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| **Date:** (1)**X/Y/ZZZZ** | **Assessed by:** (2)**Dr. Laser** | **Validated by:** (3)PI/managerLaser safety advisor | **Location:** (4)**Lab X.00Y, ABC Building** | **Assessment ref no** (5)**V1** | **Review date:** (6)Annually, or at change of use |
| **Approval of open beam work by Head of Department/ Director of Institute:** (7)**Name: ………..……………………………….Signature:……………………** |
| **Task and Environment :** (8)Operation of a high-repetition-rate terahertz time-domain spectrometer (THz-TDS) for high signal-to-noise studies of materials in the THz spectral range.The oscillator output is routed to the 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.nThe probe beam is used to detect the THz radiation by a standard electro-optic sampling scheme using a nonlinear crystal. The THz-TDS is located on an optical table in the TERA Laser System area of laboratory X.00Y. Ancillary electronic equipment for the THz-TDS is located on a mounting rack unit located next to the optical table. |
| **Justification for open beam work:** (9)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. A scheme of work governing safe open beam working procedures is in force. |
| **Details of Laser(s) used, including ELV/MPE calculations:** (10)The THz-TDS uses a Class 4 Ti:Sapphire oscillator (Coherent Mantis – Labcup #xxxx) producing 800 nm, 20 fs, 6.25 nJ laser pulses at 80 MHz (average power of 0.5 W). The Mantis oscillator is internally pumped by a Class 4 DPSS laser (Coherent Verdi) producing a 532 nm, 5 W CW beam.The Thorlabs CPS808A Collimated Laser Diode Module, Class 3R (Labcup #xxxx) produces a continuous wave output at between 795-815 nm (typically 808 nm), with a maximum output power of 3 mW. Output reduced to < 0.6 mW using a neutral density filter fixed at the laser exit. LED added to the laser power connection to provide warning light (as required by EN60825-1:2014 for class 3R invisible lasers).The Verdi pump laser is safely enclosed inside the main laser unit and under normal operation cannot be exposed, so calculations have not been performed. The Mantis laser is directly involved in experiments and relies on the interlock system for safety and therefore has associated laser safety calculations below.In addition to the Coherent Mantis oscillator, there is also another laser system in the lab used in other experiments, which can be operated simultaneously with the THz-TDS experiment detailed here in this RA. The laser system consists of Ti:Sapphire oscillator (Spectra-Physics, Tsunami) and amplifier (Spectra-Physics, Spitfire) lasers and for details of the experiments and appropriate laser safety calculations please see the relevant schemes of work and risk assessments. The scheme of work states that open beam work may only be performed with the Mantis laser-driven THz spectrometer provided the Spectra-Physics lasers in the TERA laser system area are fully enclosed. The hazards posed by the lasers in this system have been assessed by calculating the maximum permissible exposure (MPE) according to PD IEC TR 60825-14:2022, the exposure limit values (ELV) according to Directive 2006/25/EC. **Mantis Ti:Sapphire oscillator***Parameters*: 80 MHz, 800 nm (80 nm bandwidth), 0.5 W average power (6.25 nJ per pulse), 20 fs pulse duration, 1.4 mm diameter (1/e): www.lasertrack.ru/Downloads/Mantis\_DS.pdf80 MHz is a pulse period of 12.5 ns, which therefore falls into the high repetition rate regime, and where relevant effective repetition rates of 55,556 Hz (ELV) and 200,000 (MPE) will be used in calculations. ***Exposure to eyes***(10 s accidental exposure time):Single-pulse ELVsingle = 1.5x10-4CACE = 1.5x10-4 x 100.002(800-700) x 1 = 2.38 x 10-4 J/m2 MPEsingle = = 1 x 10-3 J/m2Average irradiance ELVsingle,avg = (10 CA/4CC/7)/N = (10 x 100.002(800-700) x1)/(55556x10) = 2.85 x 10-5 J/m2  MPEsingle,avg = (10 CA/4CC/7)/N = (10 x 100.002(800-700) x1)/(200000x10) = 7.92 x 10-6 J/m2Multiple-pulse              ELVtrain = ELVsingle x Cp = 2.38 x 10-4 x (55556x10)-0.25 = 8.71 x 10-6 J/m2  MPEtrain = MPEsingle x C5 = 1 x 10-3 x 0.4 = 0.4 x 10-3 J/m2 Most restrictive ELV/MPE = 7.92 x 10-6 J/m2. Using a 7 mm diameter minimum aperture for the eye means effective energy density is 1.62 x 10-4 J/m2.Therefore users must be aware that at the output of the laser, the average power is approximately **21 times** higher than the maximum permissible.***Exposure to skin***(100 s accidental exposure time):Single-pulse [ELV/MPE] single = 2x1011CA/4 = 2x1011 x 100.002(800-700) = 3.17x1011 W/m2 x 20x10-15 = 6.34 x 10-3 J/m2Average irradiance ELVsingle,avg = (2000CA/4)/N = (2000 x 100.002(800-700) )/(55556x100) = 5.71 x 10-4 W/m2 x100 = 5.71 x 10-2 J/m2 MPEsingle,avg = (2000CA/4)/N = (2000 x 100.002(800-700))/(200000x100) = 1.58 x 10-4 W/m2 x100 = 1.58 x 10-2 J/m2Multiple-pulse              ELVtrain = ELVsingle x Cp = 3.17x1011 x (55556x100)-0.25 = 6.53 x109 W/m2 x 20x10-15 = 1.31 x 10-4 J/m2 MPEtrain – not applicableMost restrictive ELV/MPE = 1.31 x 10-4 J/m2. Using a 3.5 mm diameter minimum aperture for the skin means effective energy density is 6.50 x 10-4 J/m2.Therefore users must be aware that at the output of the laser the average power is **5 times** higher than the maximum permissible.While both the safety standards only apply to wavelengths up to 1 mm, the THz sources generated using the Mantis Ti:Sapphire oscillator are many orders of magnitude below the MPE for cornea and skin exposure at 1 mm (MPE is 1000 W/m2 for 100s exposure to both eye and skin). **Thorlabs CPS808A Collimated Laser Diode Module***Parameters*: continuous wave output at between 795-815 nm (typically 808 nm), with 3.0 mW maximum output power.*Exposure to eyes:*10 second accidental exposure time, use 795 nm for most restrictive values.ELV/MPE = 10 CA/4CC/7 = 10 x 100.002(795-700) x1 = 15.49 W/m2Using a 7 mm diameter minimum aperture for the eye means the CW power must be limited to below 0.6 mW to be below the MPE.A neutral density filter is securely fixed at the output of the laser to reduce the maximum output power to well below 0.6 mW.*Exposure to skin:*100 second accidental exposure time, use 795 nm for most restrictive values.ELV/MPE = 2000 CA/4= 2000 x 100.002(795-700)  = 3098 W/m2Using a 3.5 mm diameter minimum aperture for the skin means the CW power must be below 30 mW to be below the MPE. The maximum power of the laser is only 3 mW and is therefore well below the MPE for skin.  |
| **Provided PPE, including calculated eyewear requirements:** (11)Mantis Ti:Sapphire oscillator*Required laser safety glasses rating*, calculated from BS EN:207, *Parameters*: 80 MHz, 800 nm, 0.5 W average power (6.25 nJ per pulse), 20 fs, 1.4 mm diameter (1/e)Beam area = 1.54x10-6 m2 Eyewear has plastic lenses, so F(d)= d1.2233 = 1.51For the D scale number: power density (Wm-2) = [power (W) / beam area (m2)] x F(d) = [0.5 / 1.54x10-6] x 1.51 = 4.90x105 Wm-2 = **D LB5**For the M scale number: The pulse interval is less than Ti (18 µs) , repetition rate is greater than vmax (55.56 kHz). So: energy density (Jm-2) = [pulse energy (J) / beam area (m2)] x F(d) x k x kTi where k = (vmax x 5)0.25 and kTi = v x Ti = [6.75x10-9 / 1.54x10-6] x 1.51 x (55560 x 5)0.25 x (80000000 x 18x10-6) = 2.03x102 Jm-2 = **M LB7**Each authorised user has their own pair of the following laser safety glasses, which provide sufficient protectionThorlabs 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. |

| **Activity** (12) | **Hazard** (13) | **Who might be harmed** (14) | **Existing measures to control risk** (15) | **Risk rating** (16) | **Result** (17) |
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| Use of lasers | Exposure to laser radiation from a Class 4 laser is extremely hazardous to the eyes and skin.The laser beam and its specular and diffuse reflections must not be viewed at any time as they may cause permanent loss of sight.  | Unauthorised users and visitors in other areas of laboratory  | 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 laser requires a key for operation, which is stored in a locked key cabinet that can only be accessed by authorised users. 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.  | LOW | A |
| Use of lasers | Exposure to laser radiation from a Class 4 laser is extremely hazardous to the eyes and skin.The laser beam and its specular and diffuse reflections must not be viewed at any time as they may cause permanent loss of sight.  | Users | Authorised laser users to have attended an appropriate laser safety training course (TH42e and THS43e) and have been given local training on the laser system (documented via a LS3 form submitted to the LLSA).Laser safety calculations (see above) highlight the need to avoid exposure (to eyes and skin) from all Class 4 lasers in the lab. Therefore, 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 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.A corresponding scheme of work governing safe working procedures is in force. | LOW | A |
| Open beam work with a Class 4 laser | Exposure to laser radiation from a Class 4 laser is extremely hazardous to the eyes and skin.The laser beam and its specular and diffuse reflections must not be viewed at any time as they may cause permanent loss of sight.  | Users | Open beam work is only to be performed by authorised users with sufficient training and experience, listed as Users Authorised for Open Beam Work above.Steps taken to minimise the need for open beam work (see scheme of work procedures):* The Mantis laser output is routed into the THz spectrometer using a 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.
* A Class 3R, continuous wave 800 nm diode laser (Thorlabs CPS808A), with a ND filter fixed at the output to reduce the output power to below MPE/ELV levels is used as an eye-safe pilot laser beam. This pilot beam co-propagates with the Mantis laser output and enables course alignment of the THz spectrometer optics without the need to use the beam from the Class 4 Mantis laser.

Open beam work may only be performed with the Mantis laser-driven THz spectrometer provided the other lasers in the area are fully enclosed.  | MEDIUM | A |
| Use of Class 4 laser | Fire due to the laser beam striking flammable surfaces | Building occupants | The laser output is fully enclosed inside non-flammable aluminium tubes and enclosures, whose lid is interlocked with a mechanical shutter at the laser output. There are no flammable materials inside the beam tubes or enclosure. | LOW | A |
| General lab use | Water leaksElectrocution arising from the combination of leaking water and electrical supplies. | Users | The chillers used to cool the multiple laser systems in the lab have small water reservoirs ranging from approximately 1-2 litres. Both are positioned underneath the power supplies, underneath the table in case of a leak. The connections at the laser heads and chillers are secure.All mains extension sockets must be raised above floor level to remove the risk of electrocution that may arise from the combination of leaking cooling water and electricity supplies. A spill kit is available in case of leakage. | LOW | A |
| Use of electrical equipment | Hazards associated with electricity.Burns, shock, arcing, fire, explosion.  | Users | All portable electrical equipment is PAT tested in accordance with The Electricity at Work Regulations 1989, and user checks are carried out at the start and end of lab sessions to check for excess noise, overheating, water ingress etc. | LOW | A |
| Use of electrical equipment | High voltages and currents in laser power suppliesElectrocution from laser power supplies | Users | The Verdi pump laser uses high-current laser diodes.Normal operation does not require access to the inside of the power supplies or laser heads and the covers to all these units are screwed down with numerous bolts. | LOW | A |
| General lab use | Trailing electrical cablesTrips and falls could result in injury | Users | A policy of good housekeeping is encouraged and cable guides/covers are used where appropriate. | LOW | A |
| General lab use | Kick-stoolsFalls from a kick stool could result in injury | Users | Kick-stools (stood on for reaching high places) have been registered with the Photon Science Institute for regular safety inspections. The Mantis laser system has its own dedicated kick-stool for authorised users of the Mantis laser system and this is labelled accordingly.  | LOW | A |
| General lab use | Lone working | Users | All lab use is compliant with local policy on lone working. Work hours restricted from 8 am to 5 pm Monday to Friday. Lone working is prohibited outside these times.If working alone within in the lab then a ‘buddy system’ must be in place with contact once per hour.Open beam work is not permitted outside of normal working hours. | LOW | A |

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| **Action plan** (18) |
| **Ref No** | **Further action required** | **Action by whom** | **Action by when** | **Done** |
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**User Declaration**

*I have read and understood this document and agree to abide by its requirements at all times. I accept that we are all jointly responsible for one another’s safety and undertake not to knowingly permit the infringement of these requirements by others.*

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| **Name** | **Signature** | **Date** |
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**Notes to accompany Laser Risk Assessment Form**

This form is adapted from the one recommended by Safety Services, and used on the University’s risk assessment training courses. It is strongly suggested that you use it for all new assessments, and when existing assessments are being substantially revised. However, its use is not compulsory. Providing the assessor addresses the same issues, alternative layouts may be used.

1. **Date** : Insert date that assessment form is completed. The assessment must be valid on that day, and subsequent days, unless circumstances change and amendments are necessary.
2. **Assessed by** : Insert the name and signature of the assessor. The assessor should have completed the Laser Safety Awareness course THS42e and Advanced Laser Safety Awareness course THS43e. General guidance on completing risk assessments can be found on the safety services website: https://www.healthandsafety.manchester.ac.uk/toolkits/ra/
3. **Checked/Validated by** :

**Checked by** : Insert the name and signature of someone in a position to check that the assessment has been carried out by a competent person who can identify hazards and assess risk, and that the control measures are reasonable and in place. The checker will normally be a line manager, supervisor, principal investigator, etc.

**Validated by** : Insert the name and signature of your Local Laser Safety Advisor (or their designated deputy), they will need to check that your safety calculations and control measures are adequate.

1. **Location** : insert details of the exact location, ie building, floor, room or laboratory etc. If off-campus, provide information about expected location(s) or attach itinerary.
2. **Assessment ref no** : use this to insert any local tracking references used by the school or administrative directorate.
3. **Review date** : insert details of when the assessment will be reviewed as a matter of routine. Usually this is for 1 years’ time, but might be less for a short programme of work. Note that any assessment must be reviewed if there are any significant changes – to the work activity etc.
4. **Approval of open beam work :** Where open beam work with class 3B and 4 lasers is essential, it must be signed off by the Head of School/ Department/ Institute.
5. **Task**: insert a brief summary of the task, eg research project [title] involving the use of X equipment.
6. **Justification for open beam work:** where open beam work with class 3B and 4 lasers is essential, it must be robustly justified
7. **Details of Laser(s) used, including ELV/MPE calculations:** include make, model and other details of the laser system(s) in use, including wavelength, power, energy, pulse duration and beam size where known. This is also the place to include details of ELV/MPE calculations. If the calculations are extensive (covering multiple wavelengths etc.) then the results can be summarised here and given in full in a separate referenced document.
8. **Provided PPE, including calculated eyewear requirements:** list what PPE is available, and summarise what eyewear your calculations have specified. If the eyewear available does not match that specified then clearly state what wavelength/energy rages are covered. Also include here plan for how eyewear condition will be checked regularly and monitored/recorded.
9. **Activity** : use the column to describe each separate activity covered by the assessment. The number of rows is unlimited. For example activities might include: in one particular lab or for one particular project might include: Use of Lasers, Open beam work, Experimental process, Lone Working, General lab use, Use of substances hazardous to health, etc
10. **Hazard** : for each activity, list the hazards. Remember to look at hazards that are not immediately obvious. The same activity might well have several hazards associated with it. For example ‘Use of lasers’ would include personnel exposure to beam (from the laser output), fire (from high power beams) , electrical (from power supplies), water leaks (from cooling systems), trip hazards (from cables), irritants (from laser cutting). The ‘Open beam work’ hazard would personnel exposure to beam during alignment.

Assessment of simple chemical risks (eg use of cleaning chemicals in accordance with the instructions on the bottle) may be recorded here. More complex COSHH assessments eg for laboratory processes, should be recorded on the specific COSHH forms.

Describe how harm might come about, eg an obstruction or wet patch on an exit route is a hazard that might cause a trip and fall; use of electrical equipment might give rise to a risk of electric shock; use of a ultraviolet light source could burn eyes or skin.

1. **Who might be harmed** : insert everyone who might be affected by the activity and specify groups particularly at risk. Remember those who are not immediately involved in the work, including cleaners, young persons on work experience, maintenance contractors, Estates personnel carrying out routine maintenance and other work. Remember also that the risks for different groups will vary. Eg someone who needs to repair a laser may need to expose the beam path more than users of the laser would do. Vulnerable groups could include children on organised visits, someone who is pregnant, or employees and students with known disabilities or health conditions (this is not a definitive list).
2. **Existing measures to control the risk** : list all measures that already mitigate the risk. For example, in normal operation the risk of exposure to beam has been mitigated by fully enclosing the system, and interlocking to the laser output any access panels. For exposure to beam during alignment extra precautions would be needed, access controls, further training, appropriate PPE etc.
3. **Risk Rating** : the simplest form of risk assessment is to rate the remaining risk as high, medium or low, depending on how likely the activity is to cause harm and how serious that harm might be.

 The risk is **LOW** - if it is most unlikely that harm would arise under the controlled conditions listed, and even if exposure occurred, the injury would be relatively slight.

 The risk is **MEDIUM** - if it is more likely that harm might actually occur and the outcome could be more serious (eg some time off work, or a minor physical injury.

 The risk is **HIGH** - if injury is likely to arise (eg there have been previous incidents, the situation “looks like an accident waiting to happen”) and that injury might be serious (broken bones, trip to the hospital, loss of consciousness), or even a fatality.

1. **Result** : this stage of assessment is often overlooked, but is probably the most important. Assigning a number or rating to a risk does not mean that the risk is necessarily adequately controlled. The options for this column are:

 **T = trivial risk**. Use for very low risk activities to show that you have correctly identified a hazard, but that in the particular circumstances, the risk is insignificant.

 **A = adequately controlled, no further action necessary.** If your control measures lead you to conclude that the risk is low, and that all legislative requirements have been met (and University policies complied with), then insert A in this column.

 **N = not adequately controlled, actions required**. Sometimes, particularly when setting up new procedures or adapting existing processes, the risk assessment might identify that the risk is high or medium when it is capable of being reduced by methods that are reasonably practicable. In these cases, an action plan is required. The plan should list the actions necessary, who they are to be carried out by, a date for completing the actions, and a signature box for the assessor to sign off that the action(s) has been satisfactorily completed. Some action plans will be complex documents; others may be one or two actions that can be completed with a short timescale.

 **U = unable to decide. Further information required.** Use this designation if the assessor is unable to complete any of the boxes, for any reason. Sometimes, additional information can be obtained readily (eg from equipment or chemicals suppliers, specialist University advisors) but sometimes detailed and prolonged enquiries might be required. Eg is someone is moving a research programme from a research establishment overseas where health and safety legislation is very different from that in the UK.

 **For T and A results**, the assessment is complete.

 **For N or U results**, more work is required before the assessment can be signed off.

(18) **Action Plan**. Include details of any actions necessary in order to meet the requirements of the information in Section 11 ‘Existing measures to control the risk’. Identify someone who will be responsible for ensuring the action is taken and the date by which this should be completed. Put the date when the action has been completed in the final column.