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THE SABINA TERAHERTZ/INFRARED BEAMLINE AT SPARC-LAB FACILITY

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Abstract

Following the EU Terahertz (THz) Road Map [1], high-intensity, ps-long, THz)/Infrared (IR) radiation is going to become a fundamental spectroscopy tool for probing and control quantum materials ranging from graphene [2], and Topological Insulators, to strongly correlated oxides [3-6] and novel superconductors [7, 8]. In the framework of the SABINA project a novel THz/IR beamline based on an APPLE-X undulator emission will be developed at the SPARC-Lab facility at LNF-INFN. Light will be propagated from the SPARC-Lab to a new user lab facility nearly 25 m far away from the SPARC laboratory. This beamline will cover a broad spectral region from 3 THz to 30 THz, showing ps- pulses and energy of hundreds of μJ with variable polarization from linear to circular. The corresponding electric fields up to 10 MV/cm, are able to induce non-linear phenomena in many quantum systems. The beamline, open to user experiments, will be equipped with a 5 T magnetic cryostat, and will be synchronized with a fs laser for THz/IR pump, VIS/UV probe experiment.

INTRODUCTION

The spectacular advancements observed in the last decade leads to an increasing interest to terahertz (THz) technology in the efforts to harness the power of the thermal radiation in the region from ~50 GHz to 10 THz (1.5 - 350 cm^{-1}, 7 mm - 15 μm wavelength, 0.2 - 45 meV) [1, 9-11]. The THz region of the electromagnetic spectrum is a frontier area for research in Physics, Chemistry, Biology, Materials Science and Biomedicine. Indeed, small molecules rotate at THz frequencies; biologically-important collective modes of proteins, DNA and RNA vibrate at THz frequencies; frustrated rotations and collective modes cause polar liquids such as water to absorb at THz frequencies; electrons in semiconductors and their nanostructures resonate at THz frequencies; electrons in highly-excited atomic Rydberg states orbit at THz frequencies; superconducting energy gaps fall at THz frequencies; gaseous and solid-state plasmas also oscillate at THz frequencies so that this radiation can be used to study and control an extraordinary vast number of fundamental systems and phenomena [1, 11-15]. The roadmap for the development of THz technologies [1, 16, 17] considers applications in the fields of outdoor and indoor communications, security, drug detection, biometrics, food quality control, agriculture, medicine, semiconductors, air pollution, etc. Their exploitation and realization demands high-power compact THz sources, more sensitive detectors, and more functional integrated THz systems. A further important use of THz radiation concerns the excitation and control of quantum materials. These systems which show quantum macroscopic phenomena at room temperature, are characterized by excitations resonating in the THz and Infrared (IR) frequencies [18-20].

Radiation sources of high quality in the THz region of the e.m. spectrum have been scarce [21], but this "THz gap", after continuous research efforts, has been filled by a wide range of new technologies ranging from accelerated relativistic electrons [22, 23], to high-power femtosecond laser-based sources [24, 25] and Quantum Cascade Lasers [26]. Thus, THz radiation is now available in both CW and pulsed form, down to single-cycles, with peak powers up to tens of MW [27] and several THz facilities are worldwide distributed for fundamental experiments, users' applications and industrial R&D.

However, a real bridge between THz and IR radiation is not complete in particular for what concerns high-intense ps pulsed beams. Previous discussed THz sources indeed cover a broad spectral range up to 10 THz, while IR sources, often based on the Difference Frequency Generation mechanism, reach, 20 THz at low-frequency. In this paper, we will discuss a new THz/IR source based on the Self Amplified Spontaneous Emission (SASE) mechanism from a relativistic electronic beam from the Free-Electron Facility SPARC at LNF-INFN of Frascati, Italy. This source will be extremely competitive in the international scenario and will be open for national and international users.

DISCUSSION

The Sabina beamline (Source of Advanced Beam Imaging for Novel Applications) is based on an Apple-X undulator emission of quasi-monochromatic light, with sub-picosecond photon pulses of high intensity (hundreds of μJ each), in the frequency range between 3 THz (100 μm) to 30 THz (10 μm). Polarization can be changed from linear to elliptical to circular. The intensity per pulse corresponds to associate electric fields up to 10 MV/cm, which are useful to perform non-linear and pump-probe spectroscopy measures.

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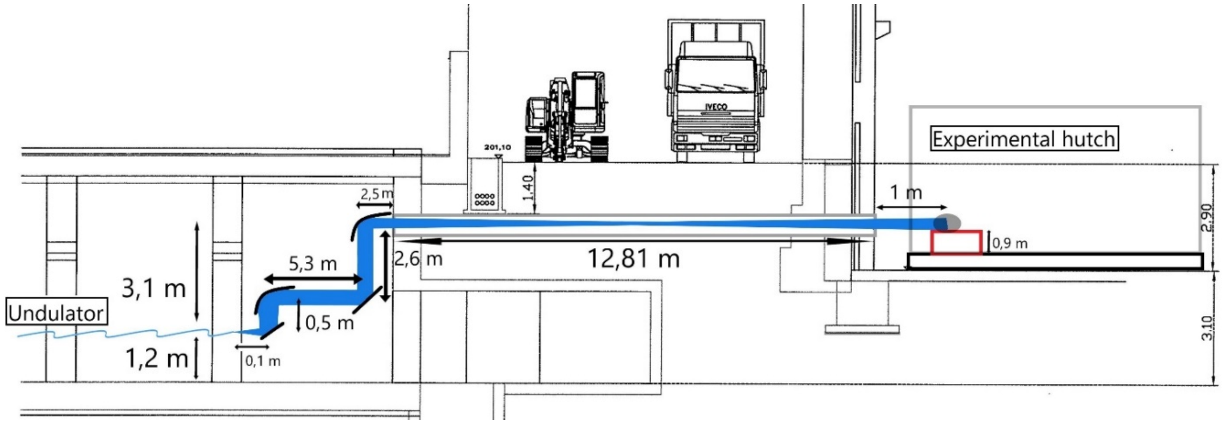

Figure 1: Beamline setup (not on scale). Light propagation is represented from the undulator source to the laboratory. M1 is plane OTR screen, M2 is an off axis parabolic mirror that collimates the beam to a plane mirror (M3). The radiation is focused by M4 into a long conduct where in the center is placed the diagnostic setup. M5, a parabolic mirror identical to M4, collimates the beam directing it to the experimental room.

The optical setup transfers the radiation from the undulator to the users' experimental hutch, placed in a separated building. The radiation is generated and transported through a ultra-high vacuum region from the undulator to a diamond window located between the first and the second mirror and to a further low-vacuum path for a distance of about 25 m. The transmission efficiency is higher than 90%. In Fig. 1 is possible to see a sketch of the optical setup. After the radiation leaves the undulator an OTR aluminium screen (M1 Mirror) reflects the radiation upward while allows the electron beam to pass through undisturbed. The diverging beam go through a diamond window propagating in a low vacuum circular pipe.

In this beamline section the radiation is first collimated and then focused onto a long pipe which connect the SPARC building to the experimental hutch building. In the middle of the trajectory is placed a diagnostic setup, which is necessary for the radiation beam alignment and characterization.

The diagnostic setup is composed by a moving mirror that deflect the radiation into a THz-IR pyroelectric camera array. The radiation is then collimated by a parabolic mirror (M3) and brought to the experimental table where is used for spectroscopy measures.

During this transport the maximum beam size vary between ~4 cm (2σ) at 3 THz and ~2 mm at 30 THz.

This setup is composed by polished and gold-coated plane and parabolic mirrors that reflect the THz/IR beam with a reflectivity of nearly the 99% maintaining the initial polarization.

The experimental hutch is finally equipped with a fs laser synchronized to the THz/IR beam for THz/IR pump, VIS/UV probe experiment, and a Liquid-He magnetic cryostat for temperature and magnetic field dependent measurements. The energy per pulse figure of merit of SABINA in comparison to existing THz/IR sources is shown in Fig. 2. Both the broad covered spectral range reaching the IR region and the high energy per pulse suggest that SABINA could represent a very versatile source for cutting-edge experiments in quantum material physics.

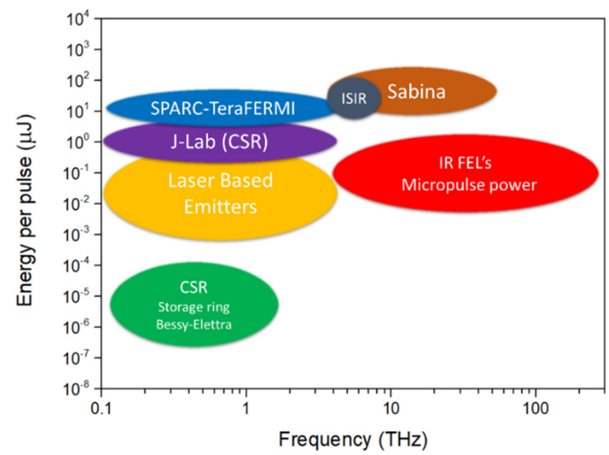

Figure 2: Energy per pulse THz/IR emission for different high-intensity ps long sources.

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