INSTRUMENTATION AND EXPERIMENTAL OPPORTUNITIES FOR MATERIAL STUDY AT TERAHERTZ NOVOSIBIRSK FREE ELECTRON LASER

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The first stage of the Novosibirsk high power free electron laser (NovoFEL) was commissioned in 2003. NovoFEL is a CW FEL based on non-superconducting, low-frequency (180 MHz) single-pass accelerator-recuperator ("energy recovery linac") with the following parameters: the electron energy is 12 MeV; charge per bunch is 1,5 nC; the bunch repetition rate is 5.6 to 22.5 MHz; the maximum average current is 30 mA; the bunch duration is from 40 to 100 ps. The laser generates tunable monochromatic radiation within a spectral range of 110 – 240 μm at the first harmonics, 60 – 117 μm and 40 – 80 μm at the second and third harmonics, respectively. The maximum average power reaches 0.5 kW at a repetition rate of 11.2 MHz for the first harmonics. The maximum average power of the second and third harmonics is 2% and 0.6% with respect to the first harmonics. The maximum peak power reaches 1 MW at a repetition rate of 11.2 MHz. The relative spectral width of generation line is 0.25 – 1%. The radiation is completely spatially coherent, and the degree of plane polarization of radiation is better than 99.6 %.

Laser radiation is transmitted through nitrogen-filled optical beamline to the experimental hall. The ultrahigh vacuum system of the FEL and accelerator-recuperator and the gas-filled beamline are separated with a diamond window. Six user stations (the metrology station, the photochemistry station, the biology station, the molecular spectroscopy station, the station for radioscopy and spectroscopy, and the aerodynamics station) are currently in operation. The second stage of the NovoFEL, based on the four-track 40 MeV accelerator-recuperator, using the same accelerating RF structure as the first stage, is to be commissioned soon. Two FELs in the second and fourth tracks are to generate radiation in the spectral ranges of 5-30 μm and 30-100 μm, respectively. Unticipated average power of each FEL is more than 1 kW.

Unique characteristics of the terahertz FEL open the opportunities for material studies. Structure and spectral characteristics of many materials, which are opaque in visible and near-IR region and practically absolutely transparent to X-ray, but appears to be partially transparent to terahertz radiation, can be studied in the terahertz region. The interest of using the terahertz radiation is due to its following properties: it is a non-ionizing radiation (the photon energy ranges from 0.04 eV to 0.004 eV); the radiation passes through opaque media and weakly dispersive materials relatively well owing to strong suppression of Rayleigh scattering ($1/\lambda^4$); the frequency range of the radiation covers the region of rotational spectra of molecules, vibrations of biologically important collective modes of DNA and proteins, and frequencies characteristic of intermolecular interactions; the terahertz radiation corresponds to the energy region of hydrogen bonds and van der Waals forces of intermolecular interactions.

Many detectors, imagers and spectrometers for the terahertz range, which were developed during last five years at NovoFEL, are available for users. Several methods for two-dimensional visualization of THz radiation, including a 160x120 uncooled microbolometer focal plane array with a frequency up to 90 frames/s, have been developed. Quasi-optic instrumentation for the experimental station (windows, beam splitters, pyroelectric detectors, bolometers, Fresnel zone plates, and kinoform lenses) is developed and also available to the experimentalists. High peak power density, in combination with the high average power of the FEL, opens the opportunity for material ablation experiments, mass-spectrometry, material modification, etc.

Experiments in physics, chemistry, biology, condensed matter and technology performed at the user stations are surveyed in this paper.