STATUS OF DESIGN AND DEVELOPMENT OF DELHI LIGHT SOURCE AT IUAC, DELHI*

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Abstract

In the first phase of Delhi Light Source (DLS) project, a photocathode based normal conducting RF gun will be used to produce electron beam of energy ~ 8 MeV. The short pulses from a high power laser system will be split in to many pulses ('Comb beam') and will be used to produce electron beam bunches which will be injected in to a compact, variable gap undulator magnet to produce THz radiation. Different components of the facility e.g. the copper cavity, photocathode deposition setup, high power RF system, laser device, Undulator magnet etc. are being designed, developed or procured. It is expected that the production of electron beam and THz radiation will be demostrated by end of 2017 and 2018 respectively.

INTRODUCTION

The project of development of a compact light source named as Delhi Light Source (DLS) based on the principle of Free Electron laser has been taken up at Inter University Accelerator Centre (IUAC), New Delhi. The project will be developed in three phases and presently the development of the first phase is going on [1].

In the conventional Free Electron Laser, the formation of the micro-bunches from a macro-bunch takes place inside the undulator magnet. But, in phase-I of DLS which will be a pre-bunched FEL, the micro-bunch formation takes place at the photocathode by striking it with ultra-short laser pulses (time width ~ a few hundred of femtoseconds). If the laser pulse is already split into many pulses (e.g, 2, 4, 8 or 16) then a 'comb beam' [2, 3] structure of electron micro-bunches with an identical separation of laser pulses will be produced at the photocathode and they will gain a final energy of about 8 MeV at the exit of the 2.6 cell RF gun for an expected accelerating field of ~ 120 MV/m. The gun will be followed by a normal conducting solenoid magnet which will focus the beam at the middle of a compact undulator magnet (length – 800 mm) which is being designed to produce tunable THz radiation in the range of ~ 0.15 to 2 THz.

The wavelength of the THz radiation will be equal to the separation of the electron bunches and this separation can be varied by changing the separation of the split laser pulses with the help of optical elements. By adjusting the electron energy and the magnetic field of the undulator, any wavelength (equal to the separation of the electron microbunches) in the tunable range of the THz radiation can be produced.

MAJOR COMPONENTS OF THE FACILITY AND THEIR STATUS

The layout of the accelerator and experimental facility is shown in Fig. 1. A class 10000 clean room with dimension of about 28m×8m is constructed to accommodate the entire accelerator and the experimental facilities (Fig. 1). Substantial progress has been achieved in many areas of the Phase-I of DLS, as listed in the following:

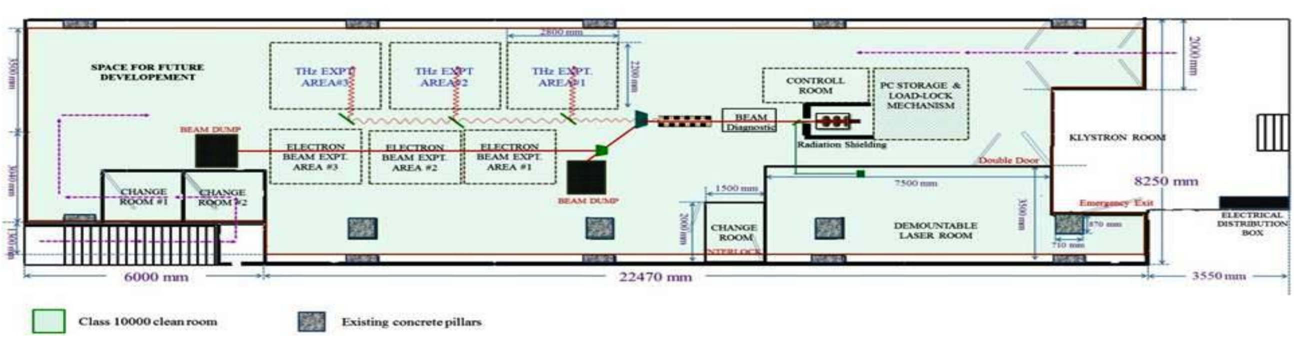

Figure 1: The schematic layout of the first phase of DLS facility.

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RF Electron Gun

The resonance frequency of the RF gun was chosen to be at 2860 MHz for a 2.6 cell copper cavity whose design is similar to those at BNL and KEK [4, 5].

The design and the fabrication of the copper cavity (Fig. 2) were accomplished at KEK, Japan. Indian researchers from IUAC and SAMEER have participated in the activity. The results of the bead pull measurement data along with the electric field profile simulated from Superfish [6] is shown in Fig. 2.

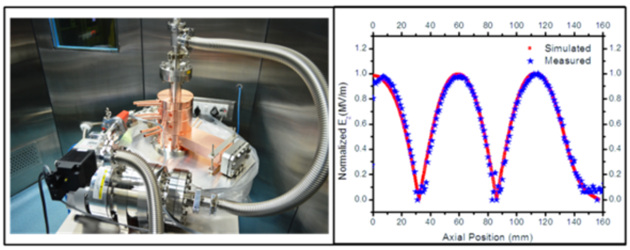

Figure 2: 2860 MHz copper cavity as RF gun and its electric field profile from Superfish and bead pull measurement.

Photocathode (PC) Preparation System

The copper photocathode plug will be used at initial stage to produce high quality ultra-short bunches of electron beam. To produce Cs_2Te and the other advanced photocathode material, the design of the deposition chamber along with the provision of laser cleaning of the photocathode, storage chamber and its insertion mechanism in to the RF cavity are in the final stage (Fig. 3). The complete deposition and the transfer mechanism of the photocathode will be carried out at a vacuum level of $\sim 1\times10^{-11}$ mbar.

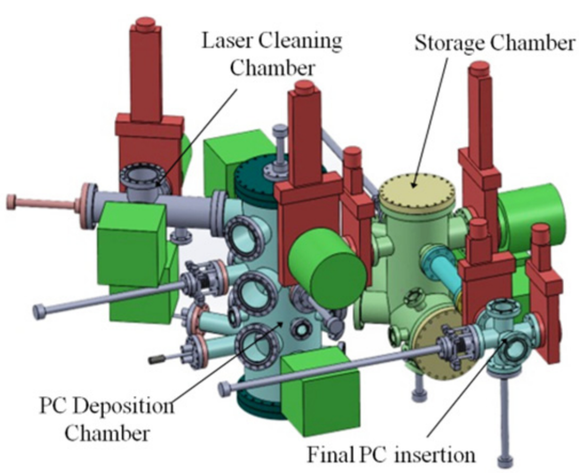

Figure 3: Photocathode preparation system.

Proposed Laser System for the Photocathode

As per the design criteria, each laser pulse (FWHM ~ 100-500 fs) will be split in to 2, 4, 8, 16 micro-pulses to generate 'comb beam' with the separation of a few hundreds of femtosecond (~ 2 × FWHM). There will be a provision to vary the separation between successive micro-pulses so that the THz radiation produced from the undulator can be tuned. A few commercial laser systems e.g. fiber, hybrid and solid state devices are currently being examined and the most appropriate one will be chosen shortly. Table 1 shows the output from three high power laser systems. The tentative laser energy required to produce the 'comb electron beam' of a nominal charge of 6 pC per microbunch from metal and semiconductor photocathodes is shown in Table 2, here the numbers correspond to pulse splitting in UV.

Table 1: Comparison of Two Proposed Laser System

Laser System	Energy/ Pulse at IR	Energy/ Pulse at UV	Pulse Width
Fiber	>200 μJ	>20 μJ	300 fs
Hybrid	>2 mJ	>200 μJ	500 fs
Ti:Sa	>10 mJ	> 1.5 mJ	100 fs

Table 2: Requirement of Laser Energy from Cu and Cs_2Te Photocathode

Charge / Pulse	No. of microbunches produced	Laser Energy (UV) required at the PC	
		Cu	Cs_2Te
6 pC	1	2.8 μJ	5.6 nJ
6 pC	2	6.29 μJ	12.58 nJ
6 pC	4	14.17 μJ	28.35 nJ
6 pC	8	32 μJ	64 nJ
6 pC	16	74.6 μJ	149.3 nJ

Beam Optics Design by Using ASTRA Code

The beam transport simulation is being done by using the ASTRA code [7]. A few results of 8 microbunches produced at photocathode and transported up to the undulator magnet are shown in Table 3. The length of the undulator magnet is 800 mm and its entrance is kept at 2 meter from the photocathode. The effect of space charge force is observed in the simulation calculation due to the small time width of the electron bunches (300 fs). So, when the charge per microbunch is increased, more separation between the successive bunches is necessary to avoid any serious overlapping of the electrons. In the simulation, the major parameters used are:

a. Accelerating field of the cavity is 120 MV/m to produce > 8 MeV of electron beam.
b. At photocathode, the FWHM of the beam is 300 fs and their subsequent separations are optimized for 6, 12, 25 pC of charge/micro-pulse by ensuring that at least 60% of the electron beams are not overlapped among the neighbouring bunches (Table 3).
c. Optimized launching phase for all three charges 35^0 and the emittances are within 0.4 to 0.6 π mm-mrad.

Figure 4 shows a few plots of 8 microbunches with (i) total charge is 25 pC/microbunch, (ii) FWHM is 300 fs, (iii) microbunch separation is 800 fs, (iv) beam launching phase is 35^0 and (v) the solenoid field is 0.273 T.

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Table 3: A few Optimized Parameters from Astra

Charge/ micro-pulse (pC)	Separation between microbunches	Solenoid Field (T)	Freq. Produced
6	500 fs	0.264	2 THz
12	650 fs	0.269	1.5 THz
25	800 fs	0.273	1.25 THz

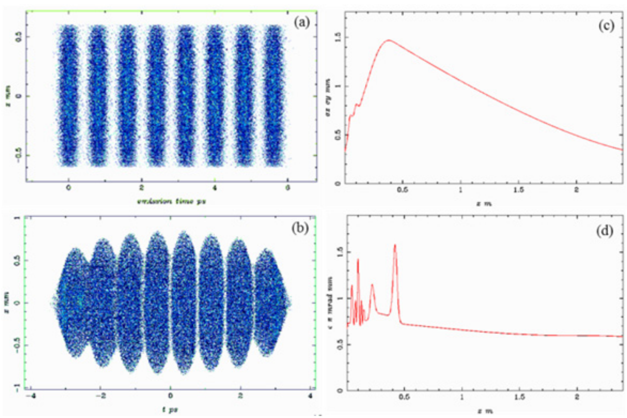

Figure 4: The figures show (a) the electron beam profile (a) at the photocathode, (b) at the middle of the undulator (2.4 m), (c) beam size profile and (d) emittance of the beam for a total charge of 25 pC/microbunch.

High Power RF System

The RF system for the Delhi light source consists of a high power klystron along with a suitable modulator having appropriate pulse flatness to match the beam stability requirement and the low level RF system (LLRF). To meet the condition of the beam stability, the RF phase stability of 0.1 degree, and amplitude stability better than 0.01% is chosen as the design goal for the LLRF system. The planned LLRF subsystem of the RF gun is composed of cavity controller with an amplitude loop and a phase loop operating in pulsed mode along with a RF protection for high power RF system. There will be a separate closed loop control to make the laser system synchronized with the cavity RF reference. The detail specification of high power RF system is mentioned below in Table 4.

Table 4: Main Parameters for Klystron & Modulator

	Parameter – RF system	**Value**
1	Peak Output power	≥ 25 MW
2	Average Output power	≥ 5 kW
3	Operating frequency	2860 MHz
4	Bandwidth (-1 dB)	± 1MHz
5	RF pulse duration	0.2 μs to 4 μs
6	Pulse repetition rate	1-50 Hz
7	Pulse top flatness	±0.3%
8	Rate of rise and fall of modulator output voltage	200-250 kV/μs
9	Long term stability	±0.05 %

Compact Undulator Magnet

The preliminary calculation related to undulator magnet has been initiated. As per the beam optics calculation, the frequency range of the THz radiation to be produced from Phase-I of DLS is to be confined between 0.15 to 2 THz which can be achieved with the undulator whose wave-length (λ_U) is 40 mm and no. of periods are 20 (Table 5).

Table 5: The Tentative Parameters of the Undulator

λ_R in mm	Freq. produced (THz)	Electron Energy (MeV)	λ_U in mm	K Value	B_u (T)	Re-quired gap (mm)
2	0.15	6	40	3.575	.96	12
0.1	2	8	40	0.475	.13	36

CONCLUSION

The DLS project of IUAC is under construction and the design, development, procurement of different subsystems are presently pursued. The normal conducting RF gun is already fabricated and tested with low power RF. The beam optics calculation is in the final stage and with the results, the simulation calculation will be started to optimize the gain of the electromagnetic radiation produced from DLS (phase-I). The high power RF system including Klystron and Modulator are being purchased from a group of companies. The finalization of the laser devices will be complete within a few months and then the purchase procedure will be started. The design of the photocathode deposition system is ready and the purchase order will be placed shortly to procure the complete system. The design and the selection of the beam line and the beam diagnostic components are presently going on. The production of electron beam and THz radiation are expected to be demonstrated by 2017 and 2018 respectively.

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