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ELBE Center for High-Power Radiation Sources

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Abstract: In the ELBE Center for High-Power Radiation Sources, the superconducting linear electron accelerator ELBE, serving two free electron lasers, sources for intense coherent THz radiation, mono-energetic positrons, electrons, γ-rays, a neutron time-of-flight system as well as two synchronized ultra-short pulsed Petawatt laser systems are collocated. The characteristics of these beams make the ELBE center a unique research instrument for a variety of external users in fields ranging from material science over nuclear physics to cancer research, as well as scientists of the Helmholtz-Zentrum Dresden-Rossendorf (HZDR).

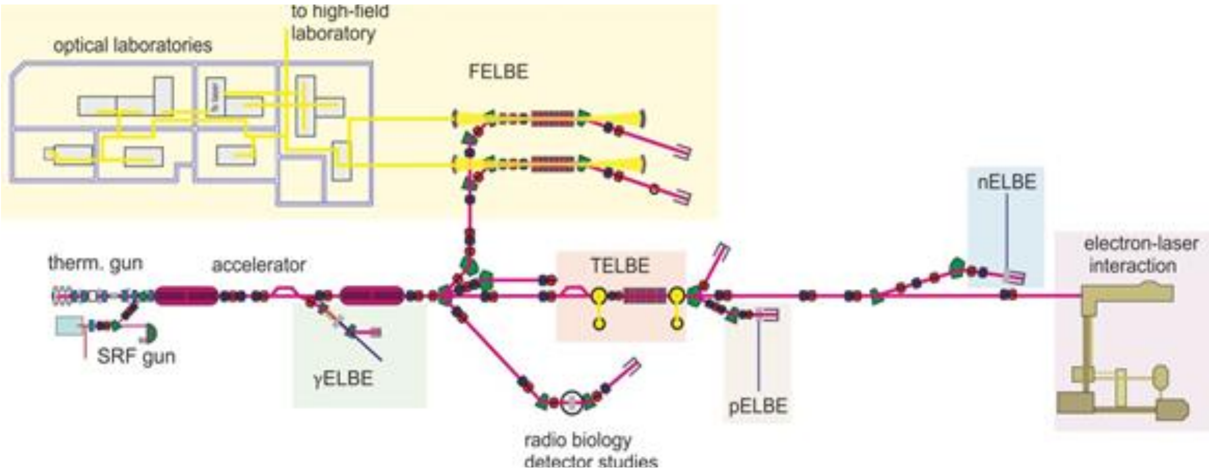

Figure1: Layout of the ELBE Center accelerator and beamlines: FELBE: infrared radiation from Free Electron Lasers; gELBE: Bremsstrahlung; TELBE: coherent THz radiation; pELBE: positrons; nELBE: neutrons, direct electron beams for radio biology and detector studies; Petawatt lasers Draco and Penelope with electron - laser interaction area.

1 ELBE Superconducting Electron Linear Accelerator

The Radiation Source ELBE is based on a superconducting linear accelerator that can be operated in high average-power mode (quasi continuous wave mode, CW). Electrons are pre-accelerated in a 250 keV-thermionic DC electron gun and are pre-bunched in a two-stage RF-buncher section. The main accelerator consists of two 20 MeV superconducting linear accelerator modules operating at 1.3 GHz which are cooled with liquid helium. The RF power is generated by transistor amplifiers, controlled by the low level RF system. With an electromagnetic chicane between the modules, the micropulse duration and energy spread of the beam can be optimized. The accelerator is mainly controlled by the control system, and the electron beam parameters can be measured by multiple diagnostic tools (Teichert et al. , 2006, 2014 and Michel et al., 2008 and Gabriel et al., 2000).

SPECIFICATIONS OF THE ELBE LINAC

Max. energy	36 MeV
Max. current	1.6 mA
Micro-pulse repetition rate	13 MHz/2^n up to single pulse n=0, 1, 2...6
Micro-pulse length	1 - 10 ps
Macro-pulse repetition rate	1 - 25 MHz or CW
Macro-pulse duration	0.1 - 40 ms
Max. bunch charge thermionic gun	100 pC
Max. bunch charge SRF gun	1 nC (goal)

2 Free-Electron Laser FELBE

The free-electron-laser facility, FELBE, provides picosecond infrared pulses. Two free-electron lasers cover the mid- and far-infrared spectral range from 4 - 250 μm.

FELBE SPECIFICATIONS

The FELBE user labs are equipped mainly for time-resolved spectroscopy. The following additional equipment is available for users:

- Various table-top NIR and THz sources that can be synchronized to FELBE
- Setups for single-color and two-color pump-probe experiments
- Time-resolved photoluminescence measurements
- Near-field spectroscopy and Fourier-transform infrared spectroscopy
- 8 T split-coil magnet with optical access
- Pulsed magnetic fields up to 70 T (150 ms magnetic pulse duration) due to an optical transfer line to the adjacent Dresden High Magnetic Field Laboratory
  (Mittendorff et al., 2015 and Ozerov et al., 2014 and Dienst et al., 2013 and Kehr et al., 2011 and Beck et al., 2013)

3 High-Field High-Repetition-Rate THz Facility TELBE

A new facility for the generation of low-frequency, high-field THz pulses, covering the lower THz range between 0.1 and 3 THz, is currently being commissioned. The fundamental generation principle is based on superradiance from electron bunches that are appropriately shorter than the inverse frequency of the desired THz pulse. Pulses from TELBE will be carrier-envelope-phase stable and can be provided at flexible repetition rates between a few tens of Hz to 13 MHz. The accelerator will be operated in a new high-charge mode, providing bunch charges up to 1000 pC and pulse energies up to 100 µJ.

TELBE SPECIFICATIONS

Radiator type	charge /pC	Reprate /KHz	Pulseenergy /µJ	Bandwidth /%	field cycles /number
Undulator	< 100	≤ 1.3 x10^4	1	~20	8
	< 1000	≤ 500	100	~20	8
Diffraction Radiator	< 100	≤ 1.3 x10^4	0.25	100	1
	< 1000	≤ 500	25	100	1

The TELBE laboratory is equipped for time-resolved spectroscopy:

- Two femtosecond laser systems
- THz spectrometers
- High-field THz source based on optical rectification
- Different end stations for time-resolved THz pump-probe experiments
- 10 T split-coil magnet with optical access

User operation with preliminary parameters is envisaged to start in 2016 (Gensch, 2013 and Tavella, Stojanovic, Geloni, Gensch, 2011).

4 Mono-Energetic Positron Source pELBE

Positron beams of variable kinetic energy and with adjustable repetition rate are used for positron annihilation lifetime studies (PALS) and Dopplerbroadening spectroscopy (DBS). Both techniques allow for depth-dependent defect characterization studies in thin films, porosimetry, and basic research on positron and positronium annihilation. Bunched positron beams are generated by means of pair production from high-energy electron bremsstrahlung (max. 36 MeV) produced inside a converter from the superconducting LINAC. Positrons are injected into a tungsten moderator, then thermalized and extracted at a fixed kinetic energy of 2 keV and transported by magnetic guiding fields to the measurement area. Before reaching the sample under study, the positron beam is rebunched and post-accelerated to the desired energies. The repetition rate can be adjusted in order to cope with various annihilation lifetimes of up to about 150 ns. With variable positron kinetic energies samples can be investigated from the surface to a depth of about 2 µm.

pELBE SPECIFICATIONS

Energy	0.5 - 20 keV
Repetition rate	1.625, 6.5, 13 MHz
Intensity	$5 \cdot 10^5$ / s

EXEMPLARY EXPERIMENTS

- Pore size distributions in micro-porous gas-separation membranes
- Porous structure of ultralow-k dielectrics for semiconductor applications
- Structural and thermal vacancies in metal alloys
- Defect-induced ferromagnetism in diluted magnetic oxides (Jungmann et al., 2013 and Elsayed, Krause-Rehberg, Anwand, Butterling, Korff, 2011 and Liedke et al., 2015 and Beck et al., 2013)

5 Bremsstrahlung Facility gELBE

Electron energy range	6 - 16 MeV
Flux on niobium foil target (2 cm) for production of γ-rays	10^9 s^{-1} (max. average current 0.7 mA)
Collimator	2.60 m long high-purity Al tube
Detectors	4 HPGe detectors surrounded by BGO escape suppression shields
Detector geometry	2 detectors at 127°, (relative to the incident beam) 2 detectors movable between 90° and 127°
Mounting of other detectors	LaBr, BaF possible

γELBE is particularly suitable for:

- Photon scattering and photodissociation experiments
- Gamma-induced positron spectroscopy (GiPS) using positron annihilation lifetime studies (PALS)
- Tests of photon detectors at high energies (Massarczyk et al., 2014 and Makinaga et al., 2014).

6 Neutron Time-of-Flight Facility nELBE

HZDR operates the world‘s only photoneutron source at a superconducting electron accelerator. Intense beams of fast neutrons with a repetition rate of more than 100 kHz are produced for high-resolution time-of-flight measurements with a background-free flight path in the range of 4-11 m. Experimental setups include:

- Elastic and inelastic neutron scattering
- Neutron-induced fission
- Transmission measurements of the total neutron cross section (Beyer et al., 2014 and Schillebeeckx et al., 2012).

7 Direct Electron Beam in Air

The direct electron beam may exit the vacuum chamber through a thin beryllium window. As the beam can be used in air, dedicated detector tests are possible as well as irradiation of living cells, thus enabling radiobiological experiments. A biological cell laboratory located close-by can be made available to users.

SPECIFICATIONS OF THE ELECTRON BEAM

Beam property	Operation mode	Value
Number of bunches/ s	CW	$13 \cdot 10^6 / 2^n$; n=0,1, 2, ...6
	single-pulse mode	$1 - 1.3 \cdot 10^7$
	single electrons	$1 - 10^5$
Charge/ bunch	CW	≤ 7.77 pC
	single-pulse mode	~1 fC - ~100 pC
	single electrons	1 - 20 elementary charges
Jitter of reference clock	all	≈35 ps

Exemplary Experiments:

- Detector time resolution in the picosecond range
- Rate characterization capability of detectors up to MHz/cm^2
- Recombination loss in gas- and liquid-filled ionization chambers
- Cell culture response to electron pulses of ultra-high pulse dose rate
  (Wang et al., 2013 and Naumann, Kotte, Stach, Wüstenfeld, 2011 and Karsch, Pawelke, 2014 and Laschinsky et al., 2013)

8 High power lasers Draco and Penelope

Advanced accelerator research on laser plasma based schemes and related secondary radiation sources is performed with the two independently operated Petawatt laser systems Draco and Penelope. With Draco building on commercial Ti:Sapphire ultra-short pulse laser technology, experimental areas for the investigation of high contrast laser-solid and laser-gas interaction are provided and presently offered to users on a collaborative basis. Joint experiments with synchronized laser and electron beams are supported. Penelope exploits unique energy efficient direct diode laser pumping technology and will provide higher pulse energies at unprecedented pulse repetition rate, optimized for ion acceleration studies.

	Draco dual beam	Penelope (under construction)
Technology	Ti:Sapphire	Diode pumped Yb:CaF2
Pulse parameters	30 J / 30 fs	150 J / 150 fs (available 2017)
	3 J / 30 fs	15 J / 150 fs (available 2016)
Repetition rate	up to 10 Hz	up to 1 Hz

(Zeil, et al., 2010, 2013 and Siebold, Röser, Löser, Albach, Schramm, 2013 and Jochmann, et al., 2013)

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