OPTICAL BEAM PROPERTIES AND PERFORMANCE OF THE MID-IR FEL AT ELBE

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Abstract

First lasing of the mid-infrared free-electron laser at ELBE was achieved on May 7, 2004. Since then stable lasing has been achieved in the IR range from 4 to 22 μm using electron beam energies from 15 to 35 MeV. At all wavelengths below 20 μm a cw optical power higher than 1 W can be produced with an electron beam of 50 pC bunch charge. The optical pulse width at it's minimum was measured to 0.9 ps at 11 μm and could be increased to 4 ps by detuning the optical cavity. The optical bandwidth was in all cases close to the Fourier limit.

THE ELBE FACILITY

The Radiation Source ELBE [1] at the Forschungszentrum Rossendorf in Dresden is centered around a superconducting Electron Linear accelerator of high Brilliance and low Emittance (ELBE), constructed to produce CW electron beams up to 1 mA beam current at 40 MeV. The electron beam is used to generate various kinds of secondary radiation, mainly to drive free-electron lasers in the infrared.

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Starting 2005, the FEL is operated as a user facility, being open to users worldwide, provided their scientific proposals have been favorably evaluated by the panel responsible for distribution of beam time. Under the name "FELBE" [2] the facility is a member of the EC funded "Integrating Activity on Synchrotron and Free Electron Laser Science (IA-SFS)", which comprises most synchrotron and FEL facilities in Europe and provides financial support to users from the EC and associated states.

MAIN PERFORMANCE PARAMETERS

The U27 oscillator FEL comprises two planar undulator units, both consisting of 34 periods of hybrid permanent magnets with a period of 27.3 mm. The distance between the two undulators is variable and the gaps can be adjusted and tapered independently. This device provides tunable radiation in the spectral range of 450-2500 cm^{-1} (4-22 μm) at 13 MHz pulse repetition rate. At all wavelengths below 20 μm an average optical power exceeding 1 W can be delivered yielding peak energies of several hundred nJ per pulse. Note that above roughly 22 μm the diffraction loss of the optical beam in the vacuum chamber of U27 exceeds the gain. In order to extend the usable wavelength range up to 150 μm (see Fig. 1) the U27 FEL will be complemented by a FIR-FEL using a permanent magnet undulator with a period of 100 mm (U100) by the end of the year 2006.

Table 1: Parameters of the optical resonators

parameter	U27	U100
undulator period λ_U [mm]	27.3	100
number of periods N_U	2*34	38
undulator parameter K_{rms}	0.3 – 0.7	0.3 – 2.7
wavelength λ [μm]	4 – 22	15 – 150
pulse length τ [ps]	0.5 – 4	1 – 10
max. extracted pulse energy [μJ]	2	3
max. extracted average power [W] at cw operation	30	40

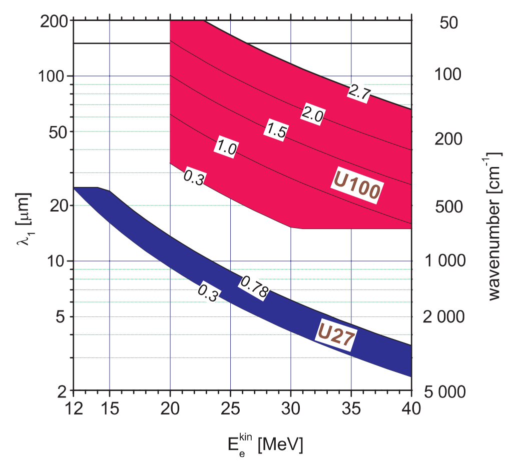

Figure 1: Wavelength ranges λ_1 of the existing U27 and the planned U100 undulator of ELBE as a function of the kinetic electron energy E_e^{kin} calculated for the indicated values of the undulator parameter K_{rms}.

OPTICAL INSTRUMENTATION

The optical resonator of the U27 FEL consists of one fixed and one interchangeable spherical mirror. Both are two-axis angular controllable with 6 μrad angular resolution. The optical resonator length is stabilized using interferometers [3] to detect the mirror positions as shown in Fig. 2. A temperature stabilization of both mirrors will soon be available. The FEL optical beam is fed to an optical table for diagnostics (see Fig. 3) from which it is distributed to the experiment stations. In addition to the pulse structure that can be generated by pulsing the electron beam (minimum 100 μs pulse width at up to 25 Hz repetition rate) a single pulse selection by photo-induced reflection with 1 Hz to 2 kHz repetition rate is in preparation.

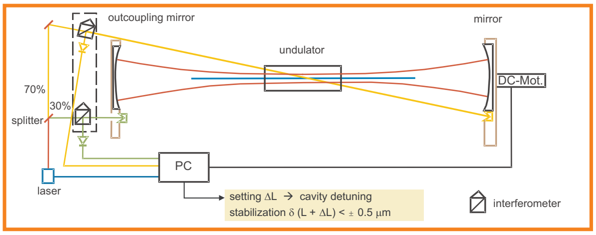

Figure 2: Schematic view of the resonator length control and stabilization system. Its time constant is 1 Hz and hence fast in comparison to the thermal time constant of the resonator.

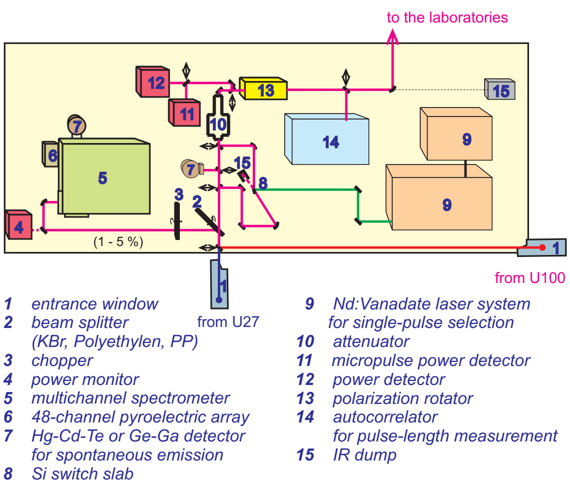

Figure 3: The IR diagnostic table. [4]

CHARACTERIZATION OF THE OPTICAL BEAM

The optical beam properties can be sensitively tuned by varying the length of the optical resonator with respect to the electron bunch repetition rate. At minimum detuning one yields the highest saturated power (see Fig. 4) and the shortest optical pulse length which then closely resembles the electron bunch length. Fig. 5 shows that by detuning the resonator the spectral width can be decreased simultaneously increasing the pulse length.

To characterize the ultrashort pulses generated by the FEL we built a non-collinear background-free autocorrelator system. We use a CdTe crystal as SHG medium, since it is transparent for a wide wavelength range in the FIR. We measured the autocorrelation function at maximum power of the detuning curve at a wavelength of 11.09 μm. We deduce a pulse duration of 0.91 ps (FWHM), assuming a Gaussian temporal pulse shape. The corresponding FWHM of the spectrum is approx. 176 nm. The calculated time-

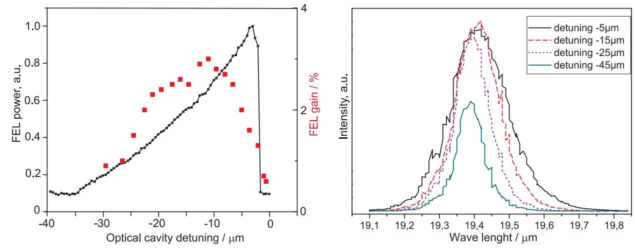

Figure 4: The saturation power (line) and the FEL single-pass gain (dots) (left panel) and the IR spectra (right panel) shown for varying optical cavity detuning.

bandwidth product is about 0.4 which indicates Fourier-transform limited operation.

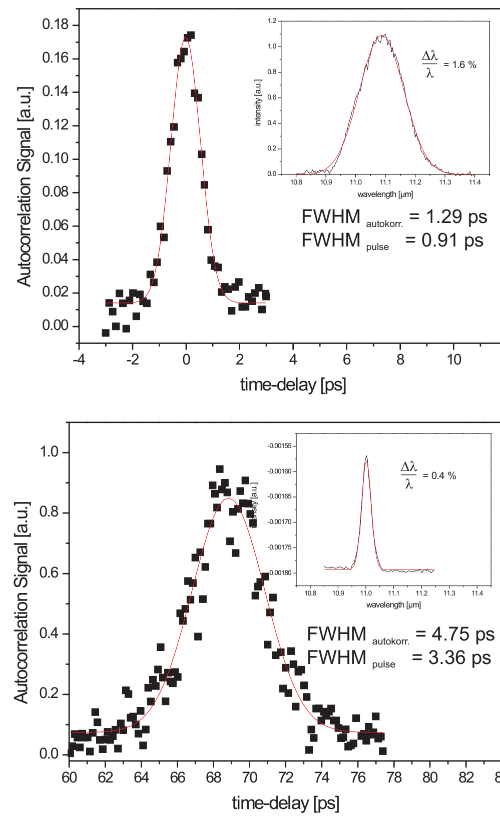

Figure 5: Very short IR pulses can be generated with minimum resonator detuning and a compressed electron bunch. Long IR pulses with narrow bandwidth can be obtained from a detuned resonator.

REFERENCES

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[4] Th. Dekorsky et al. Proceedings 24-th Intern. Free Electron Laser Conf. Argonne, USA, Sept. 9-13, 2002, pp. II-35