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PHOTOCATHODE STRESS TEST BENCH AT INFN LASA

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Abstract

A UHV test bench based on a 100 kV DC gun and a 100 MHz repetition rate laser has been setup up at INFN LASA to test Cs_2Te photocathodes. This operation mode is the base for the BriXSinO project, currently in the design phase in our laboratory, and the qualification of the Cs_2Te photocathodes is a key issue. In this paper, we present the recent progress on the different components that are part of this R&D activity.

INTRODUCTION

High brightness electron sources are nowadays a key component for the most advance accelerators capable of generating intense X-ray beams. Free Electron Lasers (FELs), Energy Recovery Linacs (ERLs) and Inverse Compton Scattering (ICS) sources are some of the leading machines in this field.

To generate the electron beam with the required specifications, a laser-driven photocathode is exposed to very intense electric fields create either in an RF Gun or in High Voltage (HV) DC gun for promptly accelerate the emitted electrons.

Besides the many applications of these electron sources, the most challenging ones require average currents up to 100 mA in CW or nearly CW operation mode with bunch repetition rate of the order of GHz. To cope with these extreme requests, significant advancements are necessary both on the lasers and on the photocathodes.

Lasers need to provide train pulse at these high frequency guaranteeing, after all the manipulations necessary for providing the spatial and temporal profile needed to generate electron beams with the smallest emittances, the required energy per pulse necessary to photoemit the requested electrons.

On the photocathode side, operation at these very high repetition rates poses questions on the capability of the photoemissive film to sustain them. Moreover, the photocathodes are required to operate for long period to reduce the downtime of the accelerators.

In the context of advanced X-ray source based on accelerators, we are designing BriXSinO, an innovative accelerator whose aim is to operate as an ERL or a two-way accelerator feeding an ICS source and a THz FEL. It is within this framework that we are developing the key technologies necessary to its operation and two hot-topics are the development of a laser capable of operating at 100 MHz and a High Voltage (HV) testbench [1], coupled to the laser, for testing Cs_2Te photocathodes. The electron beam foreseen has an average current of 5 mA at 100 MHz repetition rate.

BriXSinO

BriXSino is a reduced scale demonstrator of the modified push-pull folded ERL scheme [2], capable of accelerating electrons up to a maximum energy of 50 MeV.

In this reduced scheme, only one cryogenic module, hosting three seven-cell 1.3 GHz superconducting cavities, will be used both for ERL operation but also for two-pass mode acceleration. In BriXSino, we will also test the compression of the beam in the recirculating loop. Moreover, in the loop, two experimental stations will be available for ICS and THz FEL. Figure 1 shows a functional layout of the machine.

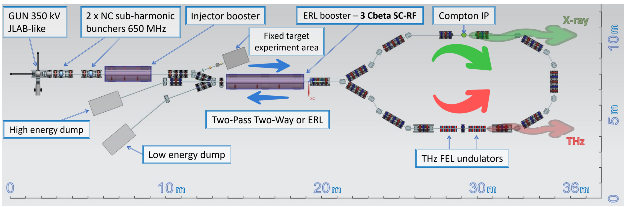

Figure 1: BriXSinO's functional layout.

The development of BriXSino's test facility (foreseen at INFN LASA in Milano) aims at maximum energy sustainability by investigating:

- best efficiency in accelerating a high-power electron beam (ERL operation)
- production of very high flux radiation beams (in THz spectral range by the FEL and in X-rays by ICS) for medical applications and applied research in general.

The Technical Design Report of BriXSinO is now available at [3] and a dedicated presentation at this conference is reporting the latest progress [4].

LASER SYSTEM

As previously anticipated, the laser plays a key role in the BriXSinO operation and, hence, we have an active R&D on this topic.

The scheme of the laser system is shown in Fig. 2. The main oscillator, model Orange from the Menlo Company, is a 1035 nm mode-locked Yb laser, with a 92.857 MHz repetition frequency. An internal amplification system guarantees

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a maximum output power of 10 W, with a spectral width of 13 nm and a pulse length of 200 fs.

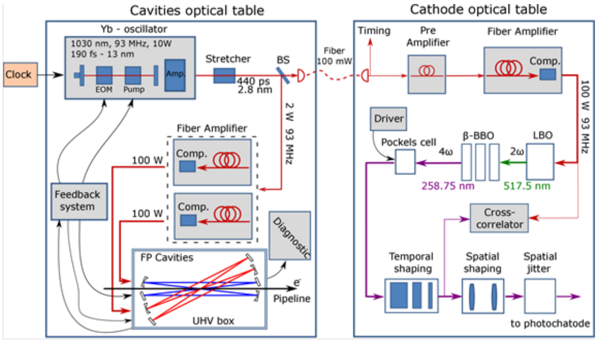

Figure 2: Schematics of the laser complex based on two optical tables. One is hosting the oscillator and the R&D on Fabry-Perot optical cavities necessary for the ICS source. The second table is dedicated to the generation of the laser pulses for the photocathode.

The 4th harmonic at 258.75 nm is generated exploiting two consecutive second harmonic (SH) stages of the original beam laser wavelength (1035 nm). The first SH generation (second harmonic, 517.5 nm) is performed by an LBO crystal, while the other (fourth harmonic, 258.75 nm) exploits a BBO crystal. The maximum efficiency for the 517.5 nm generation, assuming a 5 mm long LBO, is reached at 180.5 °C crystal temperature. The system has been tested up to 10 W of first harmonic, reaching a power of 3.1 W of second harmonic.

The phase condition for the fourth harmonic, on the other hand, is achieved in a critical phase matching condition, by rotating the axes of the BBO crystal with respect to the incident beam. In this configuration, however, the beam experiences a walk-off process. Moreover, due to the different group dispersion of the second and the fourth harmonics inside the BBO crystal, the latter slips on the first giving rise to a long slope before the peak, getting a time length of about 3 ps.

Actually, in order to minimize the walk-off, we generate the fourth harmonic using three 1.5 mm long BBO crystals, aligned with opposite optical axes so that the effect is compensated. The current maximum power level of the fourth harmonic is around 700 mW.

A temporal shaper based on a set of birefringent crystals looks suitable for our project, since it is simple, flexible, and very stable. In our system, we employed a set of three α-BBO to get 8 replicas of the initial pulse. The first crystal is 13 mm long to obtain a 22 ps pulse duration.

The temporal profile of the pulses is acquired through a cross-correlation with the first harmonic, as visible in Fig. 3 left. Such cross-correlation between the first and the fourth harmonics generates the third harmonic (345 nm). Results are displayed in Fig. 3 right. The visible ripple is due to the pulse shape of the fourth harmonic, and we are currently dealing with it. Furthermore, it depends on the time length of the starting pulse.

Finally, spatial stabilization of the pulses on the photocathode target is performed with a 4-dials photodiode and a feedback loop based on two analog PIDs and two piezoelectric actuators, providing a closed-loop stability lower than 5 µm.

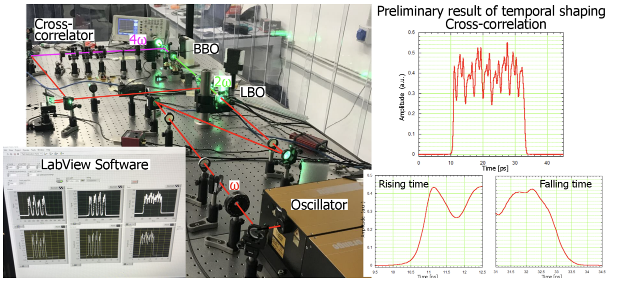

Figure 3: Cross-correlation system for the temporal characterization of the laser pulses. On the right the cross-correlator with the dedicated acquisition system. On the left preliminary results and zoom into the rising and falling edge of the temporal profile.

In the next period, we will deal with both the pulse picking and spatial shaping. As far as the first is concerned, the repetition rate of the laser pulses will be controlled by a Pockels cell from kHz up to the repetition rate of the oscillator. On the other hand, the spatial shaping aims to make the pulses rectangular in the transverse direction. We will achieve this using the so-called pi-Shaper, based on the aspheric lens method: two lenses will rearrange the Gaussian intensity distribution of the incoming pulse, in order to obtain a spatially rectangular profile.

PHOTOCATHODES

INFN LASA has a long time experience in the deposition of high quantum efficiency (QE) photocathodes used in high brightness electron sources as well as in the related Ultra High Vacuum system necessary to preserve the photocathode properties [5, 6].

For this experiment, we have selected our Cs_2Te photocathode as the best candidate. This material has already been used in different operative conditions and in different RF guns showing very good performances. However, its operation at very high repetition rate is surely a challenging request that need to be demonstrated. Indeed, our major concerns are the significant extracted charge and, in case of this experiment, its operation in a DC electric field that, besides accelerating the electrons, it also allows accelerating back the ions produced by collision of the electron beam with the molecules of the vacuum environment. The ion back bombardment can be a serious problem and might completely destroy the emitting film: mitigating actions have been proposed and they will be studied here in details. The photocathode stress experiment has been in fact design to precisely address these kind of problems.

A key parameter is also the photocathodes robustness that we will be characterize not only measuring the total extracted charge extracted, but also monitoring QE and reflectivity to investigate changes of photoemissive and optical properties under these demanding conditions. For these measurements, a custom-cross piece equipped with two sapphire UV viewports has been designed and it is now under fabrication. It will be used for the alignment of the laser on the Cs_2Te film but also for the reflectivity measurements. Further analysis will be conducted on post-usage photocathodes, once the cathode suitcase will be re-connected to the LASA production system.

Coming to the hardware necessary for manipulation and transfer of the photocathodes into the DC gun, all the components have been already assembled (as ashown in Fig. 4) and, after the operations needed to achieve Ultra High Vacuum conditions, we will be ready to start the conditioning of the DC gun.

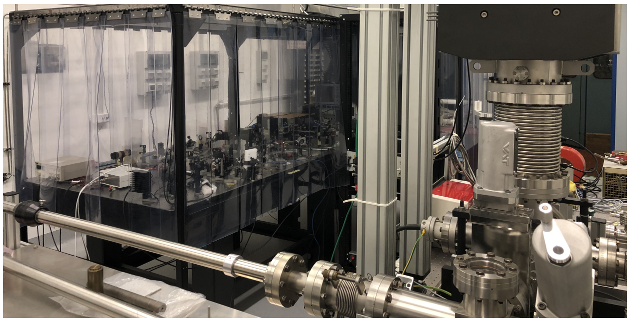

Figure 4: View of the experimental setup for the stress test of the photocathodes. On the right, the DC gun with the UHV system required for preserving the photocathode properties. On the left the "photocathode" optical table.

HIGH VOLTAGE DC GUN

The DC gun is based on a pseudo parallel–plate geometry and it was designed with a removable photocathode [7]. It is followed by a couple of solenoids to focus the beam, and a short beamline (0.4 m long) with diagnostics. The compactness of the whole system allows having the complete installation on an optical table.

Our high voltage extractor itself is based on a CERN design, modified to increase the accelerating gradient while without modifying the peak surface fields. This is done by implementing an elliptical curvature for the extraction electrode. The same concept is used in the design of the cathode region. These modifications reduced by 6 % the Kilpratick limit thus allowing an increase in the maximum accelerating gradient while keeping constant the gap voltage. The nominal maximum accelerating gradient is 12.5 MV/m on a gap of 8 mm.

The cathode polarization will be done by a special designed Heinzinger negative HV power supply. It is capable to deliver deliver up to 150 kV at a nominal current of 3 mA. The operation of this power supply might be completed done remotely.

To connect the power supply to the DC gun we are using a two meters long cable with a capacitance of 80 pF. In series to the cable, we have a 1 MΩ resistor to limit the accumulate energy in case of discharges.

Even if the DC gun structure has been designed for 100 kV, part of the activity on the stress test experiment will be to push to higher voltage the DC gun in order to improve the performances of the test bench in term of extractable charge as well as in term of beam dynamic performance.

CONCLUSIONS

The photocathode stress test is a key activity to asses the capability of laser and photocathodes to generate beam with average current in the 5 mA range.

At INFN LASA, we are developing all the necessary tools to achieve this goal. The laser system is being developed to deliver pulses at 100 MHz with the proper temporal and spatial profile, studied to minimize the beam emittance.

The photocathode system is now connected to the gun and ready to transfer photocathodes. The initial conditioning of the gun will be done using a Mo plug, much more robust than the high QE Cs_2Te photocathode.

The DC gun itself is ready and its conditioning will start in a short time. We will try to push the HV towards the maximum that the HV power supply can deliver, i.e. 150 kV, to increase the extracted charge and the beam performance.

Extracting high average current will be the goal of the photocathode stress test to learn the limiting factors. Moreover, the photocathode stress test will be also a valuable playground where new ideas and concepts will be developed.

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