# Status of the Novosibirsk High Power Free Electron Laser

V.P. Bolotin, D.A. Kayran, B.A. Knyazev, E.I. Kolobanov, V.V. Kotenkov, V.V. Kubarev, G.N. Kulipanov, A.N. Matveenko, L.E. Medvedev, S.V. Miginsky, L.A. Mironenko, A.D. Oreshkov, V.K. Ovchar, V.M. Popik, T.V. Salikova, S.S. Serednyakov, A.N. Skrinsky, O.A. Shevchenko, M.A. Scheglov, N.A. Vinokurov, N.S. Zaigraeva

Budker Institute of Nuclear Physics SB RAS, 630090 Novosibirsk, Russia
e-mail: vinokurov@inp.nsk.su

**Abstract**

The first stage of Novosibirsk high power free electron laser (FEL) was commissioned in 2003. It is based on normal conducting CW energy recovery linac. Now the FEL provides electromagnetic radiation in the wavelength range 120 - 180 micron. The average power is 100 W. The measured linewidth is 0.3%, which is close to the Fourier-transform limit. The assembly of user beamline is in progress. Plans of future developments are discussed.

## 1. Introduction

A new source of terahertz radiation was commissioned recently in Novosibirsk [1]. It is CW FEL based on an accelerator–recuperator, or an energy recovery linac (ERL). It differs from the earlier ERL-based FELs [2, 3] in the low frequency non-superconducting RF cavities and longer wavelength operation range. 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

## 2. Accelerator-recuperator

Full-scale Novosibirsk free electron laser is to be based on the four-orbit 50 MeV electron accelerator-recuperator (see Fig. 1).

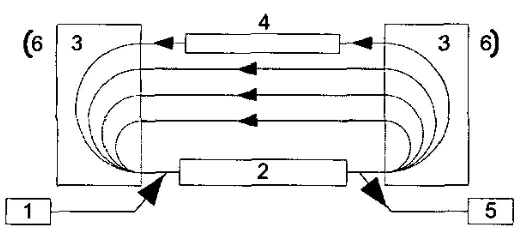


**Fig. 1**: Scheme of the accelerator-recuperator based FEL. 1 - injector, 2 - accelerating RF structure, 3 - 180-degree bends, 4 – undulator, 5 – beam dump, 6 – mirrors of optical resonator.

It is to generate radiation in the range from 3 micrometer to 0.2 mm [4, 5]. 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. 2. 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.

The FEL is installed in a long straight section of a single-orbit accelerator-recuperator. It consists of two undulators, a magnetic

Table 1: Accelerator parameters (first stage)

| | |
|---|---|
| RF frequency, MHz | 180 |
| Number of RF cavities | 16 |
| Amplitude of accelerating voltage at one cavity, MV | 0.7 |
| Injection energy, MeV | 2 |
| Final electron energy, MeV | 11 |
| Maximum bunch repetition rate, MHz | 22.5 |
| Maximum average current, mA | 20 |
| Beam emitance, mm·mrad | 2 |
| Final electron energy spread, FWHM, % | 0.2 |
| Final electron bunch length, ns | 0.1 |
| Final peak electron current, A | 10 |

buncher, two mirrors of the optical resonator, and an outcoupling system. Both electromagnetic planar undulators are identical.

The length of each undulator is 4 m, period is 120 mm, the 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 and is used now at low longitudinal dispersion $Nd < 1$.

Both laser resonator mirrors are identical, spherical, 15 m curvature radius, made of gold plated copper, and water-cooled. In the center of each mirror there is a hole. It serves for mirror alignment (using He-Ne laser beam) and output of small amount of radiation. The forward mirror has the hole with the diameter 3.5 mm, and the rear one - with the diameter 8 mm.

## 3. Radiation study

For FEL operation we used both undulators. Beam average current was typically 8 mA at repetition rate 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. Instead of fine tuning of the optical resonator length we tuned the RF frequency. The tuning curve is shown in Fig. 3.

The radiation wavelengths was tuned in the range 120 – 180 micrometers 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. The minimum relative linewidth (FWHM), measured with Fabri-Perot etalon, was near 3·10-3.

0-7803-8490-3/04/$20.00 ©2004 IEEE 

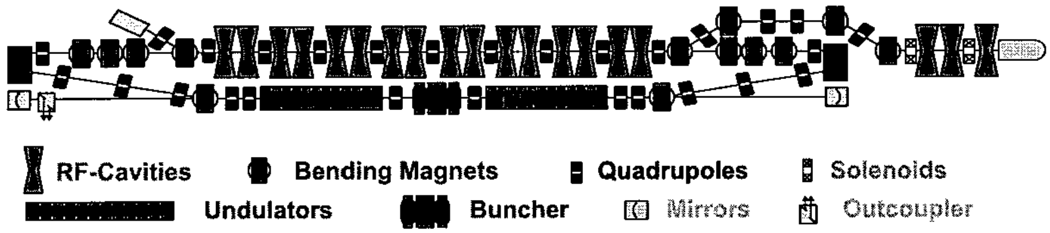


**Fig. 2**: Scheme of the first stage of the Novosibirsk high power FEL.

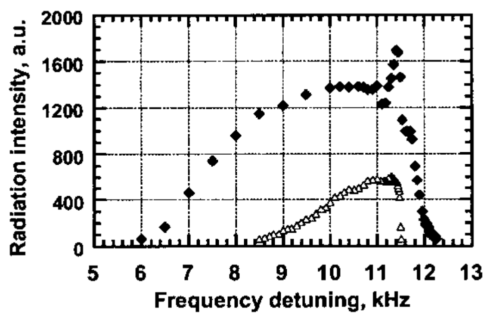


**Fig. 3**: Laser intensity vs. RF frequency detuning f-180400 kHz (diamonds at repetition rate 5.6 MHz, triangles at repetition rate 2.8 MHz).

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.

The loss of the optical resonator was measured with a fast Schottky diode detector [6]. Switching off the electron beam, we measured the power decay time. The typical round-trip loss values were from 5% to 8%. The typical radiation parameters are listed in Table 2.

Table 2: The radiation parameters

| | |
|---|---|
| Wavelength, mm | 0.12...0.18 |
| Minimum relative linewidth, FWHM | 0.003 |
| Pulse length, FWHM, ns | 0.05 |
| Peak power, MW | 0.6 |
| Repetition rate, MHz | 5.6 |
| Average power, kW | 0.2 |

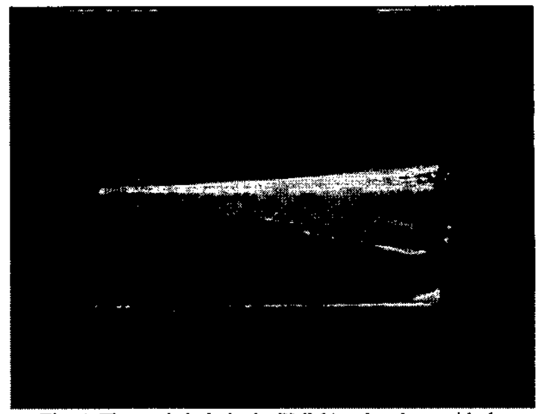

**Fig. 4**: The conic hole in the PMMA cube, done with the terahertz radiation ablation. One division is 5 mm.

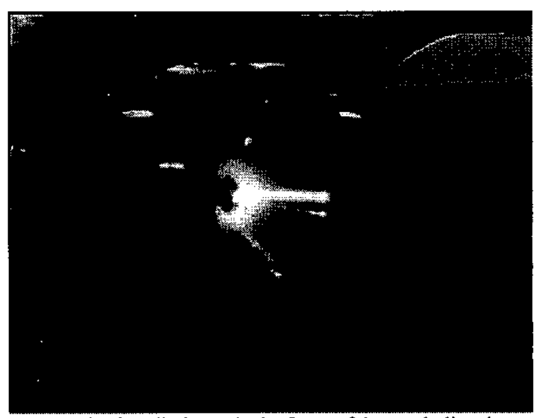

**Fig. 5**: The CW discharge in the focus of the parabolic mirror.

## 4. Optical beamline and first experiments

To transmit the radiation from the rear mirror hole to user stations, the beamline from the accelerator hall to the user hall was built. Now the beamline is filled by nitrogen. It is separated from the accelerator vacuum by the diamond window, and from the air by the polyethylene window.

To demonstrate the capabilities of our terahertz source we tested the PMMA ablation (see Fig. 4) and CW discharge in the atmosphere-pressure argon (see Fig. 5).

The beamline extension with places for five stations and first experimental station will be ready by the end of this year.

## 5. Acknowledgements

The work was supported by the integration grant 174/03 of the Siberian Branch of Russian Academy of Science.

## References

[1] E. A. Antokhin, R. R. Akberdin, V. S. Arbuzov et al., Preprint BINP 2003-53, Novosibirsk, 2003.
[2] G.R. Neil et al. Phys. Rev. Lett. 84 (2000), p. 662.
[3] E.J. Minehara. Nucl. Instr. and Meth. A, V. 483, p. 8, 2002.
[4] N.G. Gavrilov et al. IEEE J. Quantum Electron., QE-27, p. 2626, 1991.
[5] V.P.Bolotin et al. Proc. of FEL-2000, Durham, USA, p. II-37 (2000).
[6] V.V. Kubarev, G.M. Kazakevich, Y.V. Jeong, B.C. Lee. Nucl. Instr. and Meth. A, V. 507, p. 523, 2003