Novosibirsk free electron laser: second stage construction and new results at the terahertz user stations

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***Abstract*— Progress in the construction of the second stage of Novosibirsk free electron laser and main results obtained during the year at the terahertz user stations are described.**

***Index Terms*— Free electron laser, Terahertz radiation, Diffraction optical elements, Terahertz microbolometer camera, Aerodynamic experiments, Laser ablation, Biomedical experiments, Condense matter radioscopy**

I. Status of the Laser

The existing Novosibirsk free electron laser (NovoFEL) [1] is installed in a long straight section of a single-orbit energy recovery linac (Fig. 1). It consists of two undulators, a magnetic buncher, and an optical resonator. Both electromagnetic planar undulators are identical. The length of an undulator is 4 m, period is 120 mm, the gap is 80 mm. The buncher is simply a three-pole electromagnetic wiggler.

Both laser resonator mirrors are spherical, 15 m curvature radius, made of the gold-plated copper, and water-cooled. In the center of each mirror there is an opening. They serve for mirror alignment and radiation output. The distance between mirrors is 26.6 m. The front mirror has a hole with a diameter of 3.5 mm, and the rear one – with a diameter of 8 mm. The calculated transparency of the mirror with the 8-mm hole, for the wavelength of 150 μm, is 1.5%. At this wavelength the measured round-trip loss are near 7%. The output radiation passes through two windows, which separated the FEL and accelerator vacuum from the atmosphere. Behind the front mirror an additional iris and a normal-incidence quartz window are installed. Behind the rear one there is a diamond window, tilted at the Brewster angle. The output beam of monochromatic radiation, emerging as a continuous train of 100-ps pulses at a repetition rate of 2.8 – 5.6 MHz, can be gradually tuned within a spectral range of 120 – 240 μm. Maximum average power of the beam riches 400 W.

The manufacturing and construction of the full-scale four-track accelerator (Fig. 1) is underway. The existing orbit with the terahertz FEL lies in the vertical plane. The new four tracks will lie in the horizontal plane. One of the new FELs will be installed at the bypass of the second orbit (20 MeV electron energy) and the second one at the fourth orbit (40 MeV). Spectral ranges of these lasers are anticipated to be 30 – 120 and 5 – 30 μm, respectively.

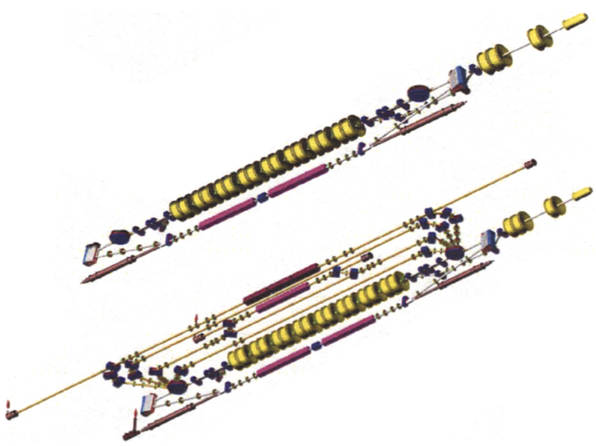

Fig.1. Schematic of Novosibirsk free electron laser and energy recovery linac: in the top – existing system; in the bottom – full scale system with three laser resonators (under construction).

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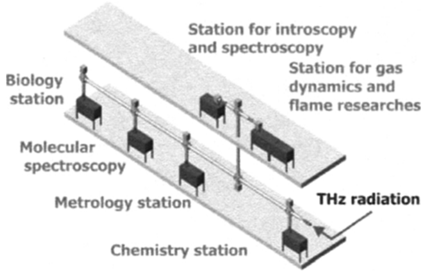

Fig. 2. The user stations.

II. Experiments at the User Stations

Four user stations at the first floor are nowadays in operation (Fig. 2). They are located in two experimental halls on the first floor. Laser radiation is transmitted to the user stations through a beamline filled with dry nitrogen, as shown in Fig. 2. The distance between the output mirror of the optical resonator and the user stations is 17 meters (the first station) and 38 meters (the distant station). Besides, a special outlet of the beamline transmits the radiation to the Bruker IFS 66v/S Fourier spectrometer for detailed study of NovoFEL radiation spectral characteristics. Detailed data on generation line shape for different electron beam conditions were obtained for the fundamental harmonic, as well as for 2nd and 3rd ones. The absorption of diamond windows and for other materials was carefully studied in the terahertz range [3].

One of the perspective results achieved at the biology user station is non-destructive ablation of DNA by intense terahertz radiation. At least a fraction of the macromolecules reveal the enzymatic activity after ablation at certain wavelength, whereas at a slightly different wavelength there observed the molecule destruction [2]. This result opens a way for the development of biochip technology.

Other result, which may be significant for the biomedical application is the observation of correlation between terahertz absorption spectra of bone tissue samples of intact and senescence-accelerated rats [4]. A difference of the spectra for the rats of different ages and different strains was discovered. If the results will be confirmed statistically, the terahertz spectroscopy can be applied for osteoporosis diagnosis and the control of pharmacology substances effect. The attenuated total reflection spectrometer with NovoFEL as a tunable radiation source for the study of complex refractive index of bone tissues, as well as other highly absorbing substances, has been developed.

Reflective diffraction optical elements (DOE) have been developed for focusing monochromatic terahertz radiation [5]. Elliptically shaped Fresnel zone plates with the diffraction efficiency of about 10%, formed by etching a copper foil clad on a fiber-glass plastic, had been applied for focusing of radiation under the right angle. The phase-type reflective kinoform lenses with the parabolic Fresnel zone profile having about 100% diffraction efficiency were fabricated by processing on a NC machine and used as the focusing element in Toepler quasi-optical system. The study of optical path gradient distribution in the terahertz radioscopy of the condense matter have been carried out using this system.

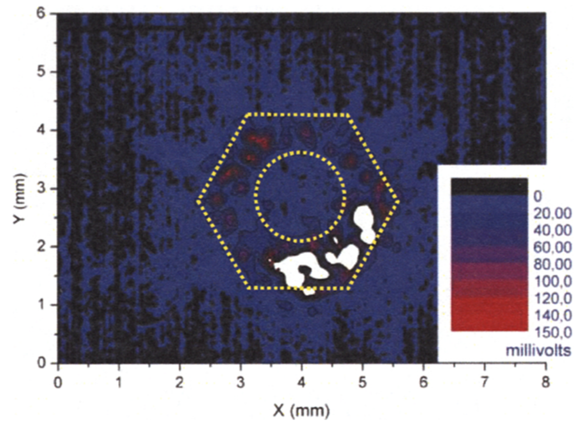

Fig. 3. Speckled image of a nut illuminated diffusely reflected coherent terahertz radiation captured by a microbolometer camera: expose time – 20 ms; magnification 1:6.3;. radiation wavelength – 130 μm.

Complete transverse coherence of the NovoFEL radiation enabled digital recording of holograms and reconstruction of plane objects in the Gabor axisymmetric scheme. Fresnel digital holography with the wavefront splitting was also used for the examination of solid samples deformations in the radioscopy mode.

High-speed terahertz imaging and the radioscopy of strongly absorbing and wrapped objects were restricted up to now for the lack of sensitive 2D-recorders. We applied for recording terahertz images of many objects a 160x120 microbolometer focal plane array camera. Maximum repetition rate achieved with this camera was 90 frames per second. A wide dynamic range and a high sensitivity of the camera allow capture images in both radioscopy and reflection/scattering modes. Because of a low divergence of the terahertz beam, images of metallic objects in the reflection mode were presented only with Fresnel flares. To obtain whole image of a sample, the samples were illuminated by the laser beam reflected from an irregular surface that resulted in speckled terahertz images (Fig. 3).

III. Near Perspectives

In near future we expect progress in the current terahertz experiments in biomedical research, spectroscopy, radioscopy, imaging and holography. Two new stations at the second floor will be commissioned in this year, and the experiments in aerodynamics, combustion, optical discharge, and material ablation are to be begun. Second laser system generating radiation on mid-infrared is also to be commissioned in near future. Exterior users may carry out experiments at all user stations with the owners' permission and approval by the NovoFEL advisory committee.

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