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THE ELBE RADIATION SOURCE PROJECT*

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The project of the future user facility Radiation Source ELBE is presented, which is being realized in the Forschungszentrum Rossendorf. After several years of intense planning, the year 1996 has brought the final approval of the project and the groundbreaking started at the end of 1997. The first electron beam is expected until the end of this decade.

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1. Introduction

The Forschungszentrum Rossendorf (FZR) is building a superconducting electron linac, which is capable of delivering a high-brilliance cw-beam of 40 MeV and 1 mA with rather low emittance; it will be used to produce bremsstrahlung, channeling radiation etc. Special emphasis at this radiation source ELBE will be given to the production of intense FEL (Free Electron Laser) radiation in different undulators in order to cover the infrared (IR) wavelength range from 5 to 150 micrometers [1]. A schematic layout of the Radiation Source Project ELBE is shown in Fig. 1. In addition to the wide wavelength range being essential for investigations in semiconductor research, physical chemistry and biomedicine, a high average radiation intensity is aimed to facilitate IR-induced modifications of materials and surfaces. By detailed numerical simulations the conditions for high yield lasing are investigated; this includes the study of various electron guns, the role of details of the acceleration process, the beam transport and the influence

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of the undulator and optical resonator parameters. Since ELBE is designed as a user facility, ample laboratory space will be provided. A simultaneous application of FEL infrared light and radiation in different spectral regions (*e.g.* X-rays) is considered.

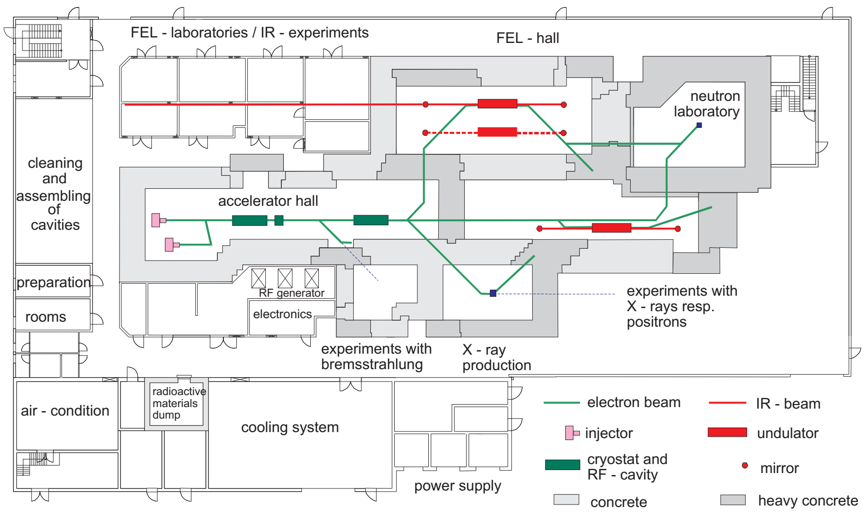

Fig. 1. Schematic plan of ELBE

2. Superconducting acceleration structure

The acceleration structure consists of two nine-cell RF cavities made of superconducting niobium. The cavities have been developed at DESY in Hamburg for the TESLA (Tera Electron Volt Superconducting Linear Accelerator) test facility [2] and will also be used at Rossendorf. First successful tests at DESY showed that acceleration gradients larger than 15 MV/m can be achieved, whereas the ELBE design is based on the rather conservative value of 10 MV/m. Some basic design values of the acceleration structure are listed in the following:

<u>Technical parameters:</u>

- Operation temperature 1.8 K
- Operation frequency 1.3 GHz
- Resonator quality $\approx 10^{10}$
- Acceleration gradient 10 MV/m
- Maximum energy 40 MeV
- Max. average current 1 mA.

The electron injectors

Three electron injectors will be built for this project. Investigations in radiation physics (channeling radiation, parametric X-rays) require a low-emittance electron beam. In this case, bunch charges are of less importance. On the other hand, an electron beam with high bunch charges is needed for operating an FEL.

For the first application, an injector has been designed and built at Rossendorf based on a thermionic gun without direct pulsing of the electron beam [3]. This cw-injector (A,B) has already been tested successfully, *cf.* Fig. 2. In addition, a second injector for the FEL is presently being

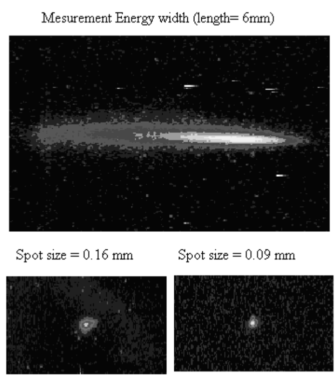

Fig. 2. Beam diagnostic measurements on the cw-injector using the optical transition radiation (OTR).

tested, which works on the basis of a thermionic cathode (C) as used at Stanford University. Furthermore, design work has been initiated for a superconducting RF-gun (D), which is expected to yield an especially high brilliance as needed *e.g.* to perform Compton backscattering studies. More details of the electron injectors are given here:

	A	B	C	D
• Micropulse frequency [MHz]	1300		11.8	11.8/23.6
• Energy width (rms) [keV]	10	7	100	25
• Maximum average current [mA]	1	0.2	1	1
• Normalized emittance [π mm mrad]	1	0.2	13	1
• Maximum bunch charge [pC]	0.77		85	85/42

A:	RF cw-injector,	design values
B:	RF cw-injector,	measured
C:	thermionic injector,	design values
D:	s.c. RF-injector,	design values

3. Free Electron Laser (FEL) user facility

The scientific program at ELBE concentrates on the usage of the 40 MeV electron beam to drive a Free Electron Laser in the far-infrared region. The design of FEL I is based on an electromagnetic undulator, comparable to that of the FIREFLY FEL at Stanford [4]. Its radiation spectrum will cover the region of about 25–150 μm wavelength. Special attention is given to the extension of the spectral range beyond 150 μm by introducing a wave-guide. FEL II will be realized on the basis of a permanent magnet (hybrid) undulator and will produce intense picosecond light pulses in the 5–30 μm region. Fig. 3 displays calculated small-signal gains for both FEL's as a function of the wavelength and for different undulator and beam parameters. It is considered to drive both FEL's parallel with subsequent beam bunches to allow pump-probe experiments with independently tunable wavelengths. Additionally, the possibility of 3$^{\rm rd}$ harmonic operation is studied.

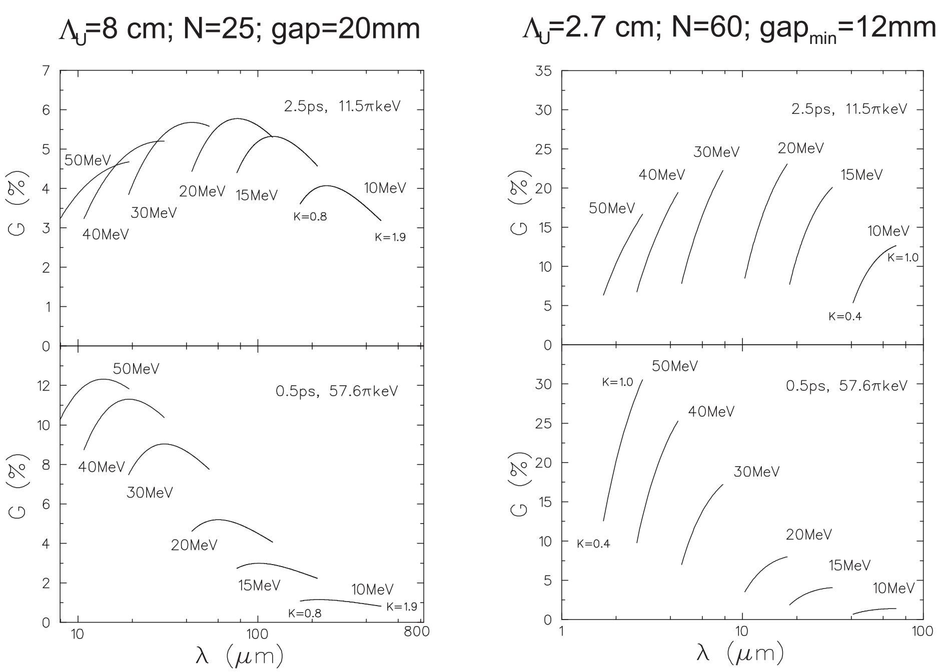

Fig. 3. Small-signal gains of the FEL I (left) and the FEL II (right) as a function of the wavelength λ for various undulator parameters K, different electron energies (in MeV), bunch lengths and energy widths (rms values in ps and πkeV, respectively). Calculations were done with the formula from Ref. [5].

4. Project of an X-ray source

Relativistic electrons travelling through a crystal along a periodic structure (axis or plane) are performing dipole oscillations and spontaneously emit the quasi-monochromatic channeling radiation [*cf.* Fig. 4]. Such a tunable source of X-rays is planned to be installed at ELBE for biomedical applications (*e.g.* CBXMT, DSA) and material research (*e.g.* TRXF, SAS).

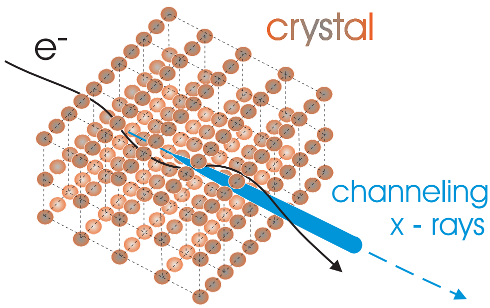

Fig. 4. Schematic view of the generation of channeling radiation.

In order to characterize the experimental conditions for radiation physics investigations at the future ELBE beam, some important features are summarized in the following compilation :

Basic ELBE beam conditions in the X-ray cave:

- Beam energy $E_e = 20$ MeV
- Average beam current $i_e = 100\ \mu$A

Crystal:

- Diamond $d = (55\text{–}80)\ \mu$m
- Crystal plane $\{110\}$
- Lindhardt angle $\Psi_{\rm cr} = 1.84$ mrad

Channeling radiation data expected for the 1–0 transition:

- X-ray energy $E_x = 31.6$ keV
- Photon yield $Y = (0.48\text{–}0.58)$ ph/sr e^-
- Photon rate ($\Delta E/E$=10%) $N_{1/3y} = (4.4\text{–}9.6)\ 10^{10}$ ph/s
- Photon flux $\phi = (2.4\text{–}3.5)\ 10^{14}$ ph/sr s.

The Compton backscattering will be also studied as a possible alternative to the channeling radiation.

Technical equipment:

- UHV goniometer chamber
- Computer controlled 6-axes goniometer(AML)
- Detectors:
  - HpGe (CANBERRA)
  - pin-diode (AMPTEK)
  - CCD-camera (Princeton Instr.).

Fig. 5 displays an example of the measured CCD resolution.

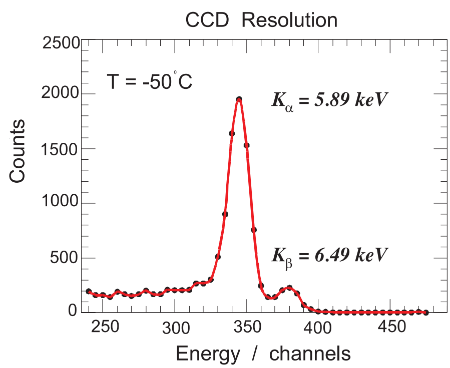

Fig. 5. Example of measured CCD resolution

5. Nuclear Resonance Fluorescence (NRF) experiments

NRF experiments using unpolarized as well as linearly polarized bremsstrahlung represent a powerful tool for a precise, systematic and model-independent investigation of the structure of stable nuclei. By studying collective electric and magnetic dipole excitations, energies, spins, parities and widths of excited nuclear states can be determined. In order to efficiently perform such experiments, a high beam intensity, stability and reproducibility as well as excellent background conditions are needed in combination with highly efficient Ge detectors. All this is planned to be realized at the new ELBE accelerator, which is currently under construction.

The designed set-up is schematically displayed in Fig. 6. The electron beam is transported by a non-dispersive dipole/quadrupole magnet system and focused onto a thin (25–100 μm Al) bremsstrahlung radiator. The steering coils in front of the radiator enable the incidence angle and the incidence direction of the electron beam to be changed in order to optimize the generation of linearly polarized photons. The electrons passing through the thin radiator are finally deflected by a 45° dipole magnet into the beam dump. The (off-axis) bremsstrahlung photons produced in the radiator will be collimated and directed onto the scattering target located approximately 4 m downstream in the experimental hall. This geometry will ensure favourable background conditions. The γ-rays scattered off the NRF target are detected with EUROBALL Cluster modules (see *e.g.* [6]) representing very powerful instruments for NRF experiments in the energy region of interest (about 5 to 10 MeV).

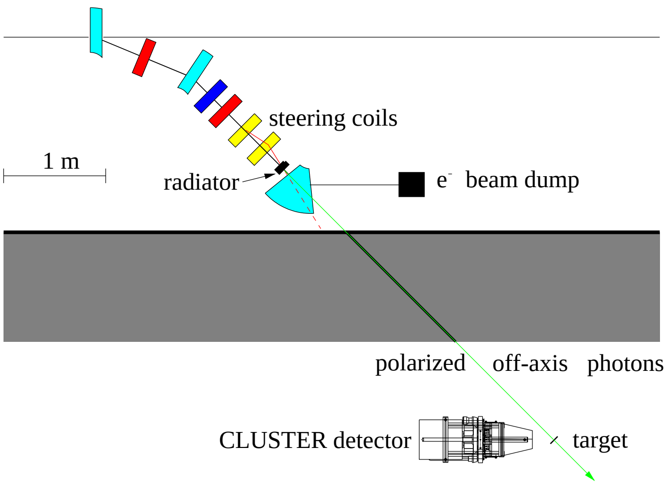

Fig. 6. Polarized bremsstrahlung facility at ELBE

By utilizing average beam currents of the order of 500 μA in the cw-regime, photon fluxes of 5×10^7 photons per MeV $\cdot$ s for 7 MeV photons at $E_{e^-} = 10$ MeV can be expected at the NRF interaction area.

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