STATUS OF THE FRITZ HABER INSTITUTE THZ FEL

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Abstract

The IR and THz FEL at the Fritz Haber Institute (FHI) in Berlin [1] is designed to deliver radiation from 4 to 500 microns. A single-plane-focusing undulator combined with a 5.4 m long cavity is used in the mid-IR (< 50 micron), while a two-plane-focusing undulator in combination with a 7.2 m long cavity with a 1-D waveguide for the optical mode, will be used for the far-IR. A key aspect of the accelerator performance is low longitudinal emittance, < 50 keV-psec, at 200 pC bunch charge and 50 MeV, from a gridded thermionic electron source. We utilize twin accelerating structures separated by a chicane to deliver the required performance over the 15 - 50 MeV energy range. "First Light" is targeted for the centennial of the FHI in October 2011. Installation and commissioning progress to date is described.

INTRODUCTION

The IR and THz FEL shown in Figure 1 is currently being commissioned at the Fritz Haber Institute for applications in gas-phase spectroscopy of (bio-)molecules, clusters, and nano-particles, as well as in surface science. Advanced Energy Systems (AES) has designed and installed the accelerator and electron beam transport system. STI Optronics fabricated the mid-infrared (MIR) undulator with Bestec GmbH delivering the installed MIR oscillator mirror optical equipment. FHI is responsible for the facility, optical transport and user laboratories. In this paper, we describe the design of the electron beam and optical components, together with the progress that has been made in the installation and commissioning of the device within the experimental vault in Berlin.

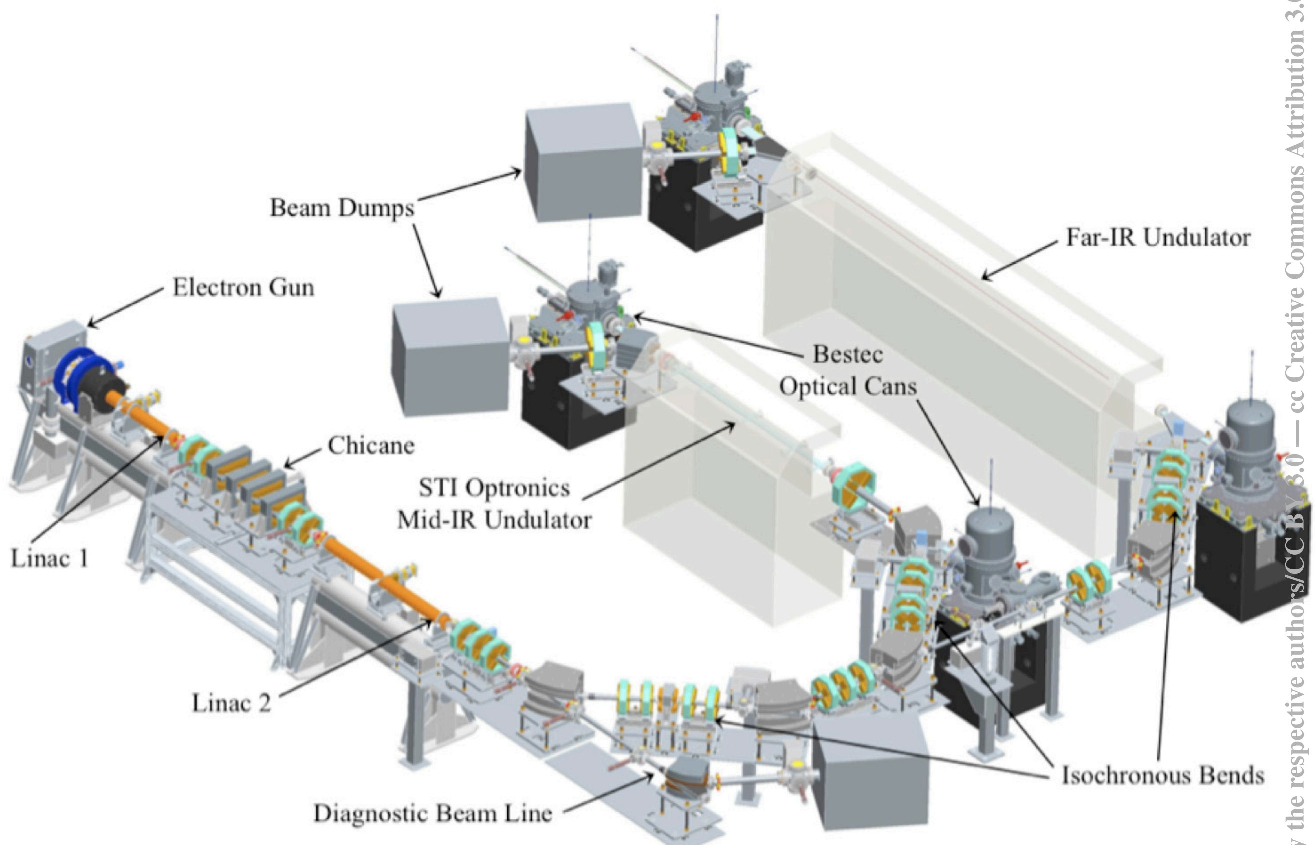

Figure 1: Schematic diagram of Fritz Haber Institute free electron laser showing key components.

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ELECTRON ACCELERATOR

The projected top-level electron beam performance is given in Table 1. The design of the accelerator and beam transport system has been described previously [2,3]. In brief, it consists of a 50 MeV accelerator driven by a gridded thermionic gun with a beam transport system that feeds two undulators and a diagnostic beamline. Two 3 GHz S-band, normal-conducting electron linacs and the gun-to-dump electron beam lines have been designed, fabricated, and installed by AES. The first linac will accelerate the electron bunches to a nominal energy of 20 MeV, while the second one accelerates or decelerates the electrons to deliver any final energy between 15 and 50 MeV. A chicane between the structures allows for adjustment of the bunch length as required.

Table 1: FHI THz FEL Electron Beam Parameters

Parameter	Unit	Specification	Target
Electron Energy	MeV	20 - 50	15 - 50
Energy Spread	keV	50	< 50
Energy Drift per Hour	%	0.1	< 0.1
Charge per Pulse	pC	200	> 200
Micropulse Length	psec	1 - 5	1 - 10
Micropulse Repetition Rate	GHz	1	1 & 3
Micropulse Jitter	psec	0.5	0.1
Macropulse Length	μsec	1 - 8	1 - 15
Macropulse Repitition Rate	Hz	10	20
Normalized rms Transverse Emittance	π mm-mrad	20	20

The final design has optimized the specifications of the linac that are most relevant for the IR and THz FEL performance. For instance, the maximum bunch charge of the micro-pulses, which are repeated at rate of up to 1 GHz, has been increased to 300 pC. In addition, the length of the electron macro-pulses has been increased to 15 μsec. The 3 GHz operation of Table 1 is not implemented at this time.

INFRARED AND THZ OSCILLATOR FELS

The electrons will be steered through either one of two oscillator FELs, each consisting of an undulator placed within an IR cavity. At this time, the MIR-FEL has been installed. It includes a 2-m-long planar hybrid-magnet undulator manufactured by STI Optronics with a period length of 40 mm, which is enclosed within a 5.4 m long IR cavity. At a minimum gap of 16.5 mm, a maximum undulator parameter of more than 1.6 is reached. As a result, it is anticipated that MIR radiation in the range of about 4 up to almost 50 microns can be produced with this system. Since hole-out-coupling of the IR radiation is used, a motorized in-vacuum mirror changer has been installed. It permits the precise positioning of either one of up to 6 cavity mirrors with different out-coupling hole diameters at the one end of the IR cavity. The mirror at the other cavity end is mounted on a translation stage to enable cavity length adjustment and, hence, compensation of potential thermal drifts. The signal from a HeNe-laser interferometer delivers a feedback signal for cavity length stabilization.

The preliminary design of the Far-IR (FIR) FEL has been completed. A 7.2 m long cavity containing a full-length 1-dimensional waveguide and a 4.4 m long undulator with 40 periods of 11 cm period length will be installed. The design wavelength range spans the far IR from about 30 microns all the way to the THz regime of 500 microns or more. Construction and installation of the FIR-FEL is scheduled for 2012.

Table 2: FHI THz FEL Optical Parameters

	MIR	FIR
Undulator		
Type	Planar Hybrid	Planar PPM or Hybrid
Material	NdFeB	SmCo
Period (mm)	40	110
Number of Periods	50	40
Length (m)	2	4.4
K_{rms}	0.5 - 1.6	1 - 3
IR-Cavity		
Length (m)	5.4	7.2
Waveguide	None	1-D 10mm High

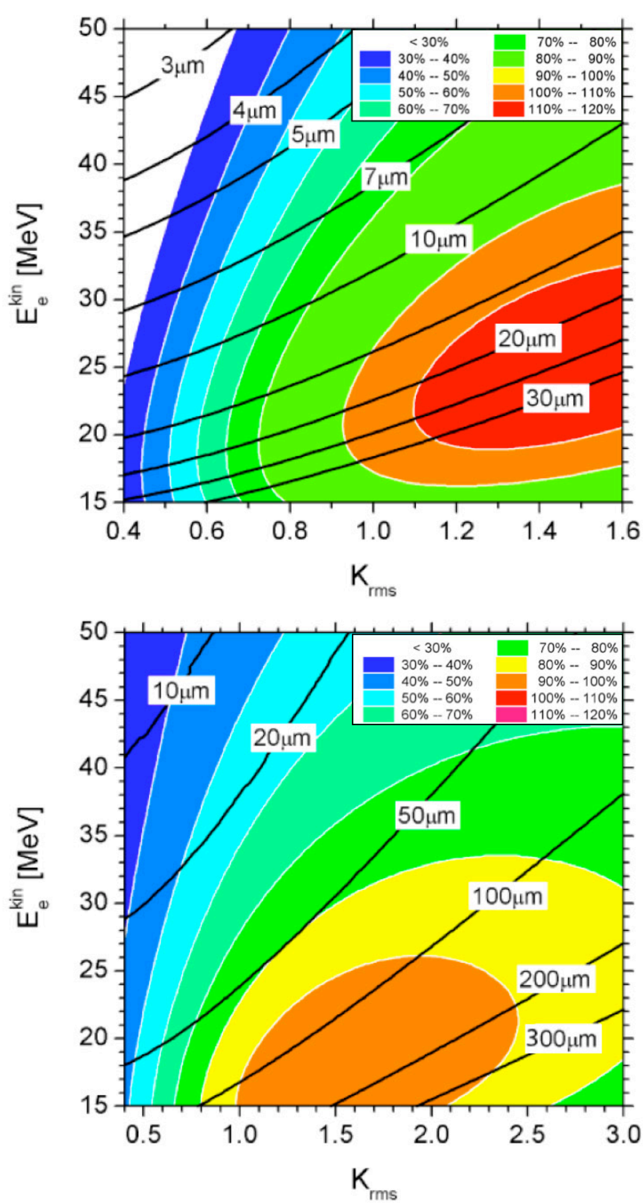

Figure 2: Calculated wavelength and small-signal gain for 3 psec long electron bunches of 50 keV energy spread for (top) the MIR and (bottom) the FIR undulators.

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The design energy of the IR-output is more than 10 µJ per micro-pulse and more than 100 mJ per macro-pulse. This corresponds to an optimized output in terms of milli-joule per micro-second, which is the figure of merit for many gas-phase spectroscopy experiments. The FEL optical properties are summarized in Table 2. Figure 2 displays the projected wavelengths and small signal gains per cavity round-trip, as a function of electron beam energy and the undulator parameter, K. With the expected gain ranging from 30% to more than 100%, lasing should be readily achievable with both, the MIR and FIR FELs.

INSTALLATION AND COMMISSIONING

The facility building with the accelerator vault, which began construction in April 2010, has been completed. Installation has been ongoing since the beginning of 2011. The present status of the FEL, as of early August 2011, is shown in Figure 3. Here we see the electron gun in front left with the two linac structures, separated by the chicane, running to the upper right. The isochronous bends carry the electron beam to the MIR undulator above the electron gun. The undulator and optical chambers, which are difficult to identify clearly in Figure 3, have already been commissioned. Figure 4 shows photographs of the undulator as well as the MIR out-coupling mirrors. The 50-mm-diameter cavity mirrors are made out of gold-coated copper and have out-coupling hole sizes ranging from 0.75 to 3.5 mm. They are mounted to a translational mirror changer, which also allows for precise adjustment of the pitch and yaw angles for easy cavity alignment.

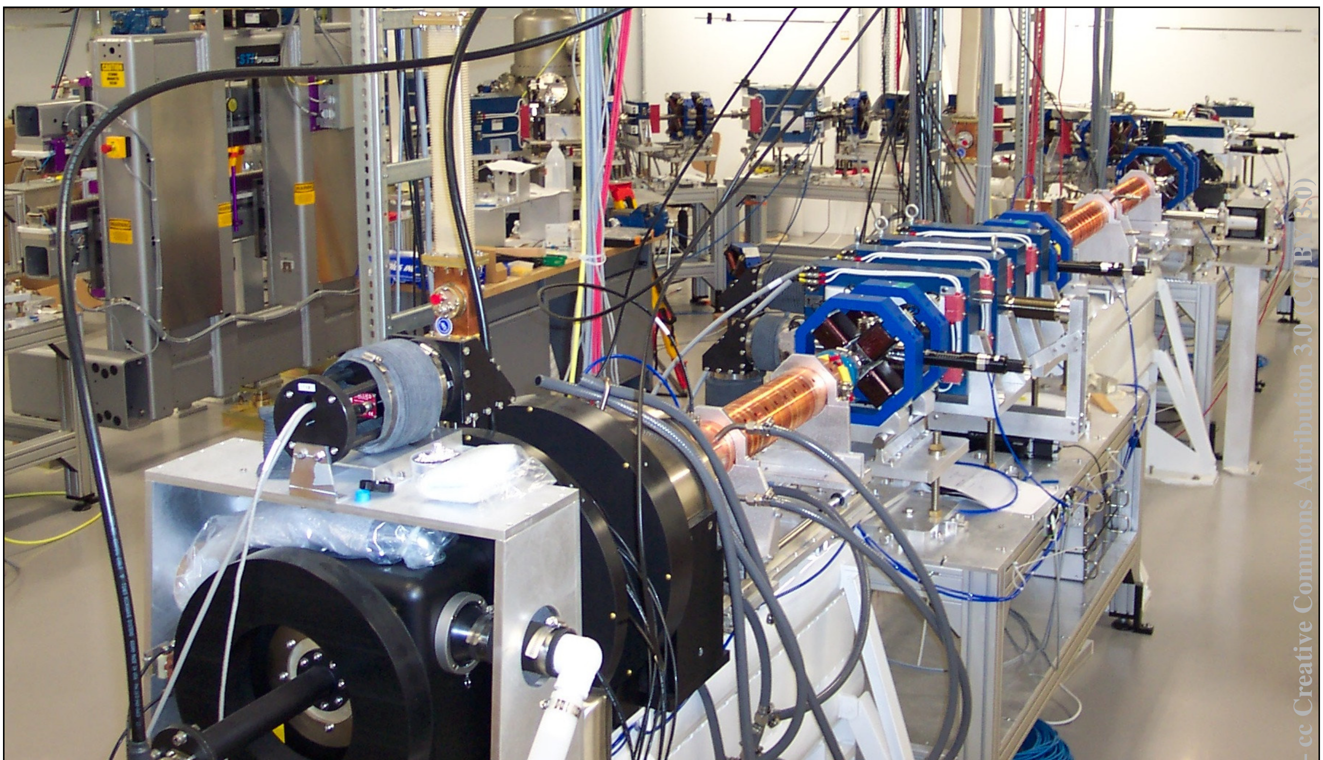

Figure 3: Beamline installation in the vault as of early August 2011.

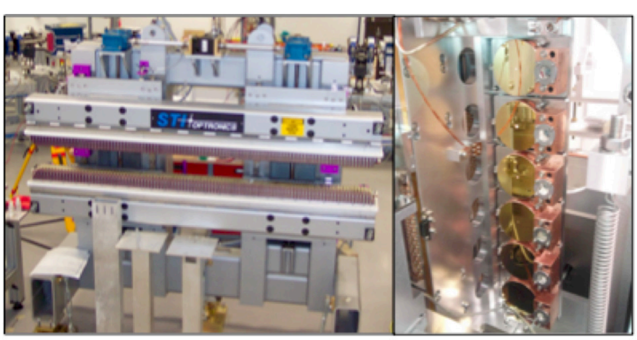

Figure 4: (left) STI Optronics MIR undulator, (right) Bestec mirror changer equipped with 6 gold-coated copper mirrors with different out-coupling hole diameters.

SUMMARY

The FHI THz FEL building facility is completed with only minor external work remaining. Virtually all hardware for the device has been received in Berlin. The linac structures are installed, pumped down and baked. RF conditioning is occurring now. The STI Optronics undulator and Bestec optical system are both commissioned. Beamline commissioning begins September 2011 with "First Light" targeted for October 2011.

REFERENCES

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