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Generating High Power Terahertz and Far Infrared Electromagnetic Radiation with Relativistic Electrons

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Relativistic electron beams are used successfully to generate electromagnetic waves. Both narrow-band and short-pulse THz generators of such type are described with examples of the free electron lasers (FELs) and prebunched-beam devices.

FELs (see, e.g., [1]) convert the power of relativistic electron beams to narrow-band radiation. The main component of an FEL is a special spatially periodic magnetic system, called undulator (see, e.g., [2]). The undulator magnetic field curves electron trajectories; therefore, electrons emit narrow-band electromagnetic radiation in free space. The scheme of the FEL amplifier is shown in Fig. 1.

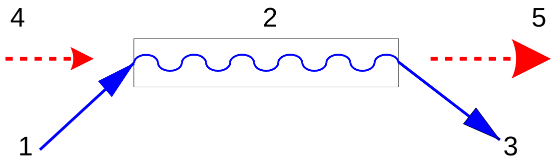

Fig. 1. The scheme of FEL amplifier: 1 – incoming electron beam, 2 – undulator, 3 – used electron beam, 4 – incoming electromagnetic wave, 5 – amplified electromagnetic wave

FELs use a phenomenon of the stimulated undulator radiation. i. e. bunching of electrons by an external electromagnetic wave and an increase of the wave field amplitude by addition of the field emitted by the bunched electron beam. On the other hand, FEL can be considered as travelling wave tube. Then undulator is necessary to provide (i) interaction of electrons with transverse electromagnetic wave and (ii) fast space harmonic of transverse electron current.

The particular problem of terahertz FELs is large diffraction divergence of the amplified wave. It require either large aperture of undulator, or the use of waveguide inside undulator. The first solution leads to the increase of the undulator period and corresponding increase of the electron energy. Moreover, big diameter of radiation beam leads to lower amplitude of electromagnetic field (at fixed power) and lower amplification. The second option is suffers from significant power losses. Therefore, it requires high enough FEL gain. For high average power FEL, the sufficient waveguide cooling has to be provided.

Another issue of FELs is the way to vary the radiation wavelength. The wavelength of the undulator radiation

$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}\right) \qquad (1)$$

depends on the undulator period λ_u, the electron energy γmc^2 and the undulator parameter $K = eB\lambda_u/(2\pi mc^2)$ (c is the velocity of light, e and m are the charge and the mass of electron, correspondingly), which is proportional to the amplitude B of magnetic field. The most straightforward way is to vary the electron energy. However, in fact, it is rather complicated, as require changing many parameters of an electron accelerator, which is typically optimized for some particular energy. The variation of the magnetic field amplitude is the most common now. It is achieved by variation of current in the coils of electromagnetic undulators or by variation of the gap between upper and lower parts of permanent magnet undulators. The drawback of the field amplitude variation is that at shortest wavelength of the tunability range the undulator performance is far from the optimal one. Indeed, for such a low field amplitude, one can build an undulator with shorter period and larger pole numbers at the same length. Last decade we developed the third option – the variation of the undulator period [3, 4]. Variable period permanent magnet undulators were built and tested successfully [5, 6]. Next year we plan to install the variable period undulator to Novosibirsk FEL facility (see [7, 8]). It will replace one of the old electromagnetic undulators there.

For some applications, short high-field pulses are required. Contemporary accelerator technology provides very short electron bunches. The common way to do it is the use of radiofrequency (RF) electron guns with photocathodes (see, e.g., [9]). Using commercial lasers one can obtain few-picosecond electron bunches with electric charge Q of about 1 nC and normalized emittance of about 1 micron. The bunch charge is limited by Coulomb repulsion of electrons inside the RF gun. After acceleration, the bunch can be compressed to sub-picosecond duration T. Then the energy of the field around the bunch, which can be converted to the electromagnetic pulse energy, $W \sim Q^2/(cT)$ may reach 1 mJ. One of the possible radiators in this case is transition radiation, when the bunch passes through a conducting foil. The efficiency of such radiator may be enhanced using many foils and combining signals from them. The example of such a device, the multifoil radiator [10], is shown in Fig. 2. Short electron bunch passes through the conical foil stack along the cone axis z. After the bunch has passed through the gap between two of the foil disks, the induced electromagnetic wave propagates radially outward. As the pulses reach the foil boundaries, they merge and form the conical radially polarized wave. One can also say that this radiator is the Cherenkov one with strongly anisotropic media. The device was tested [11] with the short bunch from laser plasma wakefield accelerator.

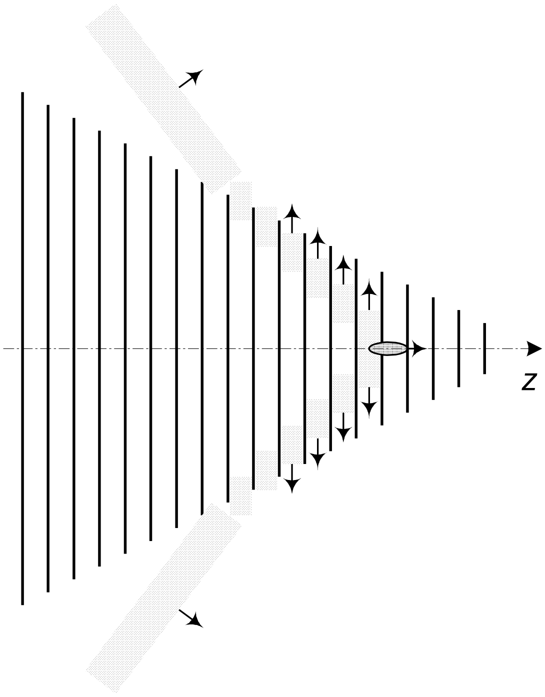

Fig. 2. The scheme of the conical multifoil radiator

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