

# ADVANCED STUDIES ON NEW GENERATION OF ELECTRON-POSITRON ACCELERATORS AND COLLIDERS FOR FUNDAMENTAL AND APPLIED RESEARCHES

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## Abstract

JINR actively leads the R&D works in particle accelerator physics and engineering, construction of the free electron laser with the aim to prepare proposals for the project of JINR participation in international collaboration on construction of the future Linear Collider (LC) CLIC/ILC [1, 2]. JINR scientists and engineers study in free electron laser physics, development and construction of systems applied for formation and diagnostics of ultra short dense bunches in the linear electron accelerators. JINR physicists also take part in several fields of activity in LC: works on photo injector prototype, participation in design and construction of cryomodules, laser metrology, and possible ILC location near Dubna.

## POWERFUL LASER DRIVER FOR EUV LITHOGRAPHY BASED ON FEL

The JINR FEL project is aimed at development of accelerator complex, based on a superconducting linear accelerator, for applications in nanoindustry, mainly for extreme ultraviolet (EUV) lithography using kW-scale Free Electron Laser (FEL) light source [3]. The project involves development of a superconducting linear accelerator to produce coherent FEL radiation for extreme ultraviolet nanolithography at a wavelength of 13,5 nm and an average radiation power of 1,7 kW. The application of kW-scale FEL source permits realizing EUV lithography with 22 nm, 16 nm resolutions and beyond. JINR-IAP collaboration constructed powerful laser source applied for photoinjector of FEL linear accelerator which can be used for EUV lithography. To produce FEL kW-scale EUV radiation the photoinjector laser driver should provide a high macropulse repetition rate, a long macropulse time duration and large number of pulses per macropulse. The laser micropulse energy should provide formation of electron beam in FEL photoinjector with the bunch charge about 1 nC.

The basic parameters of the JINR powerful laser driver applied for the FEL photo injector of EUV lithography accelerator complex are given in the Table 1.

The principal scheme of the JINR powerful laser driver applied for photoinjector is presented in Fig. 1. The generators of second and fourth harmonics (GSH and GFH) transform the wave length from 1,047 μm to 0,262 μm. The micropulse repetition frequency should be stabilized with a high accuracy of 50-100 Hz and should be varied in a range of ±1,3 kHz. The laser operates on fourth harmonic in the mode locking (ML) on base of Nd ions or Yb ions.

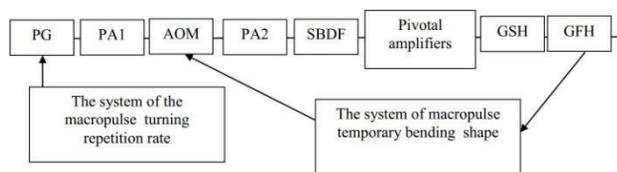


Figure 1: Scheme of powerful JINR laser driver for FEL photo injector.

Table 1: Parameters of Laser Driver for Photo Injector

Macropulse time duration, μs	800
Macropulse repetition frequency, Hz	10
Microimpulse time duration, ps	8-12
R.m.s. relative variation of micropulse time duration	1%
Micropulse repetition frequency, MHz	10
Variation of repetition frequency, kHz	±1.3
Fluctuation of repetition frequency, Hz	50-100
Number of pulses per macropulse	8000
Wave length, nm	260-266
Laser radiation energy per micropulse, μJ	1,6
R.m.s relative variation of radiation energy per micropulse	10%

The prescribing generator (PG) and the preliminary amplifiers (PA1 and PA2) are constructed on the base of the active fibers on the Yb ions. The pivotal amplifiers on the YLF crystals activated by the Ng ions are required to reach a high output radiation power. The micropulse time duration in the main harmonic corresponds to  $\tau_{0,5}=10$  ps, the average radiation power is equal to  $P_{av}=2$  mW.

## STATUS OF JINR ELECTRON LINAC

Dedicated Test Bench based on linear electron accelerator and DC Photoinjector Test Bench had been constructed at JINR during 2011-2013. Implementation of those test benches brings in the appreciable contribution to development JINR experimental and technological base and allows to carry out researches and development in following fields.

Physics and technics of accelerators: photocathodes and photo injectors; diagnostic devices; FEL and VFEL; high techniques - use of radiotechnology for perfection of the parameters semi-conductor (Si, GaAs) applied for calorimetric and track detectors real and designed colliders; the applied RF technique - generation of high-temperature plasma in the quasioptical cavity.

Main results achieved by middle of 2013 are the following:

1. Session works of the accelerator beamline and beam transporting work is being performed. Injector works in regular mode (electron gun accelerating voltage at level of 400 kV). The upgraded control system of the first acceleration station has been created and tested.

2. The first acceleration station commissioning had been performed. Electron beam current has been achieved up to 6 mA at the energy about 20 MeV [4].

3. Undulator based on permanent magnet structure had been assembled at the test-bench in VBLHEP and field quality measured. Results show required value of the field distribution and magnitude at the poles.

4. Design, manufacture and commissioning of the FEL IR deflection magnet had been performed. Synchrotron radiation of IR range from the 25 MeV electron beam bended in deflection magnet had been detected with dedicated detection system.



Figure 2: General view of the commissioned first acceleration station of the JINR electron linac.

### HOLLOW PHOTOCATHODE CONCEPT FOR E-GUN

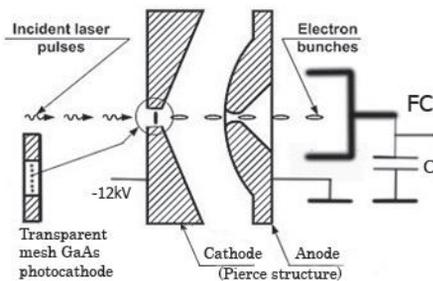


Figure 3: Principal scheme of the hollow cathode DC photo-gun for mesh type (perforated) GaAs photocathode.

The photo-gun is a key element of the injectors for producing high-charge electron bunches with perfectly controlled timing for accelerator applications. Research continues on various schemes of the cathodes, cleaning and surface preparation techniques. In DC gun schemes, a static voltage is applied between the cathode, where the electrons are generated, and a hollow electrode at the beam exit (anode) to create the static electric field that accelerates the electrons. So far the promising technically challenging DC gun with the *hollow cathode* proposed by JINR, see Fig. 3. In development of this concept by

most perspective direction there was use of photocathodes in the form of a grid with sizes: wire diameter 0,03 mm; the size of a cell 0,04 mm.

In the zone of the hollow cathode with a small depth is set the mesh form photocathode (Nb, Mo, Cu, DLC/mesh, Stainless Steel, perforated photocathodes from bulky materials, etc.) with optimum of a transparency extent for a laser beam and diameter of a wire or perforation size. Such cathode geometry allows QE rising. Backside illumination radically simplifies laser beam targeting on emitting surface and allows photocathode working surface laser cleaning. Besides, at such gun scheme the photocathode working surface practically is not exposed ion back-bombardment.

The polarized electron photo-gun must produce the required bunches with polarization greater than 80%. The most promising candidates for the polarized electron source are GaAs and strained GaAs/GaAsP superlattice structures. We have focused our attention on the GaAs mesh preparation. GaAs mesh was prepared by using electron beam litography and inductively coupled plasma etching.

The mesh shaped GaAs was fabricated from the crystalline GaAs substrate (impurity at level of 0,5 %).

Fig. 4 shows the top side which Ni mask and bottom side of the GaAs substrate after inductively coupled plasma etching using  $\text{CCl}_2\text{F}_2$  plasma. The etch rate of GaAs was  $0.40 \mu\text{m}/\text{min}$ . The diameter or side square of mesh are 8 mm and mesh type GaAs photocathode chip have  $13 \times 13 \text{ mm}$ . The resist pattern was square, and length of side was  $200 \mu\text{m}$ .

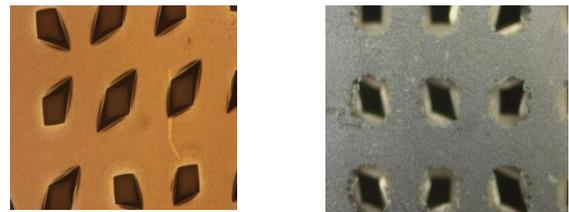


Figure 4: Top side (left) which Ni mask and bottom side (right) of the GaAs substrate after inductively coupled plasma etching using  $\text{CCl}_2\text{F}_2$  plasma.

The 15 ns UV laser pulses (quadrupled Nd:YAG laser) with laser spot size  $\leq 5 \text{ mm}$  are used to backside illuminate the perforate GaAs as photocathode. All experiments were performed under a pressure of  $3 \times 10^{-7} \text{ Pa}$ . With an accelerating voltage of 12 kV and a laser irradiance of 1 mJ, maximum bunch charge of 2,183 nC ( $C=680 \text{ pF}$ ,  $U=3,21 \text{ V}$ ) was observed.

### THE EXPLOSION WELDING TECHNIQUE FOR 4<sup>TH</sup> GENERATION CRYMODULE

JINR group in the frame of collaboration JINR-FNAL-IFN-RFNC joined the ILC topic in 2006 and proposed to use the explosion welding technique for making bimetallic titanium–stainless steel (Ti + SS) and niobium–stainless steel (Nb + SS) joints. Since SS and Ti cannot be

welded by conventional electron-beam welding methods, alternative methods are under investigation. This has been successfully done for other SRF accelerator components.

The first stage task was to make a bimetallic transition from the helium supply pipe of stainless steel (SS) to the cryomodule shell of titanium (Fig.5). This would appreciably lower the cost of the accelerator, and to produce bimetallic billets of tube type parallel circuit for explosion welding was used.

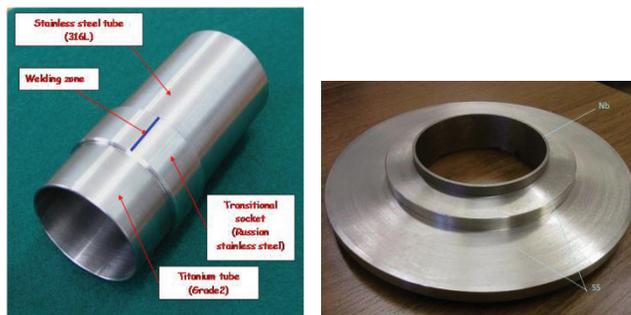


Figure 5: SS+Ti pipe (left). Nb+SS element (right).

These piping samples were then tested in superfluid helium conditions at Fermi National Accelerator Laboratory test facilities. During several extremely hard conditions tests the leak detector showed the background leak rate  $Q \leq 10^{-10}$  mbar·l/s, and no leak was observed.

Based on the results achieved in joining bimetallic tube elements by explosion welding, the collaboration set about solving a more complicated problem of redesigning the fourth-generation cryomodule by replacing titanium with stainless steel as a material for the helium Vessel shell. Four Nb+SS elements (fig.5) were produced at VNIIEF (Sarov, RUSSIA) using two explosion welding schemes, external and internal cladding. Leak tests by thermal cycling in liquid nitrogen and at 2K temperature carried out with all Nb-SS joint in samples showed rather good results: no leakage was found in the specimens at the background leak detector indication  $2 \cdot 10^{-9}$  mbar·l/s (gaseous He was used for vacuum testing). Thermal tempering of explosion-welded Ti+SS and Nb+SS specimens leads to complete relaxation of internal stresses in Ti, Nb+SS joints and makes the transition elements quite serviceable. Investigations have shown that explosion welding allows unique bimetallic components to be made for cryogenic units of accelerators, research equipment and for civil engineering tasks.

### ILC TERRITORIAL COMPLEX

In collaboration with Moscow Institute of Architecture dedicated research had been performed: “*International Linear Collider territorial complex in the north of the Moscow region*”[5]. The Scheme of the territorial development of the Moscow region, the Scheme of the development and placement of specially protected natural territories of the Moscow region, the contours of the General plans of Dubna, Kimry and Taldom, as well as Report on the results of the preliminary engineering-geological research were analyzed. For Dubna, the

optimal solution lies in the creation of a satellite town, connected with Dubna and JINR. The concept of such a town was designed.

### DETECTION ANGLE SEISMIC VIBRATIONS AT A FREQUENCY OF "MICRO-SEISMIC PEAK"

The Earth surface angular displacement was studied by the high resolution inclinometer (HRI) of a new design concept. The superweak  $10^{-7} \div 10^{-8}$  rad ground angular motions of the seismic, industrial and terrestrial origins have been registered. On the modified experimental set-up has been achieved sensitivity of  $5 \cdot 10^{-9}$  rad when angular oscillation measurements. The new measurements, besides the earth quake registration, allowed one to find the new seismic phenomenon: *the earth surface practically continuously demonstrates the angular oscillations with the so-called “micro seismic peak”* frequency [6]. The amplitude of the measured angular oscillation was up to  $10^{-7}$  rad. Their frequency was 0,13 Hz (Fig. 6).

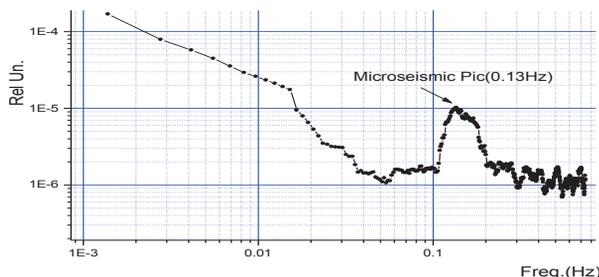


Figure 6: The Fourier analyses of the earth oscillation.

The phenomenon observed puts some limits on the linear accelerators geometry stability and, probably, one needs to make some seismic isolation of both the LFL and accelerator as whole.

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