FIRST EXPERIMENTAL RESULTS OBTAINED USING THE HIGH-POWER FREE ELECTRON LASER AT THE SIBERIAN CENTER FOR PHOTOCHEMICAL RESEARCH

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The first lasing near the wavelength of 140 μm was achieved in April 2003 using a high-power free electron laser (FEL) constructed at the Siberian Center for Photochemical Research. In this paper we briefly describe the design of the FEL driven by an accelerator–recuperator. Characteristics of the electron beam and terahertz laser radiation, obtained in the first experiments, are also presented in the paper.

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1. INTRODUCTION

A new source of terahertz radiation was commissioned recently in Novosibirsk. It is the CW FEL based on an accelerator–recuperator, or an energy recovery linac. The terahertz FEL is the first stage of a bigger installation, which will be built in three years and will provide shorter wavelengths and higher power. The facility will be available for users in 2004. The first radiation study results are discussed in this paper

2. ACCELERATOR – RECUPERATOR

Full-scale Novosibirsk free electron laser is to be based on the multi-orbit 50 MeV electron accelerator-recuperator. It is designed to generate radiation in the range from 3 μm to 0.3 mm [1,2]. The first stage of the machine contains a full-scale RF system, but has only one orbit. Layout of the accelerator–recuperator is shown in Fig.1. The 2 MeV electron beam from an injector passes through the accelerating structure, acquiring 12 MeV energy, and comes to the FEL, installed in the straight section. After interaction with radiation in the FEL the beam passes once more through the accelerating structure, returning the power, and comes to the beam dump at the injection energy. Main parameters of the accelerator are listed in Table 1.

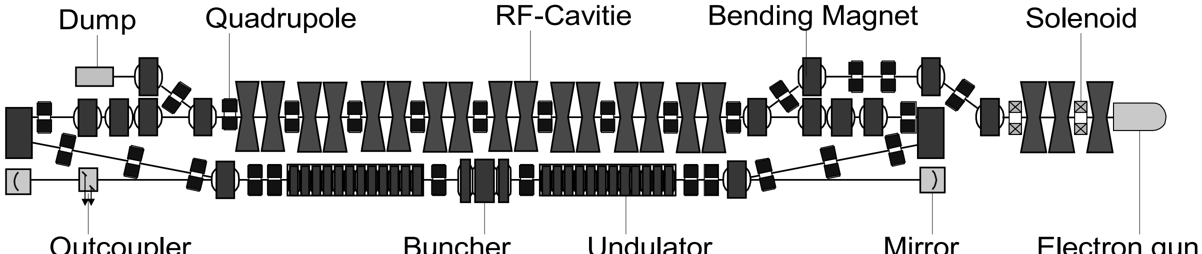

Fig.1. Layout of the first stage of the Novosibirsk high-power free electron laser

The FEL is installed in a long straight section of a single-orbit accelerator-recuperator. It consists of two undulators, a magnetic buncher, two mirrors of the optical resonator, and an outcoupling system. The both elec-

Table 1. Accelerator parameters (the first stage)

RF wavelength, m	1.66
Number of RF cavities	16
Amplitude of accelerating voltage at one cavity, MV	0.7
Injection energy, MeV	2
Final electron energy, MeV	12
Bunch repetition rate, MHz	1.4…22.5
Average current, mA	2…40
Beam emittance, mm·mrad	1
Final electron energy spread, %	1
Final electron bunch length, ns	0.02…0.1
Final peak electron current, A	40…10

tromagnetic planar undulators are identical. The length of the undulator is 4 m, period is 120 mm, gap is 80 mm, and deflection parameter K is up to 1.2. One can use one or both undulators with or without a magnetic buncher. The buncher is simply a three-pole electromagnetic wiggler. It is necessary to optimize the relative phasing of undulators. The both laser resonator mirrors are identical, spherical**,** 15 m curvature radius made of gold plated copper, and water-cooled. There is a 35 mm diameter hole in the center of each mirror. The hole serves for mirror alignment (using He-Ne laser beam) and output of a small amount of radiation. The distance between mirrors is 26.6 m. The outcoupling system contains four adjustable planar 45 copper mirrors (scrapers). These mirrors cut the tails of Gaussian eigenmode of the optical resonator and redirect radiation to the calorimeters. This scheme preserves the main mode of the optical resonator well and reduces amplification of higher modes effectively.

3. FEL COMMISSIONING

For FEL commissioning we used the both undulators. The beam average current was typically 5 mA at a repetition rate of 5.6 MHz, which is the round-trip frequency of the optical resonator and 32-th subharmonics of the RF frequency $f \approx 180$ MHz. Most of measurements were performed without scrapers recording the radiation flux from one of the mirror apertures. Instead of fine tuning of the optical resonator length we tuned the RF frequency. The tuning curve is shown in Fig.2.

Typical results of spectrum measurements with rotating Fabri-Perot interferometer [3] are shown in Fig.3. They were used to find both the wavelength and the linewidth of radiation. Radiation wavelengths were in the range from 120 to 180 μm depending on the undulator field amplitude. The shortest wavelength is limited by the gain decrease at a low undulator field, and the longest one – by the optical resonator diffraction loss increase. Relative linewidth (FWHM) was near $3\cdot10^{-3}$. The corresponding coherence length $\lambda^2/2\Delta\lambda = 2$ cm is close to the electron bunch length, therefore we, probably, achieved the Fourier-transform limit.

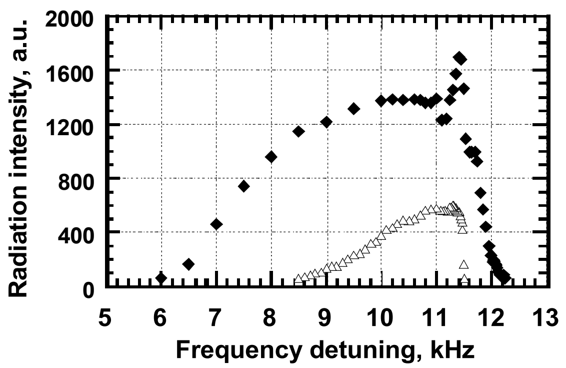

Fig.2. Laser intensity vs RF frequency detuning f - 180400 kHz (diamonds at a repetition rate of 5.6MHz, triangles at a repetition rate of 2.8 MHz)

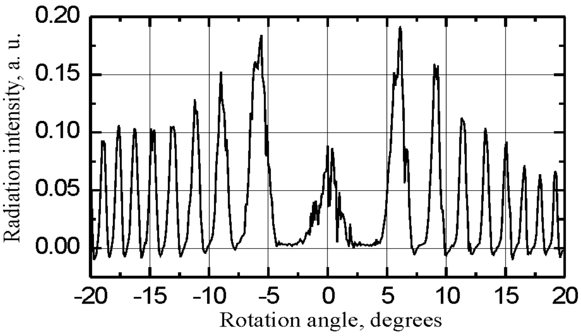

Fig.3. Results of the Fabri-Perot interferometer rotation angle scanning (laser wavelength $\lambda = 136\mu m$)

The loss of the optical resonator was measured with a fast Schottky diode detector [4]. Its typical output is the pulse sequence with the 5.6 MHz repetition rate. Switching off the electron beam, we measured the decay time (see Fig.4). The typical round-trip loss values were from 5% to 8%.

The FEL oscillation was obtained not only at a bunch repetition rate f_0 = 5.6 MHz, but at $f_0/2$, $f_0/3$, $f_0/4$ and $2{\cdot}f_0/3$. The time dependence of the intensity at a bunch repetition rate $f_0/4$ is shown in Fig.5.The radiation decay time (and, therefore, resonator loss) can be measured from this dependence too. In Fig. 6 the power as a function of the loss is shown. For example, the operation at bunch repetition rate $f_0/4$ corresponds to four times more loss per one amplification. It indicates that our maximum gain is about 30%.

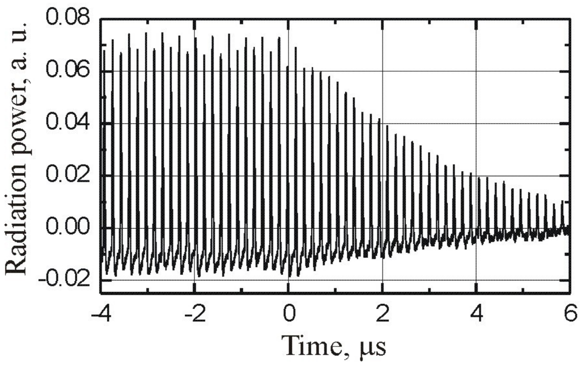

Fig.4. Time dependence of the output radiation power after switching the electron beam off

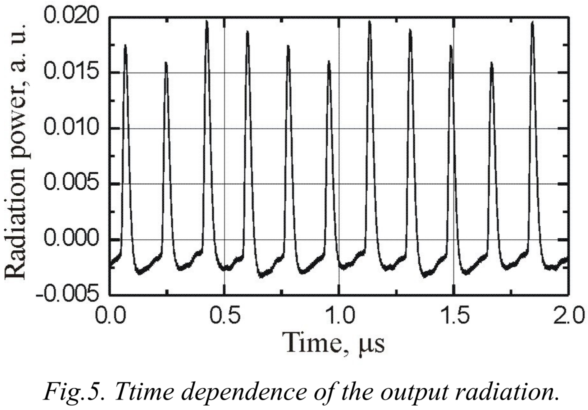

Fig.5. Ttime dependence of the output radiation. The electron bunch repetition rate of 1.4 MHz is less by a factor of 4 then the optical resonator round-trip frequency of 5.6 MHz

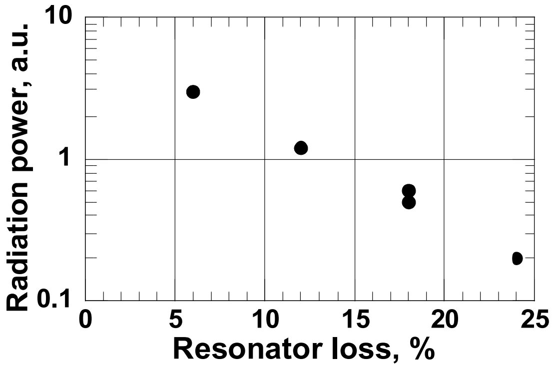

Fig.6. Average intra-cavity power vs loss per one amplification

The absolute power measurements were performed in two ways. First we measured the power coming through the hole in the mirror without scrapers. Output coupling is very weak in this case, so the power was about 10 W. It corresponds to the intra-cavity average power near 2 kW. Another measurements were performed with two (right and left) scrapers inserted. The insertion depth was chosen to decrease intra-cavity power twice. The measured power in each calorimeter was 20 W. Taking into account other resonator loss one can estimate the total power loss as 100 W. The electron beam power was 50 kW. Therefore the electron efficiency is about 0.2%. The possible explanation of so low value is too long undulator and high electron energy spread. Attempts to get the oscillation with one undulator switched off are in progress. Possible way to decrease the energy spread – the installation of a 3^{rd} harmonic (540 MHz) cavity – is under examination.

4. FURTHER DEVELOPMENT

A beam line for transporting the radiation from the accelerator hall to the user station rooms is under construction. The first experimental station is designed. The facility is to start the operation for users in 2004. Expected radiation parameters for users are shown in Table 2.

Table 2. Expected radiation parameters for users

Wavelength, mm	0.11...0.18
Pulse length, ns	0.1
Peak power, MW	0.1
Maximum repetition rate, MHz	5.6…22.5
Average power, W	100

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ПЕРВЫЕ РЕЗУЛЬТАТЫ РАБОТЫ МОЩНОГО ЛАЗЕРА НА СВОБОДНЫХ ЭЛЕКТРОНАХ СИБИРСКОГО ЦЕНТРА ФОТОХИМИЧЕСКИХ ИССЛЕДОВАНИЙ

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В Сибирском центре фотохимических исследований весной 2003 года получена генерация излучения с длиной волны 140 мкм на мощном лазере на свободных электронах (ЛСЭ). В работе кратко описана конструкция ЛСЭ на базе ускорителя рекуператора и представлены результаты измерения некоторых параметров электронного пучка и терагерцового излучения.

ПЕРШІ РЕЗУЛЬТАТИ РОБОТИ ПОТУЖНОГО ЛАЗЕРА НА ВІЛЬНИХ ЕЛЕКТРОНАХ СИБІРСЬКОГО ЦЕНТРУ ФОТОХІМІЧНИХ ДОСЛІДЖЕНЬ

Є.А. Антохін, Р.Р. Акбердін, В.С. Арбузов, М.А. Боков, В.П. Болотін, Д.Б. Буренков, А.А. Бушуєв, В.Ф. Веремєєнко, Н.А. Винокуров, П.Д. Воблий, Н.Г. Гаврилов, Е.І. Горникер, К.М. Горчаків, В.Н. Григор'єв, Б.А. Гудков, А.В. Давидов, О.І. Дейчулі, Є.Н. Дементьєв, Б.А. Довженко, А.Н. Дубровін, Ю.А. Євтушенко, Є.І. Загородніков, Н.С. Заіграєва, А.І. Єрохін, Д.А. Кайран, О.Б. Кисельов, В.Р. Козак, В.В. Колмогоров, Є.І. Колобанов, А.А. Кондаков, Н.Л. Кондакова, С.А. Крутихін, А.М. Крючков, В.В. Кубарєв, Г.Н. Куліпанів, Е.А. Купер, І.В. Купцов, Г.Я. Куркін, Є.А. Лабуцька, Л.Г. Леонтьєвська, В.Ю. Лоскутов, А.Н. Матвєєнко, Л.Е. Медведєв, А.С. Медведко, С.В. Мігінський, Л.А. Мироненко, С.В. Мотигін, А.Д. Орєшков, В.К. Овчар, В.Н. Осипов, Б.З. Персов, С.Р. Петров, В.М. Петров, А.М. Пилан, І.В. Полєтаєв, А.В. Полянський, В.М. Попік, А.М. Попов, Є.А. Ротов, Т.В. Салікова, І.К. Седляров, П.А. Селіванов, С.С. Серядняков, А.Н. Скринский, С.В. Тараришкін, Л.А. Тімошина, А.Г. Трибендис, М.А. Холопов, В.П. Черепанов, О.А. Шевченко, А.Р. Штейнке, Є.І. Шубін, М.А. Щеглов

У Сибірському центрі фотохімічних досліджень навесні 2003 року отримана генерація випромінювання з довжиною хвилі 140 мкм на потужному лазері на вільних електронах (ЛВЕ). У роботі коротко описана конструкція ЛВЕ на базі прискорювача рекуператора і представлені результати вимірювання деяких параметрів електронного пучка і терагерцового випромінювання.