Novosibirsk terahertz free electron laser: Status and survey of experimental results

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Abstract

During the past year, generation characteristics of the Novisibirsk terahertz free electron laser were growing up. It generates now coherent radiation tunable in the range 120–170 μm at the repetition rate of 2.8–11.2 MHz. Maximum average output power reaches 400 W at 11.2 MHz. Laser radiation is transmitted through a 14-m optical beamline to the user stations. Experiments on chemistry, biology, spectroscopy, imaging and holography with employment of terahertz radiation are in progress.

Introduction

Radiation characteristics of the Novosibirsk free electron laser (NFEL) [1] are gradually growing during the last year. The average output power reaches the value of 400 W (at 11.2 MHz) that corresponds to the peak power of about 1 MW. Laser pulses follow as a continuous train of 30–100 ps pulses with the repetition rate 2.8 – 11.2 MHz.

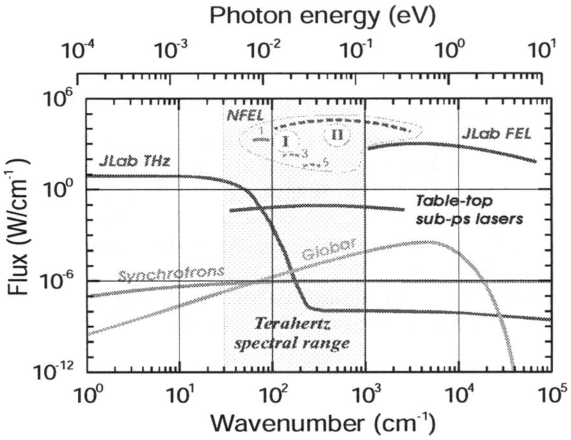

Fig. 1: Spectral power density of the terahertz sources. The curve *1* corresponds to the first harmonic of NFEL radiation. The curves labelled with figures *3* and *5* show expected flux of third and fifth harmonics. The dashed curve is the project flux of the NFEL second stage.

Laser radiation on the fundamental mode can be precisely tuned within 120 – 170 μm. Because of relatively long pulse length, generation bandwidth is rather wide and the average spectral power density $P_\lambda \sim 1$ kW/cm^{-1} of NFEL is several orders of magnitude greater than P_λ of all existing sources in this spectral region (see Fig. 1, where we adopted in part data from Ref. [2, Fig. 2]).

Laser parameters

For transmission of laser radiation from the accelerator hall to user stations, a 14-m optical beamline guiding terahertz radiation from the laser had been constructed. The beamline is separated from the accelerator vacuum with a 0.8-mm thick diamond window. Since water and CO$_2$ molecules have a great number of absorption lines in the submillimeter spectral region, the beamline is filled out with dry nitrogen at the atmospheric pressure and isolated from the atmosphere at the output with a thin polyethylene film. Areal distribution of the terahertz beam intensity at the output is close to Gaussian one $I(r) \propto \exp(-2r^2/w^2)$ with $w = 41$ mm.

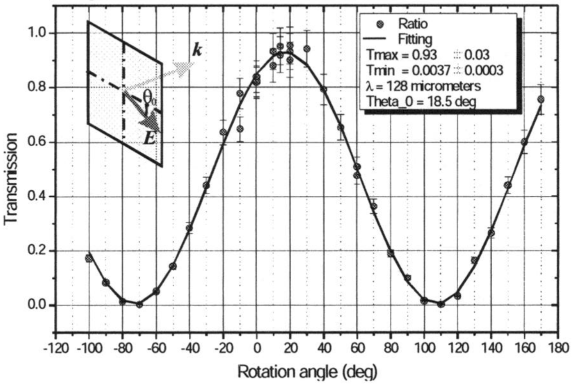

Fig. 2: Transmission of free electron laser radiation by QMC Instruments thin-film photolithographic polarizer P10 vs. rotation angle at the beamline output (λ=128 μm).

The beam is plane-polarized. To measure polarization degree we employed a QMC Instruments thin-film photolithographic polarizer (model P10: 5 μm copper stripes with 10 μm period on 9 μm polypropylene film). Transmission of the polarizer is shown in Fig. 2. It is equal to $T_s = 93 \pm 3$ % in maximum and $T_p = 0.37 \pm 0.03$ % in minimum. Calculations of the transmission performed using the expressions from [3] give the values $T_s = 98.9$ % and $T_p = 0.6$ %. Though the expressions used seem not to be very precise, comparison of theoretical and experimental results proves extremely high polarization degree of the radiation.

Classical diffraction experiments, performed using NFEL radiation, have clearly demonstrated complete spatial

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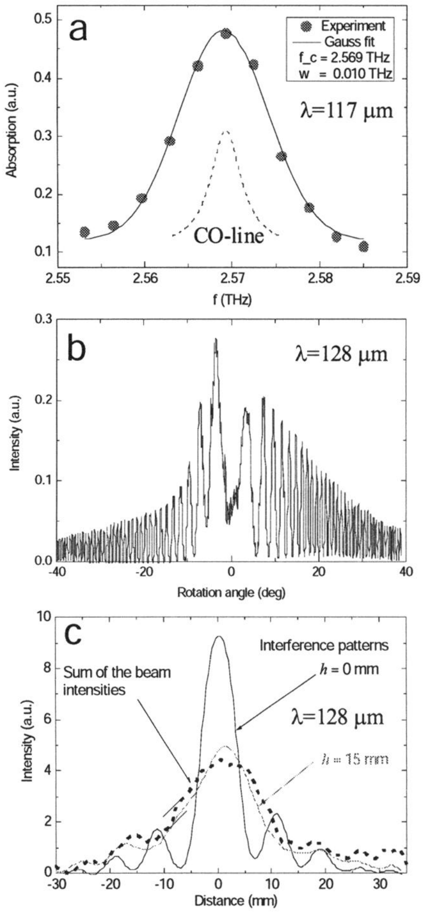

Fig. 3: (a) Absorption in CO gas cell vs. laser wavelength; the dash line is calculated profile of CO ($J=21\rightarrow J=22$) transition. (b) Transmission of laser radiation by Fabri-Perot interferometer vs. rotation angle. (c) Interference pattern formed when laser beam is reflected from the Fresnel bi-mirror; *h* is a longitudinal displacement of one of the mirrors.

coherence over the whole wavefront. Longitudinal, or time, coherence was measured with three methods. Fig. 3, a demonstrates the results of laser spectrum measurement by means of scanning of laser wavelength over 2.569 THz CO-molecule absorption line. The reverse Fourier transform gives for time coherence $\tau_c \approx 40$ ps. The same value retrieved from the laser generation spectra obtained using a Fabri-Perot interferometer in different experiments (one example is presented in Fig. 3, b) was equal to 80 and 40 ps.

Processing interference patterns (Fig. 3, c) obtained in the experiment with the Fresnel bi-mirror (see details in [4]) we have found $\tau_c \approx 50$ ps. We attribute these variations of time coherence with the electron bunch characteristics (especially with the bunch length) in the undulators. Since bunch parameters can be changed continuously, this opens the opportunity for control of the time coherence.

Experiments on the user stations

One of the priority programs for NFEL is biological experiments. The extremely large radiation wavelength of our laser enables "ultra-soft" ablation of large biological molecules (DNA, proteins) without their denaturation in contrast to the existing lasers operating in the VIS and NIR spectral regions. In first experiments on ablation of DNA samples small fragments appeared at high power density, but for an optimal terahertz power density the absence of small fragments in the ablative material have been clearly demonstrated (Fig. 4).

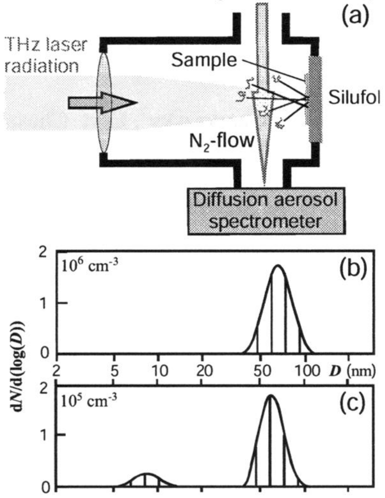

Fig. 4: Ultra-soft laser ablation of DNA samples on silufol. (a) The experimental configuration. Size distribution of ablative material recorded with diffusion aerosol spectrometer for two samples containing (b) phage DNA and (c) mixture of the phage DNA with plasmide DNA (size ratio is close to ten). Wavelength - 120 µm, power density -20 W/cm^2

Special attention we paid to imaging of the terahertz radiation. Several techniques developed for THz radiation visualization are described in [4]. Besides earlier developed thermographic and interferometric techniques [5], we have demonstrated great capability of the technique based on thermal quenching of phosphor fluorescence. Employing these imagers, we performed some optical and holographic experiments with coherent monochromatic THz radiation. Experiments on terahertz spectroscopy, chemistry and technology are in progress.

Acknowledgments

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