Status of the Novosibirsk high power FEL

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The high power free electron laser for the Siberian center of photochemical research is under construction now. The status of the project is described.

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GENERATION OF HUNDRED JOULES PULSES OF 4-MM RADIATION BY PLANAR FEM WITH DISTRIBUTED FEEDBACKS

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FEM-generator driven by a high current sheet beam is one of the promising device to obtain tens kilojoules energy content in microsecond pulse of mm radiation [1]. In this report we present the results of recent experiments with FEM of such geometry carried out at the U-3 accelerator on the ELMI device at hundred joules contents.

The experiments are performed at the following beam parameters: $E_e \sim 0.8$ MeV, $I_b \sim 3$ kA, $\tau_b \sim 5$ μs, S_b=0.4x12 cm. The sheet electron beam propagates through a plain resonator in a vacuum channel with magnetic field having two components. The first component is directed along the channel axis and the second one (perpendicular) is undulating with a spatial period of 4cm. Values of these components are independently varied from 8 to 14 kG and from 0 to 2 kG respectively. The resonator consists of a plane copper waveguide (cross section - 1x20cm, length - 64cm) and two Bragg reflectors. Each reflector is constructed of two Bragg gratings. The lengths of the gratings for the reflectors are 18cm at the beam entrance and 10cm at its exit that provides sufficient values of the reflection coefficient. In experiments performed at the U-2 accelerator before 1998, we used the gratings with one dimensional corrugation only. But in recent experiments we have replaced them by two-dimensional ones to improve spatial coherency and to increase spectral density of the microwave power.

In this paper we present the results of spectral density measurements for the emitted radiation at various values of undulating field. The comparison of them with the results of numerical simulations is performed. As a result of experiments with 2-D gratings the total energy in microwave pulse of microsecond duration has been obtained on the level of 100J that is close to the energy content for 1-D case [2].

[1] M.A.Agafonov et al. "Super power generator of mm-waves driven by microsecond sheet beam", Proc. of 11-th Intern. Pulsed Power Conf., USA(1997) p.121-126.
[2] M.A. Agafonov et al. IEEE Transactions on Plasma Science, Vol. 26, No. 3, 1998, p. 531-535.

Work is supported by RFFR grant # 97-02-17379, ISTC grant #531, State Scientific and Technical Program "Physics of Microwaves" grant 1.3.

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A project of a high-power CW mm-wave FEL

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A project of a mm-wave free electron laser driven by a 2 MeV CW high-power electron injector is described. The FEL consists of a waveguide placed inside a short-period (~10 mm) undulator. The injector provides 2 nC, 2 MeV (full energy) electron bunches of subnanosecond duration at repetition rate up to 22.5 MHz. The FEL can operate as both an amplifier or an oscillator. Supposed wavelength ~ 1 mm, average power ~ 6 kW, that can be increased up to ~ 50 kW if the repetition rate is raised to 180 MHz. Estimations of various significant parameters of the FEL and schematic design are presented.

Technological applications of the high power high energy electron beams

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The technological applications of a several-MeV high average power electron beams are discussed. The particular case of linacs and recirculators based on the low-frequency RF systems is considered in more details.

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Compact Far-Infrared Free-Electron Laser Driven by a Microtron

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We have developed a compact far-infrared FEL on the base of 8 MeV, 50 mA microtron. The wavelength of the FEL is from 100 to 200 μm depending on the magnetic strength of U-25 undulator from 5 – 6.5 kG. The period of the undulator is 25 mm and the total length is 2 m. The undulator has extremely low field error of 0.05% from the peak amplitude. We installed the horizontal focusing field of 20 G/cm inside the undulator, which provides a single period betatron motion of electrons in horizontal plane. The vertical motion of the electrons in the undulator is mainly determined by the gradient filed of the undulator and the effective number of the betatron periods is approximately 7 through the 2-m undulator. The resonator of the FEL is composed by a confocal scheme in horizontal plane with cylindrical mirrors and a parallel-plate waveguide with the gap of 2 mm in the vertical plane to increase the coupling between electron beam and radiation. The diameter of the electron beam envelope in vertical plane of the undulator is less than 1 mm and all electrons are transported through the waveguide of 2-mm gap and 2-m length. We have observed the coherent effect of the spontaneous emmision with the power enhancement more than 100 times. We will report the preliminary results of the FEL including the anomalous lasing in much longer wavelength to the main wavelength.

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High-Current 2-MeV Electron Accelerator for High-Power FEL and E-beam Irradiation Processing *

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A high-current CW electron accelerator has been developed for the free electron laser (FEL) programs at KAERI under the cooperation of KAERI and the Budker institute of Nuclear Physics (BINP), Russia. The accelerator is composed of a 300-keV electron gun, a radio frequency (RF) buncher cavity, and two RF acceleration cavities. The kinetic energy of the electron beam is 1.5 MeV nominally and 2 MeV at maximum. The duration of a pulse is 350 ps and its repetition rate is variable from single pulse to 22.5 MHz. The peak current is 6 A, and the average current at maximum repetition rate is 50 mA. The resonant frequency of the normal-conducting RF cavities is 180 MHz. The accelerator will be used as a driver of a millimeter-wave free-electron laser and an injector of a high-power infra-red free electron laser. Application of the accelerator for electron beam processing of polymers, exhaust gas, waste water, semiconductor for power electronics

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The Straight-flight Cavity for Monitoring of Microtron Intrapulse instabilityes

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It was 2.8 GHz straight-flight cavity ellaborated for investigation of intrapulse frequence instability of bunched beam in the entrance of submillimeter FEL, driven by 10-cm microtron. Cavity is cylindrical, low Q-factor resonator with the coupling less then critical. Tuning system of cavity drived by moving mechanism provide retuning in bandwidth ±7.5 MHZ. Design of cavity admit to change disposition of coupling loop to chose and control of the coupling coefficient. The geometrical aperture for transportation of beam in measuring cavity is 26 mm

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Measurements of Intra-Pulse Instabilities in the Electron Beam of High Current Microtron

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The intra-pulse instability of the buched beam from a 10-cm microtron has been measured by using the straight-flight cavity method. The microtron provides e-beam energy of ~7 MeV, micropulse current of 35~45 mA, pulsewidth of ~ 6μs. For any operation condition of the microtron it was found that the repetition rate of the micropulsee during a pulse oscillates with a period of ~0.64 μs. The amplitude of frequency deviation and the slope of frequency increase are proportional to the accelerated current and the emission current, respectively. In operating condition of microtron the increase of frequency is little more than ~100kHz during 6μs. In optimal regime, the frequency deviation is +-- 30 kHz.

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Simulation of the Operation Characteristics of the FIR-FEL driven by a Macrotron Having Timing-Jitter of Electron Beam

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The electron beam timing-jitter occurs due to the instability of RF source. The timing–jitter of the electron beam changes the effective cavity length with time. Every RF source has the intrinsic timing-jitter due to the circuit is made during the beam is injected to the beam line. We simulated this effective cavity detuning for the FIR-FEL driven by the microtron constructed in KAERI, and studied the limitation of the operation of the FIR-FEL due to this time-jittering of the electron beam.

* Work supported by the Ministry of Science and Technology under contract K98-111.

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The orbit design of the accelerator-recuperator for the free electron laser.

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The special requirements for the magnetic system of accelerator-recuperator are considered. The solution which meet these requirements is found. Some results of the lattice design are described.

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SELECTIVE PROPERTIES OF PLANAR RESONATORS WITH 1-D AND 2-D FEEDBACKS FOR MICROWAVE FEM

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Experiments on generation of microwave radiation in the free electron maser of planar geometry are being carried out now at the ELMI device (BINP RAS) [1]. In these experiments we use resonators composed of planar waveguide with the cross section 1x20cm and the length 64cm and two pairs of Bragg gratings operating as reflectors. In first series of experiments the reflectors of the resonator were formed by one-dimensional Bragg gratings corrugated with the period 2mm and the depth 0.2mm. The lengths of the reflectors are 10cm and 18cm that should provide reflection coefficient on the level of 75% and 95% respectively for 4mm radiation. In the second series the resonator has been formed by 2-D Bragg gratings with the same length which are corrugated in two perpendicular directions at the angle 45° to the direction of the beam propagation. The period of corrugation is 2.8mm in the pointed directions, the depth is 0.3mm. Selective properties of such resonators have been previously analysed in the theoretical paper [2]. In this report we present the results of measurements and computer simulations of transmission and reflection coefficients for 1-D and 2-D resonators as well as the frequency and quality of the eigen modes excited in the resonators without the beam. Comparison of spectra for these resonators has shown that for 1-D resonator a few modes with close frequencies and the same qualities are existed. In the 2-D case, one of the modes is strongly distinguished by its quality. So, at the generation with 1-D resonator a few modes possibly exist. But, as it has been shown by computer simulation for the case of presence of driving beam in the resonator it is possible to build up a super mode consisting of a few single modes of this resonator. For 2-D resonator one its mode prevails over others from the very beginning of generation that allows the device to operate at a single mode. To measure the coherence of radiation generated by the maser, the interferometer based on a concave diffraction grating was designed, constructed and tested.

[1] Arzhannikov A.V. et al. "Progress in investigations of microwave FEL driven by microsecond sheet beam", 12-th Intern. Conf. on High-Power Particle Beams, Program and Abstracts, Israel (1998) p.262.

[2] Ginzburg N.S.et al. "Dynamics of FEMs with 1-D and 2-D distributed feedback", Proc. II Asian Symp. On Free Electron Lasers, Russia (1995) p. 150.

Work is supported by RFFR grant # 97-02-17379, ISTC grant #531, State Scientific and Technical Program "Physics of Microwaves" grant 1.3.

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U-25 Undulator for the KAERI FIR FEL

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An extremely high accuracy electromagnetic undulator has been developed for a far-infrared compact FEL. The period of the undulator is 25 mm and the number of the periods is 80. The gap between poles is 5.7 mm. The field distribution along the undulator is formed by 8 mm thick poles of low-carbon steel with 4 mm thick Nd-Fe-B permanent magnets between them. The strength of the undulator can be changed from 5 to 6.8 kG in a constant gap depending on the driving current (1300 – 1600 A) of the main coils. The r.m.s error of the peak amplitude was 0.2% without field correction or individual adjustment of each iron pole. We have developed simple method to improve the field accuracy with serially connected electromagnet correction coils having 1 – 7 turns. In this case we can use only one current source of several amperes for all correction coils. We spent 2 days for serial connection of the correction coils with different turns and current polarities from the measured distribution of the undulator field. We got the final accuracy of the field amplitude less than 0.05%.

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Apparatus for Investigation of KAERI FIR FEL radiation

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For measurement of KAERI FIR FEL radiation high-sensitive infrared, sub-millimeter and millimeter detectors and mesh Fabry-Perot interferometers were developed. Liquid helium cooled Ge:Zn, Ge:Ga and In:Sb photo-resistors were used as sensitive elements of the detector in MIR, FIR, sub-millimeter and millimeter ranges, respectively with noise equivalent power, NEP < 10^{-10} W/Hz$^{1/2}$ and response time ~ 100 ns. Photo-resistors were placed in special chamber inside the dewar of EG&G Judson Co. which had small size and so was very convenient and easily screened from X-ray radiation. After our modernization, liquid helium life time in this dewar was increased in 3 times up to 9 hours that was quite enough for one-day physical experiment. Unique property of our Ge:Ga detector is its wide-range sensitivity. Measurement radiation from 20 μm to ~ 1 mm is possible by using of this detector. In KAERI FIR FEL experiment it is used to detect radiation with wavelengths 90-160 μm and ~ 1 mm. Fabry-Perot interferometers based on copper meshes were specially optimized for measurement of laser and spontaneous emission spectrum. Typical parameters of this device are: spectral resolution - $\delta\lambda/\lambda = 4–8\times10^{-4}$, transmittance – 70-90 %, range of free dispersion - $\Delta\lambda/\lambda = 1\text{-}2 \times10^{-2}$.

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