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Nuclear Instruments and Methods in Physics Research A 445 (2000) 317–319
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
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The Strathclyde terahertz to optical pulse source (TOPS)☆

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Abstract

We describe the newly created free-electron laser facility situated at the University of Strathclyde in Scotland, which will produce ultra-short pulses of high-power electromagnetic radiation in the terahertz frequency range. The FEL will be based on a 4 MeV photoinjector producing picosecond 1 nC electron pulses and driven by a frequency tripled Ti:sapphire laser thus ensuring synchronism with conventional laser based tuneable sources. A synchronised multi-terawatt Ti:sapphire laser amplifier will be used in the study of laser/plasma/electron beam interactions and as a plasma based X-ray source. A substantial user commitment has already been made in support of the programme. © 2000 Elsevier Science B.V. All rights reserved.

PACS: 41.20.jb; 41.60. − m; 41.60.Cr; 52.75.M; 52.40.N

Keywords: Terahertz facility; Free electron laser; Laser–plasma interaction

1. Introduction

A powerful new research tool consisting of a collection of synchronised state-of-the-art high-power femtosecond lasers and an electron source have been set up at Strathclyde. The facility, known as the Strathclyde Electron and Terahertz to Optical Pulse Source (TOPS), will be utilised by users from Strathclyde and further a field in a wide variety of applications programmes. TOPS, situated in a laboratory space of 250 m^2, will be an excellent research tool for the study of ultra-fast phenomena, collective radiation-matter interactions and high-power electromagnetic radiation interacting with matter.

Notable features of the sources are the provision of:

- broadly tuneable high-power optical pulses from the UV to infrared,
- 50 fs 4 TW laser source for plasma studies and X-ray generation,
- high power single-cycle terahertz electromagnetic pulses, and
- synchronised sub-picosecond relativistic electron bunches.

The electron source will be used to produce the high-power terahertz pulses in a free-electron

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☆The United Kingdom EPSRC, Scottish Higher Education Funding Council and the Royal Society are supporting this work.

PII: S0168-9002(00)00134-0

maser amplifier. The typical tuning range of the sources is given in Fig. 2.

The central terahertz source in TOPS will be a free-electron maser amplifier (FEM) driven by a photoinjector (CANDELA) [1–4]. The FEM will produce high-power electromagnetic pulses that are tuneable over a wide wavelength range, through the interaction of a high-current, high-brightness relativistic electron beam with an undulator and other periodic structures.

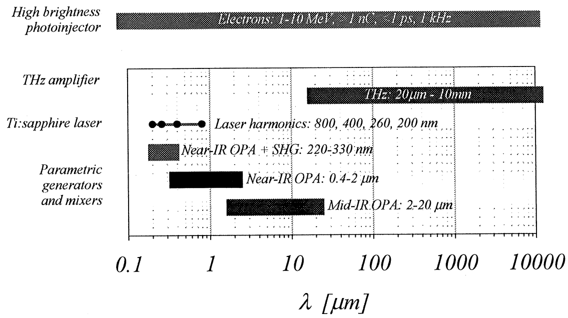

Fig. 2. Tuning range of TOPS.

2. Details of the TOPS facility

The TOPS sources are being developed around a number of conventional short pulse lasers which will include two Ti : sapphire oscillators, three amplifiers, an accelerator (photoinjector) and a free-electron maser interaction region. To achieve tuneability over a large wavelength range, harmonic generation and mixing in non-linear crystals, and parametric conversion will be utilised. The basic layout of the facility is shown in Fig. 1.

Main characteristics of TOPS:

- high power: 4 TW source (50 fs 10 Hz 200 mJ)
- high average power source (30 fs 1 kHz 4 mJ)
- moderate power source (100 fs 1 kHz 1 mJ)
- moderate power source (100 fs 1 kHz 1 mJ)
- independently tuneable: UV, visible or mid IR (2 OPAs and numerous mixers)
- ultra-short pulse duration: 0.5–20 cycles of the e–m wave (down to 10 fs)
- terahertz source (far-infrared) (FEM and plasma based source): 100 μm to > 1 mm (< 20 μm in second stage);
- high power sub-cycle (unipolar) terahertz pulses with an ultra-wide spectral bandwidth (free-electron maser)
- flexible format: multiple pulses, flat-top, chirps etc. by Fourier plane filtering
- synchronised high-brightness sub-picosecond relativistic electron beam: 1–4 MeV 1 nC 100 Hz based on RF photoinjector technology (10 MeV @1 kHz in second stage)
- suitable infrastructure for users to carry out two-colour (photon–photon) and two-type pump-probe (electron–photon) experiments

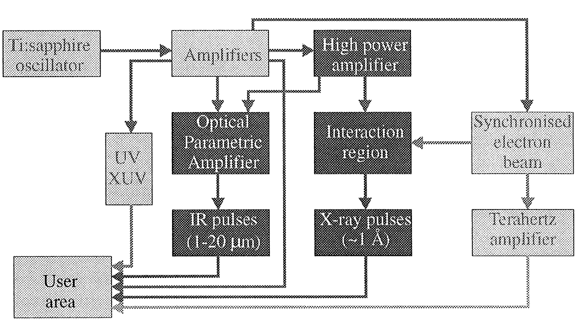

Fig. 1. Layout of TOPS sources.

The range of frequencies covered by the various TOPS sources is shown in Fig. 2.

3. Amplification of terahertz pulses by the FEM

To generate ultra short high-power terahertz pulses with durations ranging from less than a single-optical cycle to a few cycles we plan to exploit the intrinsic broad gain bandwidth available from the free-electron maser. The femtosecond laser source (Ti:sapphire oscillator and amplifiers) will be configured to provide ultra-short pulses of high-power electromagnetic radiation and terahertz injection pulses while simultaneously driving the photoinjector. Relativistic electrons from the photoinjector will be passed through a planar

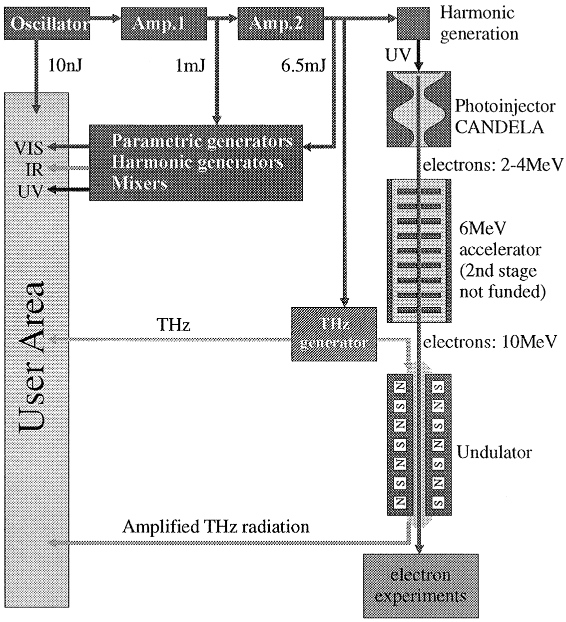

Fig. 3. Layout of photoinjector, undulator and lasers.

permanent magnet undulator (or other structure) to amplify either an externally injected terahertz e–m pulse seed or the coherent spontaneous field by a factor of up to 10^5 [5,6]. This is schematically shown in Fig. 3. The large gain factor can be achieved because of the high peak currents produced by the high brightness photoinjector. Tuneability of the source will be achieved by varying either the undulator magnetic field or the electron energy.

4. TOPS user activity

The powerful tools available in TOPS will support key members of the user community in:

- studies of collective radiation-matter interactions,
- semiconductor physics, *relevant to the development of devices and detectors*,
- surface physics and catalysts, *relevant to the development of fuel cells*,
- interaction of ultra-short pulses with plasmas, *relevant to energy production and accelerator development*
- molecular dynamics,
- chemical and biological processes involving proteins,
- femtochemistry,
- photo-ionisation studies,
- RF accelerator physics,
- femtosecond optical pulse generation, and
- development of new sources of high power electromagnetic radiation,
- ultra-short pulse propagation in amplifying and absorbing media.

A synchronous detection system is being developed to detect visible and terahertz pulses. The terahertz detection system will also enable the simultaneous detection of the phase and amplitude of the electromagnetic pulses emerging from the plasma, and therefore it will be possible to measure such quantities as the complex refractive index is being constructed. A pulsed helical micro-undulator, with a period of 1 cm, will be designed and constructed to provide a periodic magnetic force in the plasma. This will be used to study the Laser Driven Undulator Interaction (LURI) [7,8]. Linear and non-linear stimulated Thomson (Compton) and Raman backscattering, and superradiance will be studied in the plasma as will electromagnetically induced transparency using terahertz pulses.

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