COMMISSIONING OF THE FRITZ HABER INSTITUTE MID-IR FEL

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Abstract

The free electron laser (FEL) at the Fritz Haber Institute (FHI) in Berlin [1] is designed to deliver radiation from 4 to 400 microns. A single-plane-focusing undulator combined with a 5.4 m long optical cavity is used for the generation of mid-infrared (MIR) radiation up to 50 microns. A two-plane-focusing undulator, in combination with a 7.2 m long cavity with a 1-D waveguide for the optical mode, is planned for the far-infrared (FIR). Beam was delivered to the MIR beam dump in October 2011 and first light at 18 microns was achieved on Valentine's Day, 2012. We describe progress to date and plans to complete the commissioning of the MIR beamline and the installation of the FIR beamline.

INTRODUCTION

The FHI FEL shown in Figure 1 will be utilized 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 MIR undulator with Bestec GmbH delivering the MIR oscillator mirror optical equipment. The FIR beamline design has not been finalized. FHI is responsible for the facility, optical transport and user laboratories. We describe the achievement of first light at 18 microns and current plans to complete commissioning.

ACCELERATOR COMMISSIONING

The design, fabrication and installation of the FEL has been described previously [2,3,4]. The accelerator system is comprised of a gridded gun followed by a 1 GHz sub-harmonic buncher and two 3 GHz, pi/2 copper linac structures. A chicane between the linacs affords bunch length control of the 20 MeV beam out of linac-1. Linac-2 can then be operated in accel or decel mode to provide beams at 15 to 50 MeV to isochronous bends directing beam to the two undulators or to a diagnostic station.

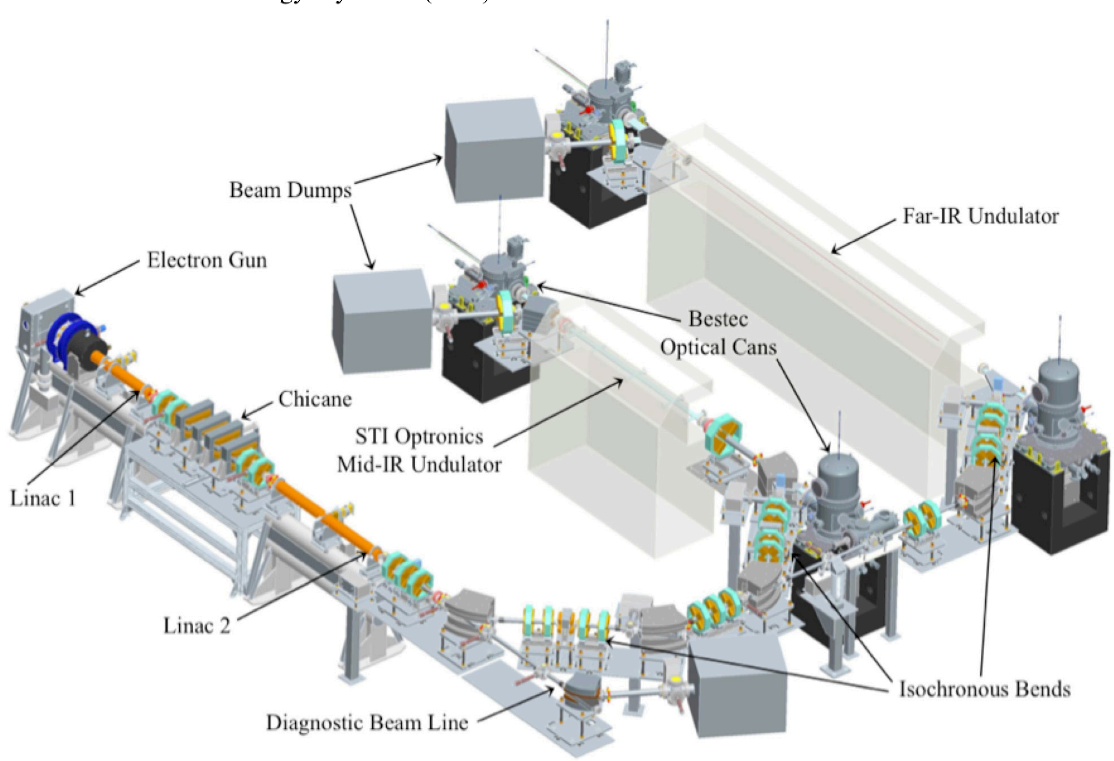

Figure 1: Schematic diagram of the Fritz Haber Institute FEL showing key components.

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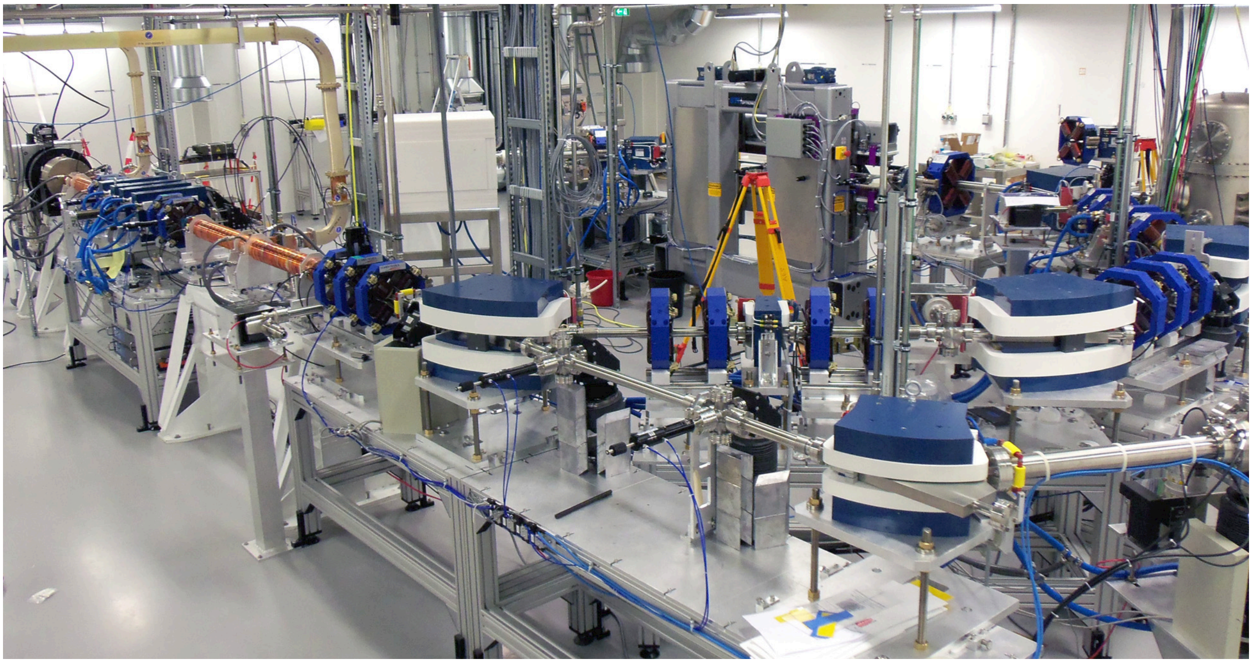

Figure 2: The MIR FEL installation in the FHI vault.

The Figure 2 photograph shows the MIR FEL installation in the FHI vault from roughly the same perspective as Figure 1. The gridded gun is at the upper left. The black items are solenoids around the initial accelerating cells. The two copper linac structures follow with the chicane in between. A quadrupole triplet leads to the first dipole where the diagnostic beamline goes straight through. An isochronous achromat follows with a small reverse 6 degree dipole between the four achromat quadrupoles. There is a quadrupole triplet in the back leg before the second 90 degree isochronous achromat delivers the beam to the 2 m radiation-resistant, wedged-pole, MIR hybrid undulator consisting of 50 periods, each 40 mm long (grey structure, upper middle). This is followed by a 60 degree bend to the white beam dump (upper left). Although not shown here, the FIR beamline is in place up to the wiggler vacuum chamber. The FIR beamline dipole boxes are an integral part of the FIR vacuum chamber and thus not yet finalized.

Table 1: FHI FEL Electron Beam Parameters

Parameter	Unit	Specification	Achieved
Electron Energy	MeV	(15) 20 - 50	20 - 50
Energy Spread	%	(<) 0.1	0.1
Energy Drift per Hour	%	(<) 0.1	TBD
Bunch Charge	pC	(>) 200	215
Micropulse Length	psec	1 - 5 (10)	TBD
Micropulse Repetition Rate	GHz	1	1
Micropulse Jitter	psec	0.5 (0.1)	TBD
Macropulse Length	μsec	1 - 8 (15)	1 - 15
Macropulse Repetition Rate	Hz	10 (20)	1
Transverse RMS Emittance	π mm-mrad	20	TBD

The electron beam performance we are seeking to achieve is given in Table 1. Where a specification value is shown in parentheses, this is a target upgrade parameter and not the base performance of the system. Table 1 also shows the measured performance that has been achieved to date.

We have achieved the energy range but have not yet operated the second accelerator in a decelerating mode to deliver beam energies lower than 20 MeV. The energy spread requirement has been met at 25 MeV but still needs to be demonstrated at full beam energy with the shortest pulse. Currents in excess of the specified 200 pC have already been achieved at the 1 GHz micropulse repetition rate, but we have not yet obtained definitive measurements of the energy drift rate, the micropulse length and jitter, or the transverse emittance. These measurements will be made shortly. We are operating with beam under an administrative limit of 1 Hz due to radiation safety restrictions. This limit should be waived shortly and we will immediately increase the repetition rate to the specification. We have already run the RF system to the full 20 Hz with 15 μsec macropulses without an electron beam.

FEL COMMISSIONING AND FIRST LIGHT

RF conditioning of the accelerating structures began in late August of 2011. First gun operation took place in mid September. By the middle of October, we had succeeded in delivering a 35 pC beam to the MIR beam dump. We continued commissioning until the FHI Centennial on October 28, 2011, but did not have the combination of beam current, bunch length, energy spread and RF stability necessary to achieve first light. Through the remainder of 2011, we made improvements to the low level RF system, increased the delivered RF power to the accelerators, increased the gun current and worked on the energy spread and bunch length.

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At the start of 2012, we began to work towards lasing in earnest. On February 13, as shown in Figure 3, we measured the energy spread of a 25 MeV beam in the diagnostic beamline. The beam spot is ~ 1 mm which yields an energy spread of 0.1% with the given calibration of 10 mm / %.

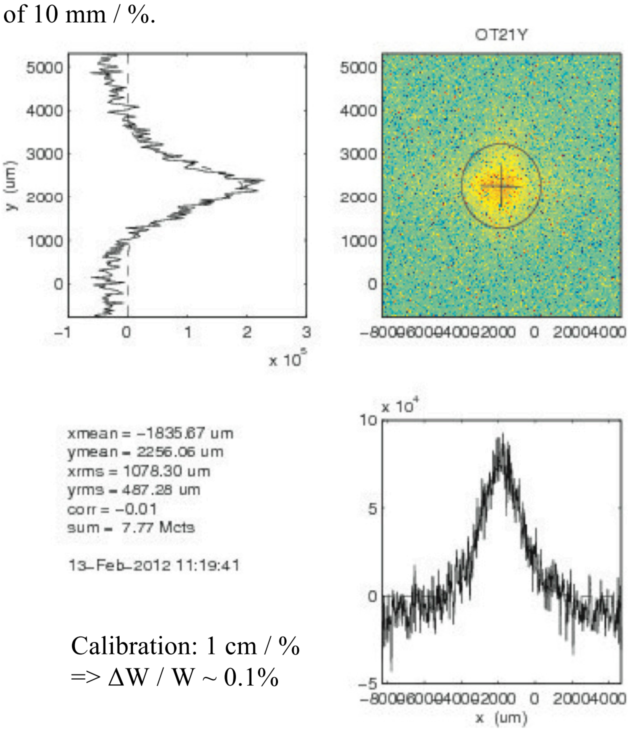

Figure 3: Measurement of 0.1% energy spread at 25 MeV.

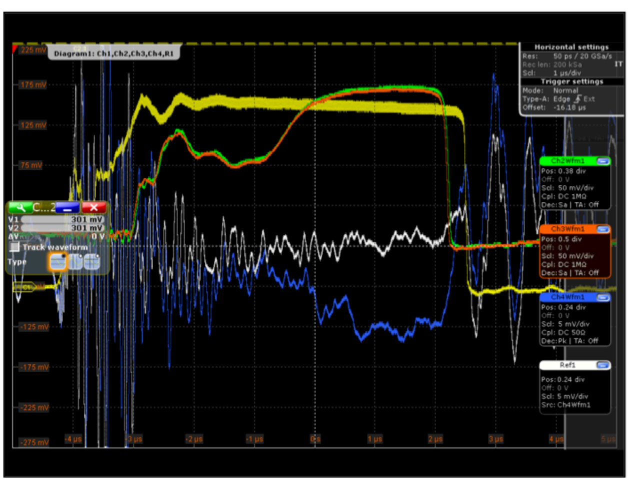

Figure 4: Observation of spontaneous emission with a mercury cadmium telluride (MCT) detector – blue trace.

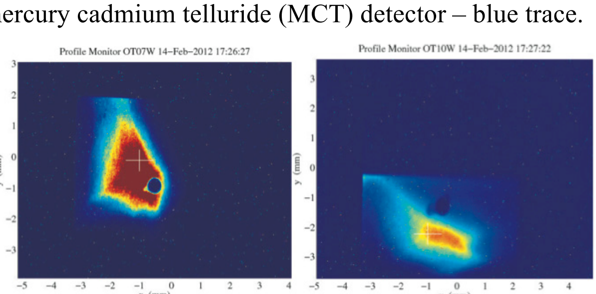

Figure 5: Electron beam spots at wiggler entry (left) and exit (right) flags. White crosshairs are the optical axis.

On running beam through the wiggler, spontaneous emission was observed in Figure 4. The following day, at 28 MeV, we worked to align the electron beam in the wiggler. The beam spots at the entry and exit of the wiggler are shown in Figure 5. With a wiggler gap of 20 mm corresponding to a wiggler parameter K_{rms} = 1.22, we achieved first light at 18 microns. This is shown in Figure 6. The MCT detector trace is blue, the current toroid signal indicating 210 mA (corresponding to 210 pC) is red, while the green and yellow traces are the sub-harmonic buncher phase and amplitude.

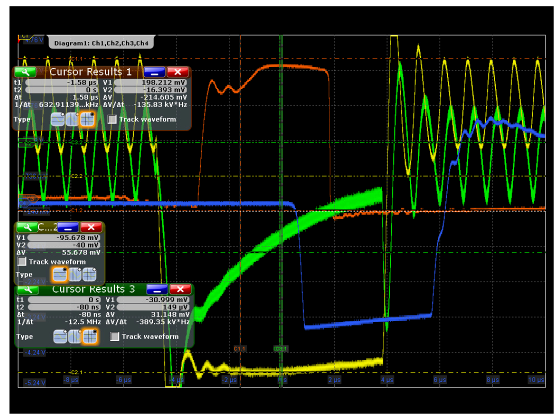

Figure 6: Blue MCT detector signal confirming first light.

In addition to lasing success, the green curve of Figure 6 indicates significant phase slew in the sub-harmonic buncher. We were also experiencing problems with one of the two klystrons. Commissioning was thus halted and both these components were returned for repair. They have recently returned to FHI and the final commissioning push to acceptance will begin shortly.

SUMMARY

The MIR beamline of the FHI FEL has been completed and commissioning started. The design of the FIR beamline has not been finalized. Beam was first delivered to the MIR beam dump in mid October 2011 just before the FHI Centennial. First light at ~ 18 microns was achieved on February 14, 2012. Following equipment upgrades and repairs to key components, the final push to mid-IR acceptance will begin in May, 2012

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