CHARGED PARTICLE ACCELERATORS

STATUS OF THE NOVOSIBIRSK TERAHERTZ FEL

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The first stage of Novosibirsk high-power free-electron laser (FEL) was commissioned in 2003. It is based on a normal conducting CW energy recovery linac. Now the FEL provides electromagnetic radiation in the wavelength range of 120…180 micrometers. An average power is 400 W. The minimum measured line width is 0.3%, which is close to the Fourier-transform limit. A user-beamline assembly is in progress, parts of the full-scale machine are manufactured. The latter will operate in the near IR region and provide higher average power.

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1. INTRODUCTION

A new source of terahertz radiation has been recently commissioned in Novosibirsk [0]. It is a CW FEL based on an accelerator–recuperator (AR), or an energy recovery linac (ERL). It differs from the earlier ERL-based FELs [0], [0] in the low frequency non-superconducting RF cavities and longer wavelength operation range. The full-scale Novosibirsk FEL is to be based on a four-track 40 MeV accelerator-recuperator (see Fig.1). It is to generate radiation in the range 3…80 μm [0], [0].

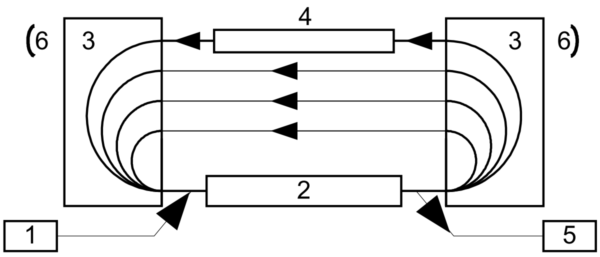

Fig.1. Scheme of the accelerator-recuperator based FEL. 1 – injector; 2 – accelerating RF structure; 3 – 180-degree bends; 4 – undulator; 5 – beam dump; 6 – mirrors of the optical resonator

2. INJECTOR

An electron source is a 300 keV DC gun with a grid cathode. The electron gun consists of:

- a cathode-grid unit driven by a controlled pulser;
- an electrostatic accelerating tube placed in a high-pressure vessel with insulating SF_6 gas;
- a 300 kV DC power supply;
- control electronics inside the high-voltage terminal with the optical link.

Basic parameters of the gun are:

Electron energy (kinetic)…...300 keV;
Current:
Peak……………….1.7 A;
Average……………40 mA;
Normalized emittance……….20π mm·mrad;
Repetition rate……………….0...22.5 MHz;
Pulse duration………………..1.1 ns;
Operation mode……………...CW.

The grid cathode of the commercial RF tube is used as a source of short electron bunches. The domestic-made pulser provides 1.2 ns 100 V pulses at the cathode (the grid is grounded). As such pulse (bunch) duration is long enough for the RF acceleration at a frequency of 180 MHz, bunch compression is necessary. The simplest way to compress a bunch is the use of klystron bunching at the same frequency. The gun voltage of 300 kV is a trade-off between suppression of the space charge induced emittance degradation and the possibility to compress the bunch in the drift space without any magnetic buncher. The RF voltage on the bunching cavity is about 100 kV. Two accelerating cavities are installed after a 2.5 m-long drift gap. These cavities increase the beam energy to 1.7 MeV and compensate the correlated energy spread gained in the bunching cavity.

3. ACCELERATOR-RECUPERATOR

The first stage of the machine has a full-scale RF system, but only one backward track. Layout of the AR is shown in Fig.2.

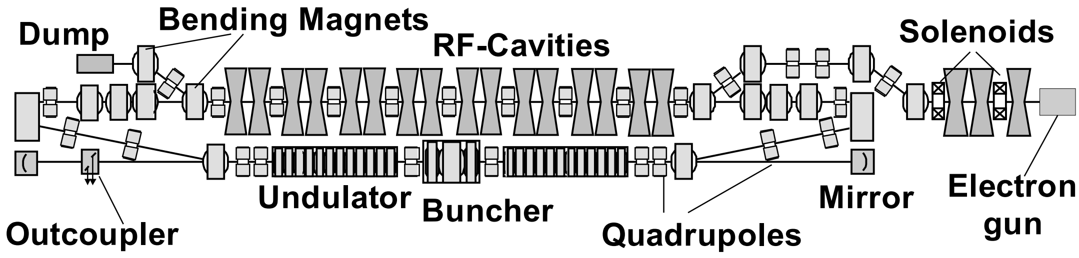

Fig. 2. Scheme of the first stage of the Novosibirsk high power FEL

A 2 MeV electron beam from the injector passes through the accelerating structure acquiring the 12-MeV of energy, and enters the FEL installed in the straight section. After a beam-radiation interaction within the FEL, the beam passes once more through the accelerating structure, returns the power, and enters the beam dump at the injection energy. Main parameters of the accelerator are listed below:

RF frequency………………….180 MHz;
number of RF cavities………...16;
RF voltage at one cavity………0.7 MV;
injection energy……………….2 MeV;
final electron energy ………..12 MeV;
max. bunch repetition rate…….11.3 MHz;
max. average current ………..20 mA;
beam emittance………………..2 mm•mrad;
final energy spread, FWHM…..0.2%;
final bunch length……………..0.1 ns;
final peak current……………..10 A.

4. FEL

A terahertz FEL is installed on the single backward track of the AR. The FEL consists of two undulators, a buncher, two mirrors of optical resonator, and an outcoupler. Both undulators are identical. They are electromagnetic planar ones, 4 m in length, period 120 mm, gap 80 mm, and K up to 0.8. The buncher is simply a three-pole electromagnetic wiggler. It is used to phase the undulators between each other. Both mirrors are identical, spherical, made of polished copper, and water cooled. The outcoupler contains two adjustable planar copper mirrors. These mirrors scrape radiation inside the optical resonator and redirect a small part of it to the consumer. The outcoupler was used during commissioning to optimize the parameters of FEL. Now radiation is extracted through an optimal hole in the mirror. Basic parameters of the FEL are listed below:

Wavelength……………………….0.12...0.18 mm;
min. relative linewidth, FWHM….$3\cdot10^{-3}$;
pulse length, FWHM……………..50 ps;
peak power……………………….0.4 MW;
repetition rate…………………….11.3 MHz;
max. average power………………0.4 kW.

5. OPTICAL BEAMLINE AND USER STATIONS

To transmit the radiation from the front mirror to user stations, a 13-m beamline guiding THz radiation from the accelerator hall to the user stations had been constructed. Since water vapor has a great number of absorption lines in the sub-millimeter spectral range, the beamline is isolated from the atmosphere and filled out with dry nitrogen. The beamline is separated from the accelerator vacuum by a 0.6-mm diamond window and from the atmosphere with a polyethylene film. Until this summer, the only user station had been available. Now a number of connection points are ready and a set of dedicated stations are being manufactured: a chemical user station, a high power density user station, a biological user station, and an atmosphere study station.

We use several types of THz detectors. A mechanically scanned bolometer is a precise, but extremely slow detector. A FIR-NIR converter (FNC) employs temperature growing of a thin-film screen exposed to terahertz radiation. Two-dimensional field of temperature at the screen surface is recorded with a thermograph SVIT, which has a 128×128 InAs focal plain array (FPA) sensitive to the radiation within the spectral range of 2.6…3.1 µm. Thermograph sensitivity at the room temperature is 0.03ºC at the frame frequency up to 40 Hz. In our case time resolution was restricted by thermal relaxation of the thermoconverter and the frame frequency in the experiments was 10 Hz.

Another technique used for the visualization of terahertz images is the Thermo-Optical Detector (TOD). The technique employs the change of the optical length of a medium, which is transparent for probe visible light but is opaque for the terahertz radiation, when the medium is exposed to the terahertz radiation.

Other possible techniques (not in the use yet) are: thermal line quenching of fluorescer, direct detection with Shottky diodes, and an array of thermal sensors.

6. EXPERIMENTS WITH FEL

Only a few experiments are mentioned here due to the lack of space.

6.1. HIGH POWER DEMONSTRATIONS

A continuous optical discharge was obtained when a laser beam had been focused with a parabolic mirror (f=1.0 cm). Power density was at least an order of value less than it requires by Raiser's theory. The discharge appears with some delay that, probably, indicates a role of statistical effects.

Ablation of PMMA in an argon flow at the atmospheric pressure was demonstrated. Non-focused laser beam drilled a conical opening in 60-mm plexiglass in 3 minutes. No combustion was observed.

6.2. COHERENCE

A transverse coherence of the FEL radiation was clearly demonstrated by classical interference pattern recorded with the thermograph when two large aluminum mirrors, positioned at a small angle, reflect the laser beam on the carbon-paper screen placed at the distance of 1.8 m.

A diffraction experiment with two circular apertures enables to compare calculated diffraction pattern with the pattern recorded with the thermograph. Two openings were 6 mm in diameter and spaced in horizontal direction at a distance of 14 mm. The diffraction pattern at the distance of 1.08 m is shown in Fig.3,*a*. The ratio of initial intensity of THz radiation at the openings was 9:20.

In order to find out the wavelengths and widths of radiation spectrum, a rotating Fabris-Perrout interferometer was used. The typical interference picture is shown in the Fig.3. By varying the undulator magnetic fields we obtained a stable lasing in the range 120…180 μm. Now, the spectrum relative width is about $3\cdot10^{-3}$. The corresponding value of the coherence length $\lambda^2/2\Delta\lambda$ = 20 mm is close to the electron bunch length.

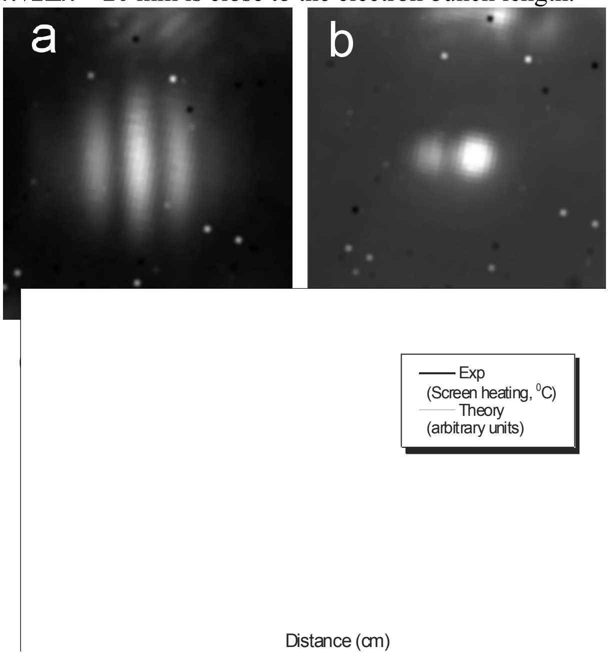

Fig.3. The diffraction pattern (a) produced by two circular apertures (b), Ø = 6 mm, Λ = 14 mm a1.08 m from the screen, is recorded by the thermograph. The plot (c) shows experimentally observed and theoretically calculated intensity profiles. The latter was calculated for λ = 0.16 mm

6.3. ULTRA-SOFT LASER ABLATION OF BIOLOGICAL POLYMERS

Ultra-soft ablation of DNA samples without denaturation was demonstrated. When the power density of THz radiation was optimal, particle size spectra contained only peaks corresponding to the initial particles. For higher power densities multi-peak spectra were observed.

Ultra-soft ablation was also demonstrated for proteins. Ferment kept its reactivity after ablation and condensation.

CONCLUSION

Stable operational characteristics of the Novosibirsk free electron laser and transmission of high power terahertz radiation through the beamline to the user facility hall indicate the beginning of the conversion of the terahertz FEL from the experimental facility to the user facility. First experiments carried out on the facility have demonstrated its great potentiality for experiments in optics, high-energy-density science and other applications.

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СТАТУС ТЕРАГЕРЦОВОГО ЛСЭ В НОВОСИБИРСКЕ

В.П.Болотин, Н.А.Винокуров, Д.А.Кайран, Б.А.Князев, Е.И.Колобанов, В.В.Котенков, В.В.Кубарев, Г.Н.Кулипанов, А.Н.Матвеенко, Л.Е.Медведев, С.В.Мигинский, Л.А.Мироненко, А.Д.Орешков, В.К.Овчар, В.М.Попик, Т.В.Саликова, С.С.Середняков, А.Н.Скринский, О.А.Шевченко, М.А.Щеглов

В 2003 году в Новосибирске заработала первая очередь мощного лазера на свободных электронах (ЛСЭ). Машина построена на базе линака-рекуператора непрерывного действия. В настоящее время ЛСЭ работает в диапазоне длин волн 120…180 мкм, его средняя мощность достигает 400 Вт. Минимальная измеренная ширина полосы излучения составляет 0.3%, что близко к теоретическому минимуму. В настоящее время монтируются каналы разводки излучения для пользователей, части полномасштабной машины запущены в производство. Полномасштабная машина будет работать в ближнем ИК-диапазоне и обладать большей мощностью.

СТАТУС ТЕРАГЕРЦОВОГО ЛВЕ В НОВОСИБІРСЬКУ

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В 2003 році в Новосибірську заробила перша черга потужного лазера на вільних електронах (ЛВЕ). Машина побудована на базі лінака-рекуператора безперервної дії. Зараз ЛВЕ працює в діапазоні довжин хвиль 120...180 мкм, його середня потужність досягає 400 Вт. Мінімальна виміряна ширина смуги випромінювання становить 0.3%, що близько до теоретичного мінімуму. Зараз монтуються канали розведення випромінювання для користувачів, частини повномасштабної машини запущені у виробництво. Повномасштабна машина буде працювати в ближньому ІЧ-діапазоні і мати більшу потужність.