ALPHA – THE THZ RADIATION SOURCE BASED ON AREAL*

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Abstract

Advanced Research Electron Accelerator Laboratory (AREAL) based on photo cathode RF gun is under construction at the CANDLE. The basic aim of this new facility is to generate sub-picosecond duration electron bunches with an extremely small beam emittance and energies up to 50 MeV. One of the promising directions of the facility development is the creation of ALPHA (Amplified Light Pulse for High-end Applications) experimental stations with coherent radiation source in THz region based on the concept of both conventional undulator and novel radiation sources. The status of the AREAL facility, the main features and outlooks for the ALPHA station are presented in this work.

INTRODUCTION

The generation and acceleration of low emittance ultrashort electron bunches present the origin for the development of new coherent radiation sources. The AREAL RF photogun electron linear accelerator is currently under construction at the CANDLE Synchrotron Research Institute [1]. The basic aim of this new facility is to generate electron bunches with extremely small beam emittance and with sub-picosecond pulse duration for advanced experimental study in the field of accelerator technology, new radiation sources and dynamics of ultrafast processes.

The first phase of the AREAL facility with the beam energy of about 5 MeV at the gun exit is completed recently [2]. The second phase foresees 20 MeV design energy with possible upgrade of up to 50 MeV.

After successful realization of AREAL phase 1 which was demonstrated during the machine run shifts in May 2014 [3], the second phase of the project implementation being in progress implies installation of two accelerating S-band modules with corresponding diagnostic equipment.

In the past decade the THz radiation has been of great scientific interest with a wide range of potential application in the field of life, material and environmental sciences, development of bio and nano-technologies [4]. One of the promising directions of the AREAL facility development is the creation of ALPHA experimental station with coherent radiation source in THz region. The project will focus on the development of THz coherent radiation sources based on 1) conventional periodic magnetic (undulator) system, 2) novel single mode slowly travelling waveguide concept and 3) modulated beam plasma interaction. In this paper we present the main features of ALPHA THz Free Electron Laser option based on the planar undulator.

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AREAL FACILITY

The schematic layout of the AREAL laser driven electron linear accelerator is presented in Fig. 1. The facility contains cupper photocathode illuminated by 285 nm wavelength UV laser, 1.6 cell S-band cavity and two 1.5 m long S-Band accelerating sections.

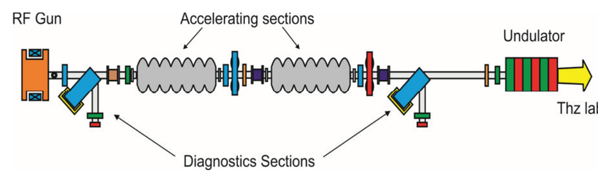

Figure 1: Layout of AREAL gun section with diagnostics.

The main design parameters of the AREAL facility electron beam are given in Table 1.

Table 1: AREAL Beam Parameters List

Energy	20-50 MeV
Bunch charge	10-200 pC
Transv. norm emit.	<0.3 mm-mrad
RMS bunch duration	0.5-8 ps
Energy spread at 20 MeV	0.2%

The ASTRA start-to-end tracking simulations are performed to optimize the acceleration phase and gradients to obtain minimum beam emittance and the energy spread. The results of the beam transverse size and normalized emittance for the beam energy of about 20 MeV is shown in Fig. 2 [5].

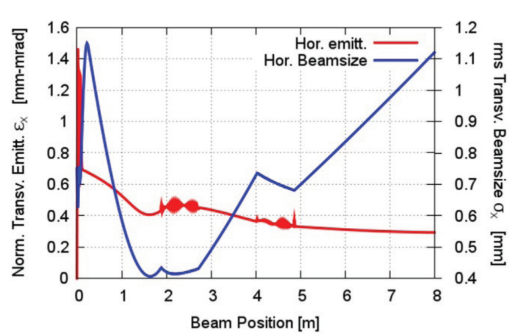

Figure 2: Transverse normalized emittance and beam size along the linac.

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ALPHA EXPERIMENTAL STATION

The tunability, high power and flexible picoseconds-pulse time structure of THz radiation turn the THz Free Electron Laser into a very attractive source of coherent radiation. The potential application can be carried out in the fields of imaging, material research, biology medicine, communication, diagnostics and others. THz FEL is already operating today and the vast majority of them operate in the infrared and far infrared regions. Several user facilities have been built to operate in the infrared region and most of them can reach or plan to extend into the THz region. As a first stage of ALPHA experimental station, the generation of coherent radiation in the range from 10 to 30 μm using FEL under Self-Amplified Spontaneous Emission (SASE) mode is considered.

THZ SASE FEL

A high-gain, single-pass FEL amplifier based on SASE is capable to produce a MW power THz pulse in a several meters long undulator. The SASE FEL radiation parameters strongly depend on the parameters of electron beam and undulator line. For the SASE process strong requirements are applied for the quality of electron beam. In the linac it is required to produce electron beam with small emittance to match diffraction limited photon beam, small energy spread to avoid gain degradation and high peak current. The electron beams produced in the AREAL linac meets these criteria and can be used for the generation of THz radiation using SASE FEL principle.

In order to get the THz radiation we consider the electron beam parameters listed in Table 2. With the current design of AREAL project the energy of 20-50 MeV will be reached by two 1.5 m long S-band travelling wave accelerating modules with 10-17MV/m acceleration gradient.

Table 2: Electron Beam Parameters

Parameter	Value	Unit
Energy	20-35	MeV
Energy spread	0.2	%
Bunch charge	250	pC
Emittance	0.3	mm-mrad
RMS bunch duration	2-3	ps

In our case we consider a 5 m long planar undulator with period of 3 cm. The electromagnetic undulator is under consideration as this type of undulator is cost-effective and very compact in structure. It also generates high magnetic field with very high precision. The field strength change depends on the electric current through the main coil. The undulator specifications for our case are listed in Table 3. Detailed study of undulator system performance and design is in progress.

Table 3: Undulator Parameters

Period length	3 cm
Total length	5 m
K	2.02
Peak field	0.72 T

The fundamental wavelength of undulator radiation is given by $\lambda = \lambda_u (1 + K^2/2)/2\gamma^2$, where λ_u is the undulator period, γ is the electron beam energy, K is the undulator parameters. For our parameters, the radiation wavelength is in the range of 10–30 μm that corresponds to 10-30 THz. The wavelength tuning will be performed via electron beam energy changes from 20 to 35 MeV.

NUMERICAL SIMULATION RESULTS

This section presents time-dependent numerical simulation results for radiation performances. Numerical simulations have been performed by GENESIS 3D simulation code [6] using parameters listed in Tables 2,3. Time-dependent simulations have been performed for the cases when radiation wavelength is 10 μm and 30 μm. In case of 30 μm radiation wavelength, rms bunch duration is assumed to be 3 ps with the energy of 20 MeV. For the case of 10 μm radiation wavelength, bunch rms duration is 2 ps and energy is 35 MeV. In Fig. 3 the average FEL power variation along the undulator line at 10 and 30 μm radiation wavelengths is shown.

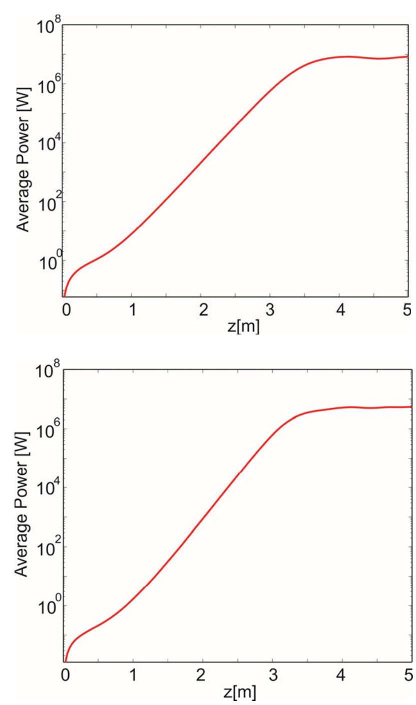

Figure 3: Average FEL power at 10 μm (top) and 30 μm (bottom) radiation wavelengths.

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For this range of parameters the FEL saturates after 3.7 m at 10 μm radiation wavelengths and after 3.4m at 30 μm wavelengths. The peak power at saturation is about 27 MW and 14 MW for the 10 μm and 30 μm respectively. The pulse energy is about 40-60 μJ. Figure 4 presents the power distribution along the bunch at the saturation point for considered cases. In these simulations 20 initial seeds for the random number generator used for particle phase fluctuation (shot noise) have been considered.

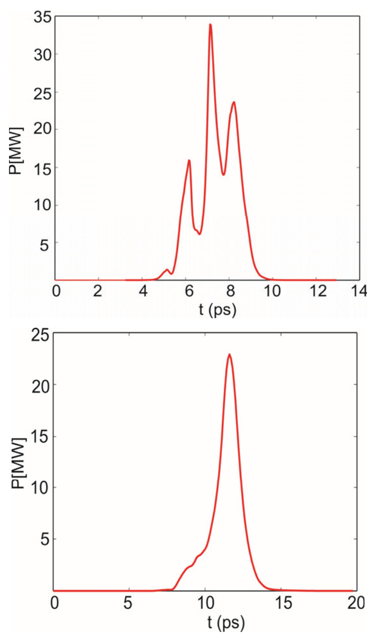

Figure 4: Power distribution along the bunch at the saturation point for 10 μm (top) and 30 μm (bottom) radiation wavelengths.

A single shot spectrum of the radiation for considered cases is shown in Fig. 5.

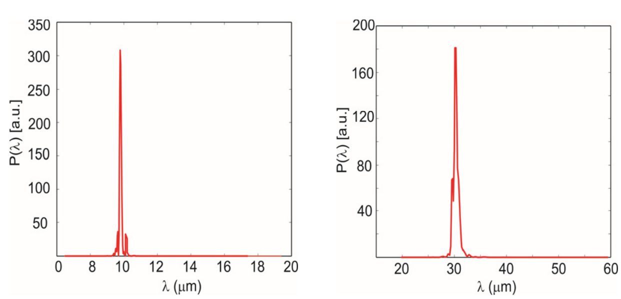

Figure 5: Spectrum of the FEL radiation at the saturation point at 10 μm (left) and 30 μm (right) wavelengths.

COHERENT THZ UNDULATOR RADIATION

In the AREAL linac, the laser system used for generation of ultra-short electron bunches can produce the pulses with the duration of 0.5-8 ps. The installation of the new module for the AREAL laser system that compresses the laser pulse down to sub 30 fs pulse duration is under consideration. The form factor of the AREAL electron bunches is then close to unity at the radiation frequencies of about 1 THz that makes the AREAL electron bunches attractive for the coherent radiation in this range.

The study of the coherent radiation sources at the ALPHA station based on the conventional undulators, single mode travelling wave structures [7] and the beam-plasma interaction is underway.

We particularly consider the usage of helical undulator for generation of high power circular polarized radiation in order to apply in a wide range of research fields based on spin resolved photoelectron spectroscopy, the circular dichroism and etc. Figure 6 shows the discrete spectrum of single electron radiation in 1m long helical undulator section [8]. For the short bunch length option the THz circular polarised coherent radiation is expected for lower modes in radiation power spectrum.

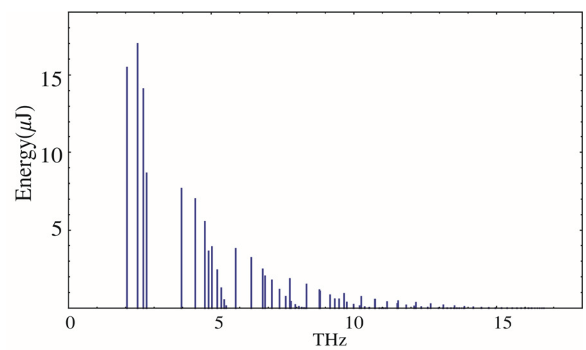

Figure 6: Discrete radiation energy spectrum for helical undulator.

SUMMARY

In this paper the status of the AREAL linear accelerator and the main features of ALPHA experimental station are presented. The SASE FEL scheme for the generation of the high power THz radiation at the wavelengths of 10 and 30 are considered. The options for the coherent THz radiation through short electron bunches are discussed.

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