Novosibirsk terahertz free electron laser: Facility development and new experimental results at the user stations

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Abstract—**The Novosibirsk FEL (NovoFEL) generates tunable monochromatic coherent radiation as a continuous stream of 100-ps pulses with a repetition rate of up to 11.2 MHz and average power of up to 500 W. After commissioning of the second laser resonator in 2010, the spectral ranges of 120-240 μm and 40-80 μm are available to users. A review of experimental results for the past year is given.**

I. NOVOFEL

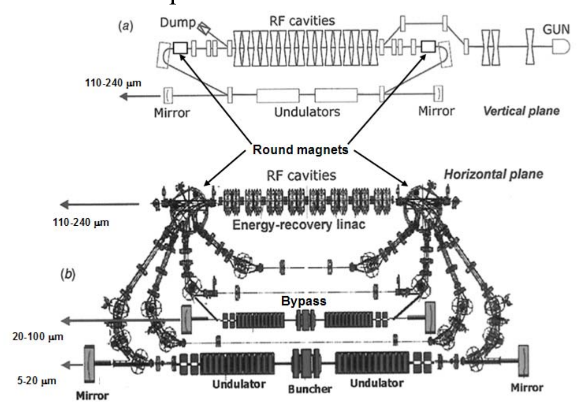
In the Budker Institute of Nuclear Physics of the RAS Siberian Branch the creation of powerful FEL based on four-track energy recovery linac (ERL) with a maximum energy of 40 MeV is close to completion. The planned range of wavelength is between 240 and 5 μm, the expected radiation power varies from 1 kW in the long-wave range up to 10 kW in the short-wave range.

The first stage of Novosibirsk high power free electron laser (NovoFEL) had been commissioned in 2003. It is CW FEL based on non-superconducting low frequency (180 MHz) single-pass accelerator-recuperator with the following parameters. Electron energy – 12 MeV, charge per bunch – 1.5 nC, bunch repetition rate – 5.6 ÷ 22.5 MHz, maximum average current – 30 mA, bunch duration – 40 – 100 ps.

The radiation spectral range is 110 – 240 μm at the first harmonic, 60 – 117 μm and 40 – 80 μm at the second and third harmonics correspondingly. Maximum average power is up to 0.5 kW for the first harmonic. Maximum peak power is 1 MW, and repetition frequency 5.6 and 11.2 MHz. Relative spectral width is 0.25 – 1%. The radiation is completely spatial coherent, the degree of linear polarization is better than 99.6%.

To move to the region of higher frequencies of the terahertz range, the second stage of the free electron laser (FEL) is created.

Novosibirsk energy recovery linac has rather complicated magnetic system. One orbit for 12-MeV energy with terahertz FEL lies in vertical plane.



Other four orbits are in the horizontal plane. The beam is directed to these orbits by switching on of two round magnets. In this case electrons pass four times through acceleration RF cavities, obtaining 40-MeV energy. Than, (at the fourth orbit) the beam is used in FEL and decelerated four times.

At the second orbit (20 MeV) we have bypass with second FEL. When magnet of bypass are switched on, the beam passes through this FEL. The length of bypass is chosen to provide the delay, which necessary to have the deceleration instead acceleration at the third passage through acceleration cavities.

Now two of four horizontal orbits are assembled and commissioned. The electron beam was accelerated twice and then decelerated down to low injection energy. First multi-orbit ERL operation was demonstrated successfully.

The first lasing of the FEL at bypass was achieved in 2009. The radiation wavelength range now is 40-80 micron. The maximum gain was about 40%. The significant (percents)

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increase of beam losses took place during lasing. Therefore sextupole corrections were installed to some of quadrupoles to make the 180-degree bends second-order achromatic. It increased the energy acceptance for used electron beam.

Now the output power is about 0.5 kW at the 9 mA at the 9 mA ERL average current. Thus, the first in the world multiturn ERL operates for the far infrared FEL.

Laser radiation is transmitted from THz FEL and bypass FEL through nitrogen-filled optical beamlines to the experimental hall. To provide ultrahigh vacuum in the FEL and accelerator-recuperator, their vacuum volume is separated from the beamlines with the diamond window. Six user stations (metrology station, photochemistry station, biological station, introscopy and spectroscopy station, molecular spectroscopy station, gasdynamics station) are in use now for experiments.

II. Experiments

Unique features of NovoFEL radiation, from one hand, require development of techniques for radiation imaging and characterization and, from other hand, enable the development of new metrological methods and techniques.

Our center has developed various experimental equipment for the THz range. First of all, there was developed a number of terahertz imaging techniques based on the relatively high power of radiation. We develop and apply 2D imaging systems of various types. There are commercially available thermal image plates of Macken Instruments Inc. and piroelectric cameras Pirocam III of Spiricon Inc. with 120x120 pixels and 12x12 mm in size.

The uncooled vanadium oxide 320x240 microbolometer focal plane array (MBFPA) was applied to direct recording “terahertz video” with frequency up to frames per second.

Spectral investigation can be made with three types of spectral devices: high resolution simple mesh Fabry-Perot interferometers; grating monochromators, which are especially useful for on-line spectral adjustment and harmonics measurement, and Bruker Fourier spectrometer for fine spectral measurements in a broad spectral range.

Keeping time-resolved experiments in mind, we have developed Schottky diode detector of two types: a fast detector with high sensitivity and ultra-fast detector. The latter device has now a rise time of about 20 ps and we plan to decrease the value in the near future. The detector allows us to observe and investigate a time structure of a single FEL pulse, which is very important for measurement of FEL parameters and their optimization.

In 2010, work on the FEL involved employees of Budker Institute of Nuclear Physics SB RAS, the Institute of Chemical Kinetics and Combustion SB RAS, the Institute of Cytology and Genetics SB RAS, the Institute of Inorganic Chemistry SB RAS, Rzhanov Institute of Semiconductor Physics. SB RAS, the Institute of Theoretical and Applied Mechanics SB RAS, the Technological Design Institute of Scientific Instrument, and the Scientific-Technological Center of Unique Instrumentation RAS (Moscow) as well as teachers, students and graduates of Novosibirsk State University and Novosibirsk State Technical University.

The themes of works using NovoFEL THz radiation in 2010-2011:

1. Study of the spectrum of electronic states in Si / CaF_2 BaF_2 / PbSnTe:In nanoheterostructures.
2. Investigation into the interaction of THz radiation with new functional resonant metamaterials for devices controlling the polarization, phase, intensity and direction of propagation of radiation.
3. Metamaterials based on precision micro- and nanoshells for terahertz and infrared ranges.
4. Investigation into the interaction of THz radiation with materials based on carbon nanotubes.
5. Production of carbon nanostructures with the help of NovoFEL radiation.
6. Determination of the fractional composition of nanoproducts of mechanical activation of double oxsides.
7. Exploration of composite silicon-polymer nanostructures.
8. Spectroscopy of attenuation total reflection (ATR).
9. Plasmon spectroscopy of surfaces and films.
10. Development of physical foundation of tomography, holography and metrology using a source of coherent monochromatic THz radiation.
11. Development of methods for flame diagnostics using the THz FEL.
12. Study of the impact of THz radiation on genetic material.
13. Exploration of the impact of THz radiation on stress-sensitive biological cell systems.
14. THz radiation influence of the katG and E.coli dps genes.
15. Study of the integrated proteomic response of E.coli to exposure by terahertz radiation.

Conclusion

At present, intense work on the creation of powerful FELs (> 1 kW of average power) is carried out worldwide. For the purposes of industrial applications, it is necessary to reach the average power level of about 10 kW.

In some cases, the problem is a rather wide radiation spectrum (usually, not less than 1-3%). For some industrial applications (for example, isotope separation) the required monochromaticity should be not worse than a few hundredths of percent.

The Novosibirsk terahertz free electron laser is becoming a user facility. We invite those researches who want to perform interesting experiments with a high power monochromatic coherent tunable THz radiation to carry out them in Novosibirsk.

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