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Properties and Planned Use of the Intense THz Radiation from ELBE at Dresden-Rossendorf

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Abstract. The radiation source ELBE at Dresden-Rossendorf is centered around a superconducting ELectron accelerator of high Brilliance and low Emittance (ELBE) which produces electron beams up to 40 MeV. This new facility delivers secondary radiation of different kinds. Special emphasis will be given to the production of intense THz radiation from its Free-Electron Lasers (FEL). This radiation will be used for various research activities including the life sciences. Two additional femtosecond Ti:sapphire laser systems allow to exploit different methods of THz generation for such investigations.

Key words: Dynamics in biomolecules, free-electron laser, IR-beam diagnostic, THz-radiation

1. Introduction

At the Forschungszentrum Rossendorf (FZR) at Dresden, a superconducting ELectron accelerator with high Brilliance and low Emittance (ELBE) has been built and provided the first beam in May 2001 [1]. It will accelerate electrons up to 40 MeV at a maximum beam power of 40 kW. This new facility will deliver secondary beams of different kinds. Intense bremsstrahlung will be used to investigate resonance fluorescence in nuclei up to high excitation with the potential of polarization studies and production of neutrons (0.1–10 MeV) used for cross section measurements. Starting in 2003, the electron beam of ELBE will be used mainly to drive a FEL system providing radiation of 5 to about 150 μm. A mid-IR FEL covering the 5–25 μm range is based on a hybrid undulator structure (U27) consisting of permanent magnets and high permeability iron. The 20–150 μm range will be covered by a Halbach-type undulator (U50) constructed at ENEA/Frascati [2] and installed in a collaboration between the two laboratories. Pulse lengths will be a few ps at a repetition rate of 13 MHz. For biomedical research ELBE will also be equipped to generate channeling X-radiation (generated by passing the electron beam through single crystals) synchronously with the IR-pulses.

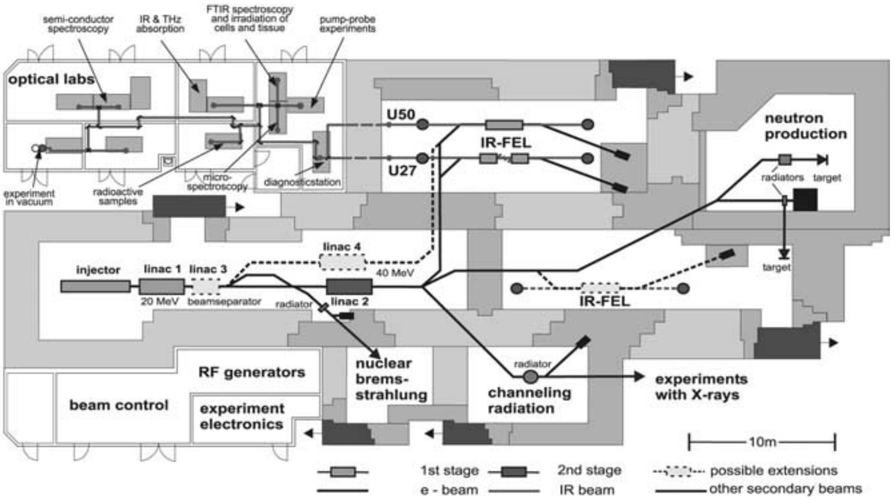

Figure 1. Floor plan of ELBE.

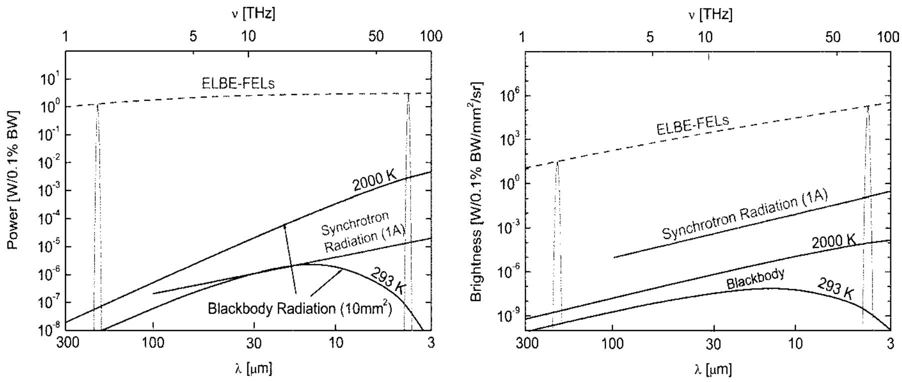

Figure 2. Spectral power and brightness of the ELBE-FEL as compared to a black body radiator and an IR-beam from a typical synchrotron bending magnet.

2. IR-Production at ELBE

Figure 1 shows the floor plan of the ELBE (accelerator vault to the left). The acceleration structures consist of superconducting niobium cavities developed at DESY in Hamburg. At ELBE they have reached acceleration gradients of about 12 MV/m for cw operation. To deliver an electron beam of 1 mA to the FEL, an injector based on a thermionic dc gun has been installed. Two-color pump-probe experiments will use either a tandem-undulator or a synchronisation to conventional pulsed lasers.

Numerical simulations developed for existing FEL facilities predict the power and power density (i.e. brightness; based on a pulse length of $20 \cdot \lambda$) for the ELBE FELs as shown in Figure 2. The maximum energy of an extracted single laser pulse is estimated to be about 4–5 μJ (about 50 W average in cw operation). Its width is given by $\Delta\nu/\nu = \Delta\lambda/\lambda = 1/2N_u$ with N_u the number of undulator periods

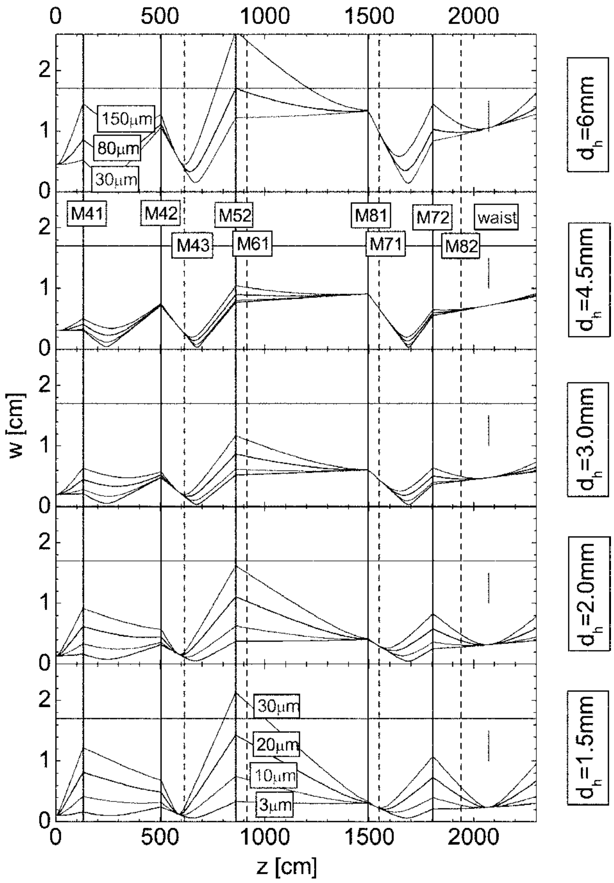

Figure 3. Variation of the beam radius w from the diagnostic station into one of the user laboratories (to experiment in vacuum, see Figure 1) calculated for different wavelengths and hole diameters d_h in the outcoupling mirror of U27. Solid vertical lines: curved mirrors, dashed lines: planar mirrors.

and the beam is fully linearly polarized. The centroid can be shifted continuously and the peak power follows the broken line. With U27 and U50, ELBE will produce IR beams of a brightness similar to that of VUV and X-rays from modern synchrotrons. As compared to thermal sources, the ELBE FELs will deliver up to 7 orders of magnitude higher brightness. With respect to the recently installed synchrotron IR-beamlines the gain, between 5 and about 150 μm, is still several orders of magnitude larger.

The resonator of U27 is equipped with exchangeable mirrors with four different outcoupling holes varying from 1.5 mm up to 4.5 mm in diameter. U50 has a single outcoupling hole 6 mm in diameter. The THz radiation in the range of 2–100 THz will be transported from the outcoupling holes to a diagnostic station and further to six laboratories by reflective optics (see Figure 1). The FEL beams pass through a thick wall protecting the optical laboratories from bremsstrahlung and other radiation produced in the FEL cave. The beams enter the diagnostic station for power monitoring, optional attenuation, and wavelength measurement using a Czerny-Turner type spectrometer equipped with a 48-channel pyroelectric linear array detector. More sensitive measurements can be performed by MCT or Ge-Ga detectors using the second exit slit of the spectrometer. The diagnostic system [3] includes a second-order autocorrelator set-up for measuring the pulse duration. A polarization rotator consisting of three metal mirrors as installed at FELIX [4] allows to change the polarization continuously. A semiconductor plasma switch [5] excited by a synchronized Nd: Vanadate/YAG laser/amplifier system serves to reduce the micropulse repetition rate from 13 MHz to 2 kHz–1 Hz. The transport system is designed to produce a magnified image of the outcoupling hole, in a defined location in each laboratory. Spot size and position are independent of the wavelength and linear polarization is conserved. The beam profiles predicted from detailed wave and ray optical calculations are shown in Figure 3. Each of the six user stations will be equipped with optical tables, optics, detectors and interfacing with the FEL control room. A broad range of ancillary equipment, such as additional lasers synchronized with the FEL, cryostats, high-field magnets and spectrometers will be available. A special laboratory for the preparation of living cells is in operation. With two femtosecond Ti:sapphire laser-systems different methods of THz-generation for such investigations will be exploited. The synchronization of these lasers to the FELs allows pump-probe studies with the potential to study the pre-equilibrium sub-ps stage of biomolecules. With such experiments we aim at characterising lipid protein interactions in heptahelical receptors which play a crucial role in hormone signalling, neurotransmission and other cellular signalling events. Correspondingly, the knowledge of their physico-chemical properties is required in drug development. In 2003, a high-resolution vacuum Fourier-transform spectrometer will be combined with the different THz/ IR-radiation sources to investigate μs-structural dynamics in biomolecules using the step-scan mode. To reduce heating problems of sensitive samples, the micropulse repetition rate can be reduced as mentioned above.

3. Conclusions

The THz region of the EM spectrum and especially the ‘THz gap’ may thus be covered by a fully tunable high-brightness radiation source with a versatile pulse sequence, with the option of bandwidth and pulse width variation. The radiation is fully linearly polarized. Interaction between THz radiation and biological tissue may be exploited in the production of images, but it is likely that micro-spectroscopy using near-field techniques will yield comparable benefits [6]. In these and in many other applications the high brightness and the other outstanding properties of THz radiation from a FEL will be of great advantage.

Table I. Parameter of the ELBE-FELs

Parameter	Undulator	
	U27	U50 (mod)
Undulator period λ_u [cm]	2.73	5.0
Number of periods N_u	2×34	45
Undulator parameter K_{rms}	0.3–0.81	0.4–1.2 (1.6)
Wavelength λ [μm]	3–25	20–150
Pulse length τ [ps]	0.3–3	1–10
Extracted max. pulse energy [μJ]	5	5
Extr. max. average power [W]	60	60

References

1. Gabriel, F., Gippner, P., Grosse, E., Janssen, D., Michel, P., Prade, H., Schamlott, A., Seidel, W., Wolf, A., Wuensch, R. and ELBE-crew: The Rossendorf Radiation Source ELBE and its FEL Projects, *Nucl. Instr. and Meth. B* **161-163** (2000), 1143–1147.
2. Gallerano, G.P., Doria, A., Giovenale, E. and Renieri, A.: Compact Free Electron Lasers: From Cerenkov to Waveguide Free Electron Lasers, *Infrared Phys. & Tech.* **40** (1999), 161–174.
3. Seidel, W., Grosse, E. and Wohlfarth, D.: Diagnostic Station for the ELBE-FELs, Annual Report 2001, *FZR* **341** (2002), 34–35.
4. Knippels, G.M.H. and van der Meer, A.F.G.: FEL Diagnostics and User Control, *Nucl. Instr. and Meth. B* **144** (1998), 32–39.
5. Haselhoff, E.H., Knippels, G.M.H. and van Amersfoort, P.W.: Slicing Single Micropulses at FELIX, *Nucl. Instr. and Meth. A* **358** (1995), ABS 28–29.
6. Knoll, B. and Keilmann, F.: Near-Field Probing of Vibrational Absorption for Chemical Microscopy, *Nature* **399** (1999), 134–137.