lewis, *J. Appl. Phys.* **98**, 126104 (2005).

[8] R. Mendis, M. L. Smith, R. E. M. Vickers, R. A. Lewis, C. Zhang, *The Joint 31st International Conference on Infrared Millimeter Waves and 14th International Conference on Terahertz Electronics* (2006).