Coherent and cost-effective multi-THz superradiant light source for standalone and THz pump-FEL probe experiments, compatible with high-repetition rates.

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Project Objectives: to significantly increase the frequency coverage, longitudinal coherence, spectral brightness and pump-probe capabilities of THz and FIR sources driven by electron beams at existing and planned free-electron laser facilities, the project aims at developments and practical demonstrations of electron beam manipulation techniques applicable to a wide energy range, from few 10's of MeV to GeV. The developments will serve present and future user facilities driven by high-gradient normal conducting (NC) LINACs as well as high average current superconducting (SRF) LINACs. The project also aims to improve cost effectiveness of the facilities operation.

Motivation: Beam-driven THz sources are well established and operate as user facilities in their own right as well as part of larger short-wavelength FEL user facilities. The presently operating sources provide single-cycle broadband pulses generated via coherent diffraction (CDR) or transition radiation (CTR) and multi-cycle pulses generated in super-radiant undulators. In all these sources, the significant bunching factor at the radiation wavelength is achieved via strong bunch compression. This allows to reach few THz in the frequency range, and the pulse energies between ~1 and ~100 μJ depending on the beam energy and repetition rate, i.e., accelerator technology (NC RF vs. SRF) used. User communities of such facilities, present strong science cases for the need to extend the frequency coverage of such sources from 0.1 THz up to 30 THz, and simultaneously reach pulse energies on the order of a few 100 μJ or reaching E-field strength of few MV/cm, as outlined in the next paragraph. Such requirements exist at standalone FIR-THz facilities in combination with the required repetition rate of up to ~1 MHz. At the short-wavelength facilities where FIR-THz sources are used mainly for pump-probe experiments, the repetition rate of pumps naturally needs to match the repetition rate of the short-wavelength probes. The physics of the longitudinal phase space dynamics would not allow reaching such parameters with presently used architectures of the radiation sources. This is especially true in the high-frequency part of the range.

Despite its prominent importance it is still challenging to cover the 5-30 THz range with high peak power and sub-ps pulse duration with one single photon source. The production of coherent, multi-THz light, tunable both in wavelength, intensity and repetition rate, would however open new doors in THz control of matter for standalone experiments as well as in THz pump-FEL probe self-synchronized experiments in condensed matter physics, chemistry and biology. In particular, the energy range between 5 and 30 THz is rich of excited modes (phonon modes, vibrational modes, electronic and magnetic resonances, etc.) which can be used as knobs to induce phase transitions (as in light induced superconductivity, ferroelectricity and insulator to metal transitions) and to drive material's properties in the desired direction. Intense THz pulses can be used to transiently orient dipoles in molecules, thereby allowing for instance to address the solvation properties of liquid water, and may be employed to excite low-frequency anharmonic large amplitude modes of macromolecules thereby affecting their conformational properties.

The project will provide to industries in the field of advanced mechanics specifications for the production of corrugated structures as a function of the range of electron beam and THz light parameters, and the possibility of developing/advancing internal know-how in the manufacturing of the structure in the perspective of massive and therefore cost-saving production.

Project Summary: Design study, prototyping and experimental test of a sub-picosecond coherent multi-THz light source compatible with MHz repetition rate, delivering several hundreds' µJ pulse energy and MV/cm peak electric field at the sample. We envision that R&D on two avenues will allow us to achieve the required parameters, which were outlined above. The first direction is the use of longitudinally modulated beams in place of strongly compressed ones. The second direction is the development of optimized bunch compressors.

An electron beam of 0.1-1 GeV can be energy-modulated with corrugated metallic (or dielectric) structures in the range 5-30 THz and successively compressed in time through a dedicated self-linearizing magnetic arc. A large bunching factor (>10%) at relatively high bunch charges (0.1-5 nC) will generate intense and collimated multi-THz radiation. The scheme is intrinsically passive, thus free from time-varying radiofrequency and e.m. sources, and adaptable to any repetition rate and duty cycle (in case of bunch trains), compatible with FEL-spent beamlines in large scale x-ray FEL facilities as well as with small-scale standalone light sources managed for example by universities or private companies. The two-step model proposed (energy modulation, magnetic compression) is flexible enough to be beneficial for normal-conducting accelerators at low repetition rates, where the energy modulation is implemented through low gap corrugated structures, as well as to superconducting accelerators in which a pre-existing FIR-THz FEL oscillator can be used instead for the energy modulation

Work breakdown structure (work packages):

1. Conceptual design study of electron beam manipulation through corrugated structure, self-linearized magnetic bunch compressor (chicane and/or dog-leg) and simulation of coherent THz generation. The design study would advantageously profit of beam parameters at an existing source of high brightness electron beam, capable of electron beam and THz diagnostics, e.g., 25 - 50 MeV beam energy, 0.1 - 1 nC bunch charge, emission in the frequency range 5 - 30 THz.
2. Prototyping of module of corrugated structure with fixed period and variable gap, acquisition of DC magnets and diagnostics
3. Implementation of the corrugated structure and self-linearizing magnetic compressor at an existing infrastructure for proof-of-principle production of >5 THz coherent light
4. Physics design of 2^{nd}-order magnetic bunch compressor for the energy range of 25 - 50 MeV and 1 nC bunch charge
5. Contraction and beam test of such compressor prototype at an existing facility
6. Physics design of optimized dispersion section for the energy range 25 - 50 MeV, and 1 nC bunch charge, to allow high bunching factor in the wavelength range from 200 µm down to 10 µm (30 THz)
7. Contraction and beam test of the dispersion section

Beneficiaries: Elettra Sincrotrone Trieste-FERMI (?), HZDR, BESSY (?), MAX IV (?), FELIX (?), DESY-FLASH (?), Solaris (?), Polfel (?), PSI (?)

Third Partners: Univ. Uppsala, Canadian Light Source, Cockroft Institute (?)