**Task/ Work:** Operation of a high-repetition-rate THz time-domain spectrometer (THz-TDS) for high-sensitivity studies of materials at THz frequencies

**Location (Room/ Building):** Lab X.00Y, ABC Building

**Date :** X/Y/ZZZZ

**Reference / Version :** V1

**Review Date :** Annually, or at change of use

**University Laser Safety Officer :** Dr Ian Haslam, ian.haslam@manchester.ac.uk

**Local Laser Safety Advisor :** laser safety advisor’s name

**Issued under the authority of :** PI/Lab manager’s name

**Purpose & Scope**

The principal aim of this document is to outline the elements of good laser practice as they apply specifically to experiments currently undertaken in the TERA Laser System area in laboratory X.00Y, ABC Building. This document describes the use of controls identified in the risk assessment, and plans for any reasonably foreseeable incidents. General aspects of laser safety are covered in the accompanying risk assessment. This document implements the University’s laser safety policy at a practical level and form part of the University’s duties under Section 2(3) of the Health and Safety at Work etc Act 1974.

**Introduction & Description of Lasers**

The HRR THz-TDS system can be used for the following experiments:

• Exploring and characterising the ultra-broadband THz emission of spintronic emitters.

• Studying the effects of novel structured spintronic emitters, including multiple layer stacks and patterned structures.

• Investigating the THz electric field amplitudes versus magnetic field strength for spintronic emitters, in the low laser energy-density excitation regime.

• Testing of the remanent magnetization as a function of angle for a range of spintronic emitter thicknesses, in the low laser energy-density excitation regime.

For the above experiments, this scheme of work outlines safety protocols covering the following situations:

• Routine safety checks required before and after every use of the laser system

• Day-to-day running of the experiments

• Open beam work inside the THz spectrometer

• Servicing (usually carried out by a contractor)

• Emergency procedures

• Shutdown procedures

The experiments use the output of:

Class 4 lasers: an oscillator (Coherent Mantis) producing 800 nm, 20 fs, 6.25 nJ laser pulses at 80 MHz (average power of 0.5 W). The Mantis oscillator is pumped by a DPSS laser (Coherent Verdi) producing a 532 nm, 5 W CW beam.

Class 3R laser: Thorlabs CPS808A Laser Diode, producing a continuous wave output at between 795-815 nm (typically 808 nm), with a maximum output power of 3 mW is used as a pilot-laser for alignment.

The oscillator output is routed to the HRR THz-TDS and split into a pump (99%) and probe beam (1%) using a beam sampler. The pump beam is used to excite THz sources (spintronic emitters and nonlinear crystals) to generate THz radiation. The probe beam is aligned through a delay stage and used to detect the THz radiation by a standard electro-optic sampling scheme using a nonlinear crystal with a set of balanced photodiode detectors.

To obtain transform-limited 20 fs pump and probe pulses, a number of methods to control the pulse duration through pulse-chirping are incorporated into the setup. Firstly, a pair of negative-dispersion mirrors (Compact Pulse Compressor, Coherent) are used to compress the output of the Mantis laser. Furthermore, a prism compressor on the pump beam and additional windows (to add positive chirp) on the probe beam are utilised to obtain fully compressed pulses at both the THz emitter and THz detector, respectively.

An acousto-optic modulator operating at 1.4 MHz is used on the pump beam in combination with a lock-in amplifier for high signal-to-noise measurements of the THz pulses using PC-controlled acquisition software.

**Justification for Open Beam Work**

Despite the steps taken to minimise the need and frequency of open beam work inside the THz spectrometer, it is however still necessary albeit infrequently. The THz spectrometer optics require complex (multi-axis) fine adjustments which cannot be automated due to insufficient space and the multi-axis adjustments required. The available space cannot be increased as it is dictated by the focal length of the optics themselves and this cannot be changed.

**Authorised Users / Responsibilities**

xxxxxx (PI), xxxxxx (PDRA), xxxxx (PhD), xxxxx (PhD), xxxxx (PhD), xxxxx (PhD), xxxx (MPhil), xxxxx (MPhil)

Users Authorised for Open Beam Work: XXXXX (PI), xxxx (PhD)

The above named persons must have successfully completed the University Laser Safety Training courses THS42e (awareness) and THS43e (advanced), completed the LS3 training checklist, and be familiar with the risk assessment, and this scheme of work, in order to be authorised to work with the lasers.

**Laser Controlled Area**

The THz-TDS system used for the above experiments is located on an optical table in the TERA Laser System area of laboratory X.00Y. Access to the laboratory is restricted to authorised users and is controlled by the centralised swipe card entry system. The entrance door is interlocked such that if an unauthorised user attempts to gain entry to the laboratory, an automatic laser beam shutter is engaged preventing exposure to the laser beam.

The experimental area is located in the corner of the Laser System area, which is completely enclosed by laser safety curtains during any open beam work. There is one designated entrance/exit from this area.

**Protection Measures / PPE**

The laser requires a key for operation, which is stored in a locked key cabinet that can only be accessed by authorised users. Within the Laser System area, all laser experiments are constrained to optical tables by black, anodised aluminium pipes, skirting and lids, which form complete laser-safe enclosures that prevent exposure to any laser radiation in the laboratory area, allowing for normal lab operating procedures without the requirement of PPE (laser safety glasses for the eyes and gloves to protect the skin). All the enclosure lids are interlocked to the shutter system, such that if a lid were to be opened while the laser beam was active, an automatic shutter would block the laser beam at the laser output and prevent exposure to the beam.

Eyewear requirement calculated to EN: 207: 800nm D LB5 M LB7

Each authorised user has their own pair of the following laser safety glasses which provide sufficient protection:

Thorlabs LG12: 180-315 D:LB7 + R:LB4, >315-534 + 730-740 D:LB5 + IRM:LB6, >740-1070 D:LB6 + IRM:LB7.

Gloves must be worn at all times when working with an open beam inside the THz spectrometer.

**Procedures**

**Routine Safety Check Protocol**

• The room interlocks and exterior laser warning signs for the lab must be activated, unauthorised persons excluded and doors closed. Ensure curtains are in place around the entry to the laser lab area.

• During normal operation of the experiment the laser beam is fully enclosed and there is no requirement for the use of laser safety glasses.

• Check chiller for the Mantis laser system making sure it is operating as expected (e.g. adequate levels of coolant liquids, correct pressure levels and temperature range).

• Before starting the laser, beam paths on the optical table must be inspected for any objects that should not be there.

• Check that the position of beam blocks are appropriate for the experiment.

• Place magnetically sensitive items such as pass cards, mobile phones, and credit cards away from the optical table as magnetic sources are present.

**Laser Start-Up Protocol**

• Take the Mantis key from the key box and turn on the power supply up to 5 W.

• Initiate mode-locking of the laser by pressing and holding for 2 seconds the tapper button on the back of the Mantis laser unit.

• Check the spectrum and the output power of the Mantis laser using the Mantis laser system’s dedicated power meter and the shared fibre spectrometer, comparing the spectrum against the reference spectrum on the Avantes spectrometer software. This is done in the interlocked access box at the exit of the Mantis by first closing the laser shutter to block the beam, opening the lid and then placing the power meter and spectrometer in position, using the labyrinth to allow the cables/fibre out of the box. Only once the interlocked lid is closed, the laser shutter can re-opened and the measurements made without exposure of the laser beam to the lab. The separate “diagnostics” laptop must be used to run the Avantes spectrometer control software when the spectrometer is used with the Mantis laser system. The laptop used to control the Spitfire laser system must not be used.

• Allow the laser system to warm up for 30 minutes before use.

**Laser Shut-Down Protocol**

• Close the Lasermet laser shutter at the output of the Mantis laser by pressing the red button on top of the shutter.

• Turn the laser key in the Mantis power supply to the off position and return the key to the key box.

• Turn off the ThermoTek chiller, which is positioned under the optical table directly below the Mantis power supply. The ON/OFF power switch is located on the right side above the hose connections.

• Place all optics and tools not in use back to their correct storage locations.

• Return the laser safety glasses to their named storage units on leaving the TERA laser area.

**Laser safety protocol: Day-to-Day running (normal operation)**

Day-to-day running applies to the normal operation of the Mantis laser system.

**Laser Protocol**

• Carry out all routine safety checks as detailed in the routine safety check protocol.

• Check for the correct acousto-optic modulator frequency.

• Check the electro-optic detection system is operational and appropriately balanced by monitoring the signal on the lock-in amplifier (auxiliary channels) of the probe beam on the two photodiodes.

• Open the PC-controlled module software that controls the delay stage and performs data acquisition from the lock-in amplifier.

• Perform a THz time-domain scan when the system is ready, to check that the system is operational and ready for measurement.

• If necessary, use the continuous wave 808 nm diode laser (Thorlabs CPS808A) pilot laser to check routing of the beam inside the spectrometer.

• If necessary, the Mantis laser output routing into the THz spectrometer can be optimised using the motorised mirrors, alignment irises and webcams, all located inside the laser enclosure. This allows the laser beam to be re-routed into the THz spectrometer while being fully enclosed. This automation minimises the need for open beam work inside the spectrometer as a significant proportion of realignment work stems from changes to the laser output pointing.

**Sample Handling and Transfer Protocol**

• Suitable gloves must be worn when handling bare samples.

• Mounting of samples must be carried out on the Mantis laser system’s designated side bench, away from the optical table.

• Close the laser shutters before changing or removing the samples on the optical table.

• When not in use, all samples must be returned to labelled boxes and any hydroscopic samples (e.g. spintronic sources) must be stored in the Mantis laser system’s dedicated desiccator.

**Alignment procedure by diode laser**

Because the power of the Thorlabs diode laser is reduced to <0.6mW, all alignment work can be done with an open beam without laser safety goggles. This is supported by MPE and ELV calculations given in risk assessment.

• Initial laser beam alignment must be performed with the Class 3R Thorlabs pilot laser with the Mantis laser off or shuttered with the spectrometer interlocks active.

• The diode laser power is reduced to <0.6mW by a ND filter bolted at the laser exit in order to be below the MPE and ELV. Users must not remove this filter or interfere with it in any way.

• Use the flip mirror to reflect the pilot laser beam of the diode laser into the THz spectrometer beam path, but remember to flip the mirror down so as not to block the Mantis laser beam when finished.

• Remember that the final beam path may differ slightly due to dispersion (i.e. the beam path may be slightly wavelength-dependent)

• Pass the Thorlabs pilot laser along the path through the optical system and ensure the beam terminates on each optical component. This will give an approximate position for each optical element.

• A visualization card or infrared viewer can be used to track the path of the invisible laser beam through the system.

• At this stage, each and every optic element in the beam path must be analysed for stray reflections. Initially this can be done by predicting the likely path of specular (i.e. non-diffuse) reflections and the actual reflections of the Thorlabs pilot laser may also be used to help identify stray reflections.

• Beam blocks positions must be modified at this point to capture all stray paths.

**Alignment using the Mantis laser – Class 4 Open Beam Work**

Internal work in the Mantis laser is not covered by this scheme of work.

• Alignment may be carried out by one or at most two authorised laser operators. No one else may be present in the area during this procedure and watches, bracelets and other reflective jewellery must be removed or covered.

• Open beam alignment work must only be carried out during normal working hours (08:00 to 17:00hrs).

• Laser safety curtains must be closed to isolate the TERA laser system area from the rest of the lab.

• Earphones and headphones are not to be worn at any time.

• Under no circumstances must direct viewing of the laser beam be attempted even if the beam has been attenuated.

• Laser safety glasses (Thorlabs LG12) must be worth at all times during open beam work with the Mantis laser output. Gloves must also be worth to protect the user’s hands from accidental exposure, although users should be aware of the beam path at all times and try to avoid placing their hand in the path of the beam.

• Safety eye wear must be checked for damage before use, and inspected periodically with a record of the inspection made

• All optics must be checked for damage, and the stability of optics mounts verified prior to operation of the Mantis laser.

• The alignment of the beam at each location can be visualized by using a visualization card or IR viewer.

* No lasers should be left unattended in an open-beam state: all lasers must be shuttered or powered-down before the room is left vacant, this includes if the building fire alarm is activated. When alignment is not being performed then lids must be replaced.

**Servicing**

Servicing is the performance, by an approved external contractor, of those procedures or adjustments described in the manufacturer’s service instructions.

• Access arrangements and an appropriate permit to work for service engineers (contractors) are required.

• These will include how they must be managed together with any handover arrangements or restrictions that may apply. Copies of risk assessments and method statements must be requested in advance of the engineer attending site and work must not commence unless these have been provided. Where the engineer intends to carry out work with open beams of the TERA laser system, they must also be asked to provide copies of their scheme of work and again work must not proceed without these being reviewed by the Laser Safety Advisor and approval from a member of the Health and Safety Committee.

• In the case of anything other than routine maintenance, and/or when the laser manual does not give a procedure, the advice of the Laser Safety Advisor must be sought.

**Summary of Hazards**

• Class 4 beam hazards – Laser radiation from a Class 4 laser is extremely hazardous to the eyes and skin. The laser beam, as well as its specular and diffuse reflections must not be viewed at any time.

• High voltages in laser head

• Water cooling

• Trip hazards.

• Electrical hazard from ancillary equipment.

**Contingency Plan**

In case of emergency call your nearest first aider, outside of normal working hours call Security on 0161 306 9966.

If an ambulance is needed, telephone 999 stating clearly the full postal address (XXX), and what is wrong with the casualty, together with your name. Also inform building reception (XXXX) and arrange for somebody to meet and direct the ambulance staff to the casualty.

In the event of an accident involving eye exposure, as soon as possible and within 24 hours of the incident, take this completed card and any relevant risk assessments to:

Manchester Royal Eye Hospital, Oxford Road, Manchester, M13 9WL

Emergency Eye Department opening times: 08:00-20:00, 7 days a week

Outside these hours call: 0161 701 0249, or attend general A&E at Manchester Royal Infirmary (address as above)

Do not drive yourself. Get a friend or colleague to take you, or use a taxi.

It is important that the affected person does not rub their eye after exposure as this can lead to corneal abrasions.

All injuries, however small, and any near-misses must be reported to the Local Safety Advisor in order that an accident form or near miss form may be completed.

In the event of any unsafe condition or fault being apparent with the equipment, the experiment must cease immediately, the laser be turned off if it is safe to do so, and the matter reported to local staff supporting the experiment.

**Scheme of Work Approved by:**

Name: ………………………… Signature:………………………… Date:…………

**THIS DOCUMENT SHOULD BE REVIEWED ANNUALLY**

**User Declaration**

*I have read and understood this document and agree to abide by its requirements at all times.*

*I understand that in the event of any malfunction, or suspected malfunction, of any part of the laser system or its security and safety systems that the experiment must be stopped immediately, the laser switched off and the matter reported to local staff supporting the experiment. I accept that we are all jointly responsible for one another’s safety and undertake not to knowingly permit the infringement of these Rules and Procedures by others.*

**Authorised Users**

 **Name Signature PI Signature Date**

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| Laboratory Address: |  |
| Laser classification: |  |
| Type: Pulsed, Continuous Wave |  |
| Wavelength (nm) |  |
| Effects on Eyes of excessive exposure. | Delete as appropriate:180 – 315 nm: Photokeratitis315 – 400 nm: Photochemical cataract400 – 780 nm: Photochemical and thermal retinal injury780 – 1400 nm: Cataract, retinal burn1400 – 3000 nm: Aqueous flare, cataract, corneal burn3000nm – 1 mm: Corneal burn |
| Pulse energy (duration, peak power, repetition frequency) |  |
| Circumstances of accident / injury: |  |
| Time & Date of Injury |  |
| Eye affected: Left / Right / Both |
| Were protective goggles being worn? Yes / No |