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Laserlab-Europe AISBL - Interest/Expert group on laser-generated electromagnetic pulses

When high power lasers interact with a material target, they accelerate electrons that can leave the target surface and produce powerful electromagnetic pulses (EMPs). This EMP is emitted across a broad frequency band from MHz to THz, determined by the complex interplay of laser and target physics and multiple distinct emission mechanisms. Radio- and microwave-frequency EMP can disrupt electronic equipment when it exceeds a threshold ~10 kV/m [1], which continues to cause problems on laser facilities around the world. On the other hand, EMP sources can be used for scientific research, with diverse applications including laboratory astrophysics, THz imaging and charged particle acceleration.

Fundamental properties of EMP emitted from solid targets were summarised in a review paper published in the *High Power Laser Science and Engineering* (HPLSE) journal in 2020 [2]. This review describes how an electrical discharge across the target support produces antenna radiation that is a major source of GHz-frequency EMP. It outlines how to reduce the damage caused by EMP *directly* - through disruption of the antenna emission process or reducing the laser energy or intensity - and *indirectly* - by enclosing the target in a Faraday cage or shielding sensitive instruments.

Though the HPLSE review is a valuable reference work for the scientific community, significant gaps in our understanding of EMP physics remain. There are several GHz and THz EMP emission mechanisms (e.g. charged particle deposition) that have not yet been systematically studied but which can produce MV/m fields inside the target chamber [3]. EMP emitted from liquid and gaseous targets has also not been studied in detail. Although they generally emit reduced EMP compared with solid targets, when gas jets and liquid droplets are irradiated by multi-PW lasers they may produce EMP of comparable magnitude to less powerful lasers focused on solid targets. Understanding how EMP is emitted from these lower density targets is therefore increasingly important as they are installed on a new generation of high intensity, high repetition-rate laser systems [4]. Then there are questions about how to produce terahertz sources that are sufficiently bright and energetic to image materials, probe lattice dynamics and excite phonons [5]. The major scientific goals of the EMP expert group are therefore:

(i) To develop models of laser-induced charging and discharging in solid, liquid and gaseous targets, as well as laser intensity regimes that are less well-understood ($<10^{17}$ Wcm^{-2}).

(ii) To learn how to produce radiation sources useful for a wide range of applications, such as laboratory-scale astrophysics experiments, studies of magnetized high energy density plasmas, terahertz pumping and probing of materials, charged particle guiding, etc.

(iii) To develop diagnostics and measurement techniques that are accurate and resistant to EMP noise. This includes diagnostics that will directly measure charge accumulation in the laser target.

(iv) To develop technologies to reduce harmful EMP emission.

We want to explain how to reduce the disruption caused by EMP so that laser facilities can function at the highest possible level. We also want to promote applications that may benefit scientific research. Success in these fields could have a marked positive impact on the other Laserlab expert groups, particularly “Laser science for cancer research” and “Lasers for clean energy”.

Achieving the research goals of our group will require the development of new models of EMP emission and dedicated experiments where they can be tested. An ideal experiment combines detailed modelling prior to the experiment with accurate measurements from multiple independent diagnostics. This ensures the experiment is designed well, results are interpreted as objectively as possible and models can be rigorously tested. Particularly important are measurements of discharge currents, fields and charged particle spectra so we can benchmark target charging models and monitor facility function. However, expertise in EMP research is currently spread across our 25 partner institutions, with experts in radio and microwave emission separated from THz experts and experimental physicists separated from theorists. Simulation codes and measuring equipment are also unevenly distributed. It is therefore important to bring academics together so they can benefit from each other's resources and advice.

Establishing an expert group with Laserlab-Europe has helped build a community of researchers interested in EMP and makes it easier to apply for research funding. We have an annual EMP workshop and regular teleconferences where progress can be tracked and collaborations can grow. We would also like to take advantage of schemes offered by Laserlab-Europe which will help drive forward research into laser-generated EMPs. We would like to run regular seminars to help researchers broaden their understanding of the field as well as deepen their knowledge in their own areas of expertise (i.e. foster T-shaped skills). The Laserlab staff exchange programme will be useful to bring skills and equipment where they are needed. There is also a cloud space, where we can pool data and codes that will help us standardise analysis techniques and produce higher quality research. We will divide our research effort into two work packages: (i) *Theory, Modelling, Mitigation and Applications* and (ii) *Diagnostics and experiments*. A work package commission of three-to-four scientists will coordinate our research activity in each of these groups.

- **Producing EMP-resistant equipment and diagnostics** will help us…
  - improve scientific research at high-power laser facilities and push forward all the goals of Laserlab-Europe
  - improve our ability to accurately characterise EMP
- **Modelling EMP emission from gaseous and liquid jets** will help us…
  - reduce damage from EMP on multi-PW high repetition rate laser systems
  - understand how to prevent damage to supersonic gas jet nozzles - an expensive obstacle in developing sources of energetic ions
  - produce models of laser absorption physics and hot electron generation in underdense and critical plasmas
- **Developing more accurate models of laser-induced charging** will help us…
  - produce 10-100T-level magnetic field sources for applications in magnetized HED physics experiments, with potential impacts ranging from atomic physics to laboratory-scale astrophysics experiments and extended MHD studies.
  - predict hot electron production and refluxing in various intensity regimes, with implications for inertial fusion energy (IFE).

- **Optimising sources of terahertz radiation** will help us…

➢ to *image* transient states of matter, such as those caused by ion vibration/rotation, spin precession, or electronic degrees of freedom.
➢ to *excite* these transient phenomena directly, e.g. to generate lattice vibrations (phonons), accelerate electrons or to control material properties like electrical conductivity and molecular orientation.
➢ develop pump-probe experiments for time-resolved nanometre-scale imaging of materials, where terahertz radiation is used to modify a target's internal structure and then x-rays are used to capture an image of the target.
➢ learn more about biological systems, whether through advances in medical imaging or by directly influencing biological processes.

- **Testing new experimental platforms for EMP measurement** will help us…

➢ to use EMP fields as a diagnostic of the laser interaction, allowing us to track laser absorption and plasma expansion.
➢ develop more practical applications of laser-generated fields, such as studies of living cells, material and device characterization, or electromagnetic-compatibility.

Ultimately, our ambition as an expert group within Laserlab-Europe is to advance the scientific understanding of laser-generated EMP across its full bandwidth (MHz-THz), to develop ways to reduce its negative impact on laser facility performance and to control the emission in a manner that is scientifically expedient. The group aims to be a reference for the community on this broad topic. We will help disseminate information and support people or institutions who are interested in EMP, identifying the members of our group who can help them the most. Running seminars on specific topics within the field of EMP will be integral to this goal.

References

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