A.8: Saturation of lasing in the Infra-Red Free Electron Laser (IR-FEL) at RRCAT

The Infra-Red Free Electron Laser at RRCAT, designed to lase in the 15 – 50 µm wavelength band, employs an electron beam of energy, variable from 15 – 25 MeV, and a 2.5 m long, pure-permanent magnet undulator. The first signature of lasing was observed in the setup in November 2016, with an out-coupled power estimated to be ~ 10^5 times the expected spontaneous power output for the electron beam parameters used in the experiment (K.K. Pant et al., Current Science, 114-2 (2018), 367-373). Saturation of lasing could not be achieved then since the electron beam parameters achieved did not fully meet the design parameters.

The injector system of the IR-FEL was upgraded in the second half of 2019 with a new electron gun, and with the addition of an S-band pre-buncher, an S-band accelerating buncher and a 3 m long S-band travelling-wave linac. A new low-energy beam transport line (LEBT) was also built. This upgrade resulted in a doubling of the peak electron beam current delivered at the undulator to more than 60 A, from the earlier value of less than 30 A. Figure A.8.1 shows the IR-FEL setup with the upgraded injector system.

Fig. A.8.1: IR-FEL setup with upgraded injector.

Commissioning experiments with the upgraded system resulted in the first observation of saturation of the IR-FEL, with a measured out-coupled continuous wave (CW) average power ~ 7 mW at a pulse repetition rate (PRR) of 2 Hz (Sona Chandran et al., NIMA 1003 (2021) 165321). The power output was, however, not very stable. An upgrade of the sub-harmonic pre-buncher vacuum system and optimization of the LEBT resulted in a significant improvement in the stability with a higher peak current. In recent experiments, an out-coupled CW average power of 19 mW at 2 Hz PRR has been regularly achieved at 23 µm wavelength, with a power stability within ± 5%. Figure A.8.2 shows the variation of the measured power with time. The peak power at saturation is estimated to be more than 2.5 MW in 10 ps full width at half maxima (FWHM) pulses, which is ~ 10^7 times the expected spontaneous power for the electron beam parameters of the experiment.

Figure A.8.3 shows the transverse optical mode profile, measured at 0.5 m from the out-coupling hole using a pyrocam (Ophir Spiricon, Pyrocam IV).

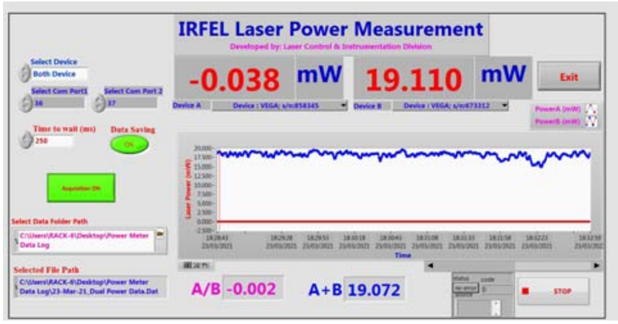

Fig. A.8.2: Time variation of out-coupled power.

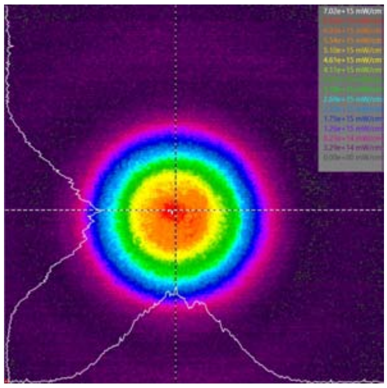

Fig. A.8.3: Transverse optical mode profile.

More recently, tunability of operation from 12.5 to 38 µm wavelength has been demonstrated by simultaneously varying the electron beam energy and the undulator parameter. Figure A.8.4 shows the tuning curves for the IR-FEL. The out-coupled power beyond 30 µm is relatively low, and optimization is presently underway to increase this to more than 5 mW with the wavelength range extended up to 50 µm.

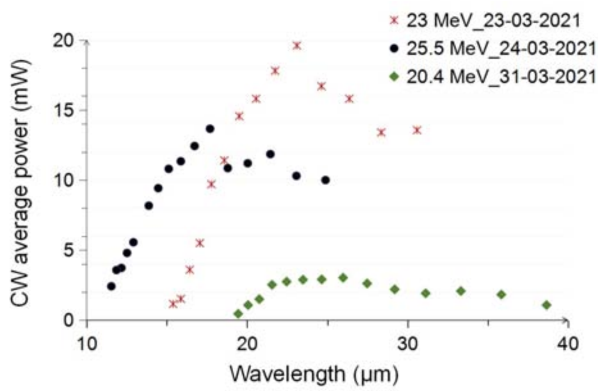

Fig. A.8.4: Tunability of operation of the IR-FEL.

Efforts are also currently underway to transport the IR radiation to the user area for experiments.

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