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# A new THz facility for condensed matter physics

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# A New THz Facility for Condensed Matter Physics

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## Introduction

This paper describes a new THz facility for condensed matter physics that complements the existing infrastructure at the University of Wollongong (UoW). The THz regime (Table 1) is of immense importance in condensed matter physics as many energies of interest fall in this region — phonon energies, cyclotron energies in laboratory magnetic fields, energies of shallow impurities in semiconductors and bound levels in heterostructures, to name a few. THz technology also finds widespread application in such diverse areas as biology, medicine and security. For a recent review, see Ref. [1].

Table 1: THz energy scales, in various fundamental and practical units.

| Frequency (THz) | Energy (meV) | Linear frequency ($cm^{-1}$) | Energy ($\times 10^{-23}$J) | Wavelength ($\mu$m) |
|---|---|---|---|---|
| 0.1 | 0.414 | 3.34 | 6.63 | 2998 |
| 1 | 4.14 | 33.4 | 66.3 | 299.8 |
| 10 | 41.4 | 334 | 663 | 29.98 |

## Three generations of THz technology at Wollongong

The historical development of far-infrared (FIR)/THz spectroscopy has been followed at UoW. We have a number of "slow-scan" interferometers (Beckman, Polytec) that do not differ significantly from Michelson's equipment. A "rapid-scan" Fourier transform spectrometer (Bomem) averages out short-timescale source power fluctuations, Fig. 1(a). A FIR laser, Fig. 1(b), produces strong radiation, but only at particular energies. This system has been described in detail earlier [2, 3]. THz is now being generated by fast near-infrared (NIR) pulses, Fig. 1(c), and time-domain spectroscopy (TDS) is being developed.

## THz detectors

Detection systems include TDS (under development), room-temperature thermocouple and thermopile and pyroelectric (DTGS) sensors and He-cooled 4.2-K and 1.5-K Si bolometers.

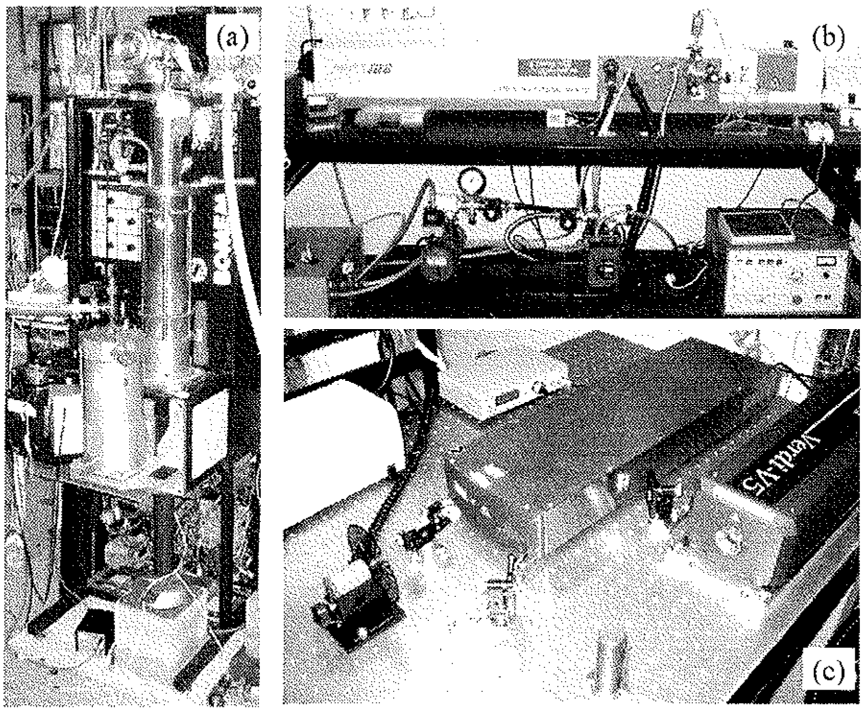


Figure 1: THz technology at Wollongong. (a) Bomem "rapid-scan" Fourier transform spectrometer. (b) Edinburgh Instruments FIR laser. (c) Femtosource Compact Pro 12-fs oscillator.

**THz sources**

A standard source in FIR spectroscopy is the Hg lamp. Another source, which extends into the mid-infrared, is the globar. A source developed more recently (which may also be employed as a detector) is an electro-optical crystal, such as ZnTe. Emission from these three sources is compared in Fig. 2(a) up to 3 THz. The Hg lamp and globar are plotted on the same ordinate; the ordinate for the ZnTe emitter is expanded 200×. The globar increases in power relative to the Hg lamp as energy increases; the globar is the stronger source for frequencies of, typically, 7 THz and higher. On the contrary, the peak of the ZnTe emission is at a lower frequency than that of the Hg lamp. Fig. 2(b) compares different ZnTe crystals.

The principle of generating short THz pulses by illuminating electo-optical materials such as ZnTe with fast optical pulses [4] has been developed greatly in recent years. We employ a Femtosource Compact mirror-dispersion–controlled Ti-sapphire oscillator pumped by a Verdi V5 laser. The pulsewidth $<12$ fs and so bandwidth $>200$ nm when mode locked (see Fig. 3). The output from ZnTe crystals of different thicknesses and resistivities when illuminated by such pulses has been shown in Fig. 2(b).

The THz output power depends on many factors. The dependence on NIR pump power is shown in Fig. 4(a). The dependence is clearly super-linear. The fit shown is quadratic. The dependence of THz output power on the angle of rotation of the ZnTe crystal about the direction of the NIR beam is shown in Fig. 4(b). The theoretical dependence of THz output power on the angle of rotation is taken from Ref. [5].

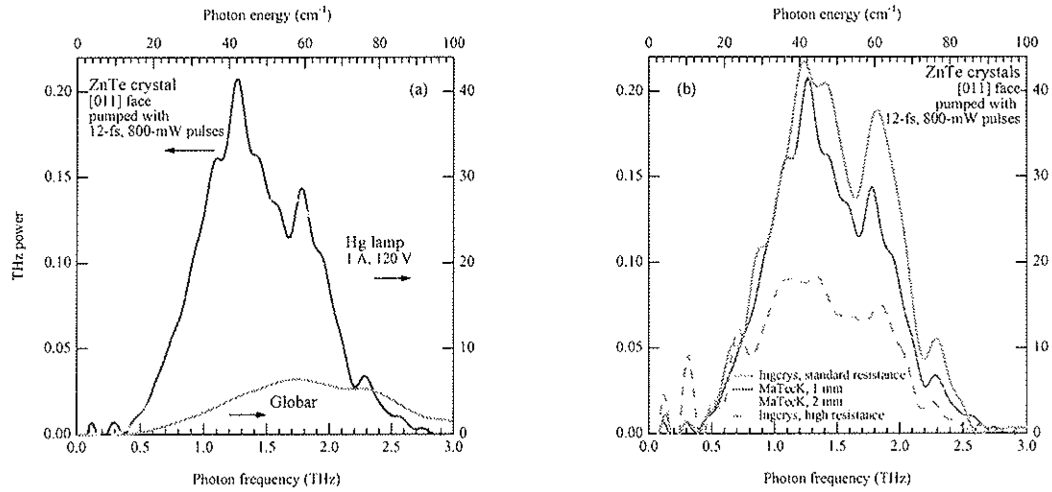


Figure 2: Comparison of THz sources measured using rapid-scan spectrometer. Fall off in signal at low frequency is due to the 23-$\mu$m beamsplitter in the interferometer and fall off at high frequency is due to the 3-THz filter on the 1.5-K bolometer detector.

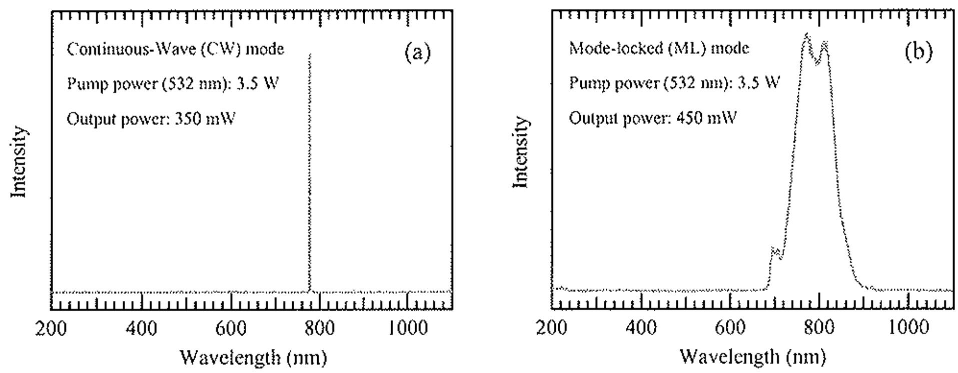


Figure 3: Output of Femtosource Compact mirror-dispersion–controlled Ti-sapphire oscillator pumped by Verdi V5 laser in (a) continuous-wave operation and (b) mode-locked.

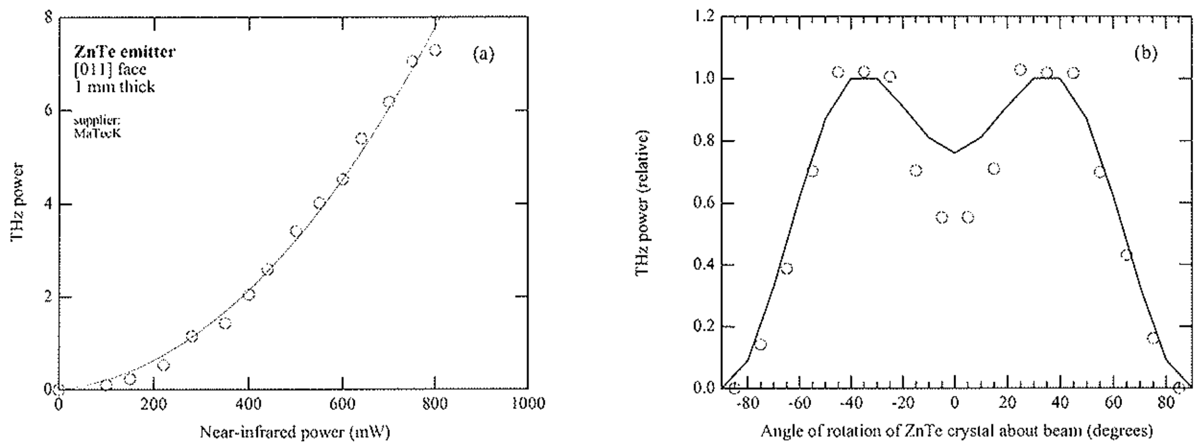


Figure 4: Dependence of THz output power on (a) NIR pump power and (b) angle of rotation of the ZnTe crystal about the direction of the NIR beam.

## THz filters

Optical filtering is required to simultaneously cut out the NIR but pass the THz. Black polyethylene film, often employed as a NIR cut-off filter, melts at the NIR powers used here. Table 2 shows the efficiency of candidate materials in blocking near infrared. The data demonstrate that the mechanism is often scattering, rather than absorption. We have found that a number of materials conventionally used as THz filters (teflon, polystyrene) have rather high absorption coefficients for THz radiation. The results are shown in Fig. 5.

Table 2: Percentage of broadband NIR [Fig. 3 (b)] blocked when filter material is placed (a) near the source and (b) near the detector. Scattering plays a greater role in (a) than (b).

| | Mylar | Poly-propylene | TPX | Poly-ethylene | Filter Paper | Teflon | Poly-styrene | Silicon |
|---|---|---|---|---|---|---|---|---|
| thickness (mm) | 0.13 | 0.85 | 3.6 | 3 | 0.18 | 3.7 | 2.3 | 0.5 |
| (a) near source | 8 | 93 | 99 | 99 | > 99 | > 99 | > 99 | > 99 |
| (b) near detector | 6 | 45 | 73 | 95 | 99 | 99 | > 99 | > 99 |

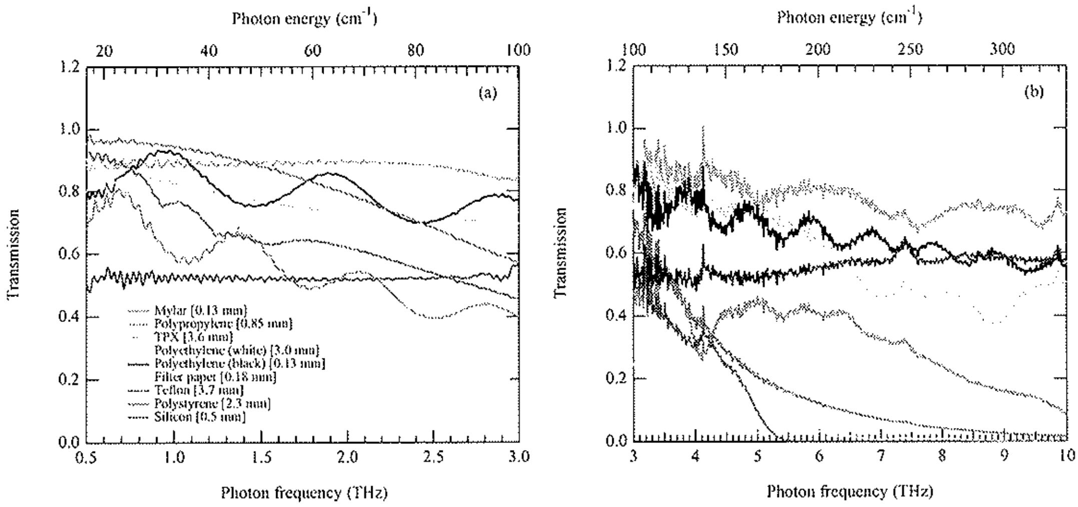


Figure 5: Comparison of transmission of candidate THz filter materials over two ranges.

**Acknowledgments**

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