General concept of the free electron laser POLFEL at Soltan Institute for Nuclear Studies

The fabulous properties of the coherent radiation generated with the free electron lasers (FEL) gained broader perspective on the experimental capabilities in physics, chemistry, biology, material engineering and medicine.

We propose to settle a high average power VUV FEL facility POLFEL at The Andrzej Soltan Institute for Nuclear Studies in Świerk. POLFEL is planned as a node of the EuroFEL network of complementary facilities, recommended by the European Strategy Forum for Research Infrastructure (ESFRI).

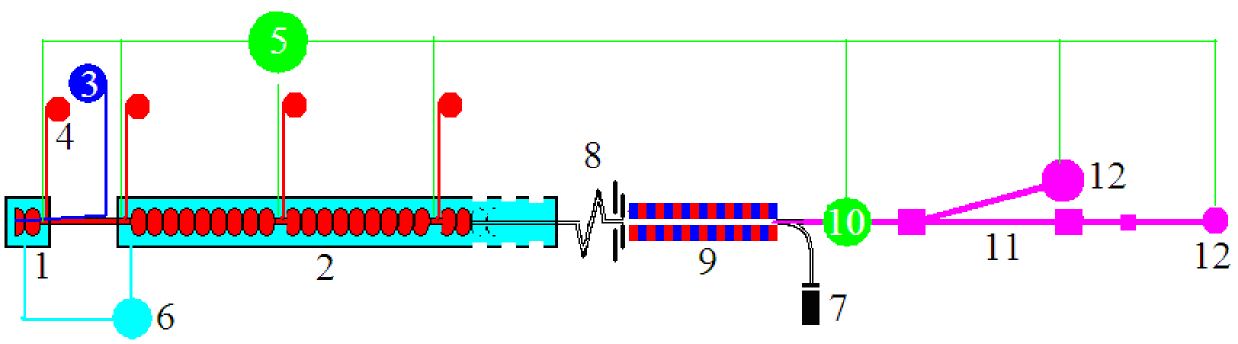
It is already a lane practiced by a number of nuclear and high energy physics laboratories to extend their scientific scope by constructing an accelerator based source of outstanding electromagnetic radiation and employing it to investigate the phenomena beyond the reach in other way. Examples are DESY, SLAC, LURE, PSI, INFN. That way seems to be the most effective to extend the benefits from a rich expertise cultivated in those sites.

There are three unequalled characteristics of the VUV radiation emitted by FEL, which are often named as its fundamental advantages: femtosecond pulse duration, huge peak brilliance and high average intensity. As the first two of them are adequately accounted in the existing facilities or those being in the advanced phase of construction: FLASH, FERMI and LCLS, we turn our efforts towards the last of mentioned parameters – the average power. The principal goal, which dictates that approach, is to enable experiments requiring maximization of the time integrated number of interacting photons. They are spectroscopic, imagining, and warm dense plasma experiments dealing with diluted samples, or processes occurring with a low probability or requiring high energy dose deposited on the surface. This research may be complemented with a photo-induced material processing, medical imaging and surgery applications.

Injector. One of the main limitations precluding the emission of a large number of photons per second is the millisecond duration of the radio frequency (rf) pulse. In the existing and up to now proposed facilities, based on the sc linacs, this disadvantage results from the normal conducting electron injectors, which can operate only in the low duty factor pulse mode when they generate low emittance highly populated beams. For POLFEL we propose a fully sc injector, based on the lead photocathode. The lead film, having one micrometer in thickness, has been chosen due to the superconducting Pb properties below its critical temperature of 7.32 K and high, as compared to other superconducting materials (e.g. Nb) quantum efficiency.

The UHV cathodic arc – based technology of the Pb film deposition onto the back wall of cavity has been established and is being currently implemented and optimized in Plasma Physics and Technology Department P5. A number of TESLA type injectors were furnished with Pb thin film photocathode. That technique, uniquely developed at IPJ, represents a significant contribution to wide research and development cooperation taken up in frames of European Coordination in Accelerator Research and Developemnt (EuCARD) and IRUVX enterprises

Crymodules and cryogenics. The Figure presents the object marked with number 2 which stands for a whole chain of cryogenic modules housing TESLA – like niobium superconducting cavities cooled with superfluid helium to the temperature of 2 K. Cavities are immersed in vessel thermally isolated from the laboratory environments by the intermediate zones kept in the temperature of 40 – 80 K Each cryomodule contains nine-cell accelerating structures, fed with the 1.3 GHz rf power supply system with the couplers ranging across the three thermal zones of the module Each structure contains a piezzo tuner and two absorbers of higher orders modes. They work with an accelerating gradient from 9 MVm^{-1} up to 27 MVm^{-1} dependent on the duty cycle. Each cryomodule contains electron beam position monitors, electromagnetic system for beam trace correction, and ion vacuum pump. All those elements are wired with cables crossing the thermal zones.



1 – electron injector, 2 – cryomodules, 3 – UV laser activating photocathode, 4 – microwave source (IOT), 5- synchronization and diagnostic system, 6 – cryogenics, 7 – electron beam dump, 8 – electron beam compressor and collimator, 9 – undulator, 10 – photon diagnostics system, 11 photon beamlines, 12 – experimental chambers

Cryogenic system bases on the 500 W cooler. Pressurized helium is expanded with Joule Thompson valves into the two phases transfer line guiding it to the vessels containing the niobium structures. The boiled helium is retraced through h the gas return pipe. Heat losses below 6 W per 9-cells structure at 2 K are expected for 9 MVm^{-1} gradient.

Two kind of cryomodules are being considered: short ones which house 2 nine-cells structures and long hosting 8 structures. Finally up to 4 short and 6 long cryomodules are foreseen for the final version of accelerator. That enables the electron energy about 1 GeV

UV laser for the photocathode initialization. Lead photocathode will be initiated with the Nd:YAG laser providing the light of fifth harmonic wavelength equal to 213 nm in pulses of 1μJ in energy and 20 ps duration time, repeated with the rate of 100 kHz.

Microwave source. The microwave power will be provided by the Inductive Output Tubes. Dependently on technical and commercial availability 30kW 60 or 120 kW source will be applied for two, four or eight 9-cell structures. IOT is the modern high power source of rf electromagnetic wave. Differently than klystron, IOT bunches the electrons by using a density modulation rather than velocity modulation. It results in

- easy switching between pulse and cw operation modes.
- higher DC/RF Power conversion efficiency
- less sensitive to DC unstability
- lower life time cost

Synchronization, control and diagnostics system. It includes rf field real time measuring and optimization, measurements of electron beam propagations parameters and safety interlock. To control the field in the cavities, a digital feedback system based on digital signal processing will be used. The analog part of the system must assure low-noise field detection and precise synchronization on the length of hundreds meters. The digital electronics must perform effective real time signal processing based on field programmable gate array (FPGA) devices and digital signal processors (DSP). Particularly ATCA and uTCA standards are considered for electronics panels while the VME is considered as a backup solution.

Electron beam compressor and collimation. The length of electron bunch is reduced in magnetic chicanes. Magnetic filed separates the faster electron from slower and directs them to the longer paths. As a result they are retarded and caught by those slower. That allow to reduce the bunch length to few tens of micrometers and peak current in range of tens kiloampers. Subsequently, the collimating slits shape the electron beam entering the undulator. That defines the beam position in the undulator channel and protects its magnets form damageous exposition to energetic electrons

Undulators. A 20 m long, single track of APPLE II – type (Advanced, Planar Polarised Light Emitter) [16, 17] permanent magnet undulators will be installed behind the accelerator. It assures the tunability across various orientation of linear and elliptical polarization and wavelength tuning without changing the linac parameters. The whole system will be divided onto 10 sections. Each section will contain about 50 periods of magnetic structure, each period includes four magnets.

Electron beam collector. Behind the undulator, the electron beam is deflected toward the beam collector. It is capable to absorb 100 kW of electron beam power and avoiding the overheating and secondary radiation, mostly gamma and neutrons. The detailed project of the collector will be prepared in IPJ based on own expertise and the experience of other accelerator facilities.

Photon beam diagnostics The aim of this system is to provide the complete data on the light generated by the laser. Particularly: pulse energy and duration time, wavelength spectrum, beam polarization, size, divergence and wavefront shape. These parameters define the experimental conditions for users working at the experimental stations and present the feedback information for steering and optimizing the facility. Photon diagnostics system contains gas photoionisation detector, spectrometers, wave front detectors, auxiliary synchronized laser and fast oscilloscope.

Beamline optics and experimental stations. The light pulse will be directed to the experimental chamber by mean of switching mirror located directly behind the diagnostic system. Optical elements: slits lenses and mirrors shape the beam accordingly to requirements of the performed experiment. The optical path is kept in ultrahigh vacuum conditions in order to avoid the oxide and hydrocarbons impurities on the optical elements an avoif the beam attenuation in the gaseous atmosphere. They save the light wavefront and focus the beam in the interaction point located in the sample held by the manipulator installed in the experimental chamber and surrounded with the measurement instruments. A part of them including light spectrometers, electron detectors, is permanently installed in the chamber. Synchronized auxiliary Vis-UV laser will be installed together with appropriate pulse distribution system in order to enable pump and probe experiments The other instruments , those dedicated for a particular experiment, will be temporary mounted by users into appropriate ports. In general the particular beamline is capable to satisfy one from two needs, which cannot be satisfied together: high energy resolution and high flux. Experimental chamber furnished with the differential pumping pipes enable the experiments in gaseous environment at the pressure ranged up to 10^{-3} mbar.

The generally formulated range scientific application expected for the proposed light source can be structurised in shape of the following topics: imaging of sub-micrometric objects, plasma physics, ultra-fast phenomena, physics of atoms, molecules clusters and solid state, photo-induced processes in technology. All they impose their unique experimental conditions, requirements for the beam parameters and instrumentation

Civil engineering. The whole facility will be hosted in four objects dedicated to

- rf supply and diagnostics system, control room
- cryogenics supply system

- accelerator tunnel with a beam collector
- experimental hall with beamlines, workshops, laboratories and office space

<u>Time schedule.</u> The projects is planned to be realized in two stages. The first will be dedicated to srf electron injector implementation and exploiting it to feed short cw linac based on 4 short cryomodules. That linac provides up to 150 MeV electron beam which passing through the planar 10 m long undulator will generate the light in the visible range (fundamental). In the second stage, the linac will be extended by number of long cryomodules and will provide 1 GeV beam in the maximal option. Six beamlines will be constructed and routinousely operated in the frame of transnational access granted to the scientific and industrial groups of users. Selected topics related to FEL technology i.e dwvelopement of photocathodes, synchronization, photon diagnostics and experimental techniques will be permanently investigated bringing, beside the results of performed experiments, a new contribution to the IPJ activity