SUMMARY OF WG1 ON INJECTORS – ERL 2015

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Abstract

Here we summarize the recent progress made in injectors for high average power Energy Recovery Linacs. The progress during the past two years is discussed along with the remaining technical challenges for producing reliable, high brightness, high average-power electron sources.

INJECTOR PERFORMANCE – DC GUNS

During the plenary session results from the commissioning and measurements with the DC gun at Cornell were reported. The Cornell injector was commissioned for high bunch charge operation at 9 MeV, in order to determine whether it would be a possible design option for the proposed LCLS-II injector. Initial problems with asymmetric and poor emittance were traced to a stray quadrupole field in their solenoids, and were fixed by adding a correcting quadrupole interior to the solenoid. In the end, all major objectives were achieved, demonstrating that a DC gun at 400 kV is a viable option for high brightness with bunch charges up to 300 pC. Comparison with simulation was excellent when using a measured transverse laser profile in the simulation (Fig. 1).

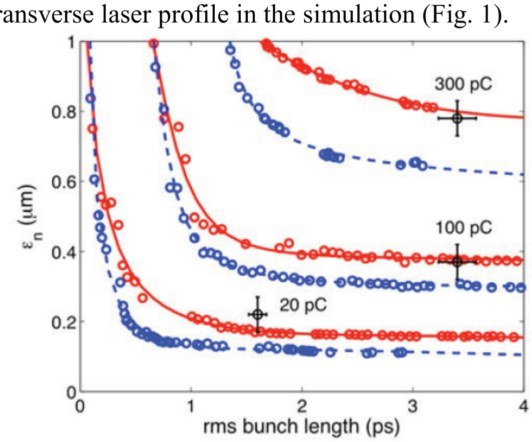

Figure 1: Cornell injector emittance results at 20, 100, and 300 pC. Black points are measured, blue points are simulated with ideal laser, red are simulated with measured laser profile.

In the first injector performance session the status and progress of the DC guns for cERL in Japan were discussed. Their gun has been designed to push the limit of the voltage possible from a DC gun. Currents up to 1.8 mA have been demonstrated, operating at the full target voltage of 500 kV, showing the benefits of the design of the guard rings on their insulating ceramic (Fig. 2). Unfortunately, two of those rings were accidentally broken during transport of the gun, resulting in performance limited to 440 kV. To regain 500 kV operation, an additional ceramic is planned to be installed.

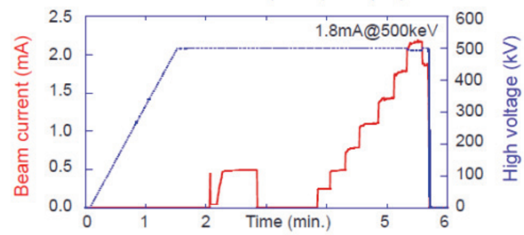

Figure 2: High current beam operation of the cERL DC gun at 500 kV.

We also heard from the status of the 70 mm DC gun at KEK. Their gun has been processed up to 550 kV, and a gradient of almost 7 MV/m—and remarkably, has shown repeatable trends in the processing (Fig. 3). A new model was presented to explain this reproducibility, explaining the mechanism as due to electron stimulated desorption (ESD). Beam operation at a more conservative voltage of 400 kV has just begun, and preparations are underway for a mA level beam test.

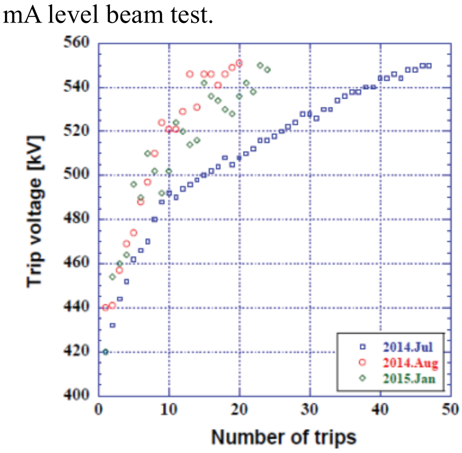

Figure 3: Processing reproducibility in the KEK DC gun.

Finally, the status of the funnelling gun at BNL was reviewed. The gun has been fabricated, assembled, and tested by industry. Importantly, a brief beam test was performed where two low current (nA) beams were correctly combined, showing that no cathode cross talk is observed at this current level. After that initial test, the system has been shipped to BNL for further high current tests.

INJECTOR PERFORMANCE – SRF GUNS

Results from commissioning activities with SRF guns were discussed in a joint session Injector and SRF for ERLs. The first session gave an update on the BNL 704 MHz SRF gun. Importantly, the new multipacting-free (MP-free) cathode stalk design has been completed (Fig. 4) and has allowed the SRF gun to operate up to 2 MV CW. A

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beam test was performed with a K2CsSb cathode, which successfully demonstrated that the QE of the cathode is preserved after cryogenic cooling—no cathode degradation was observed. In addition, up to 0.55 nC per bunch was extracted from the gun, in a low-rep rate beam test at 0.85 MeV.

Figure 4: New multipacting-free cathode stalk with Ta tip, used in the BNL 704 MHz SRF gun.

Results from the recent beam measurements with the new SRF gun II at ELBE were presented. Though operating at a smaller gradient than expected due a cavity breakdown event, 7 MV/m, it should still potentially allow up to 500 pC, improving user operation. The cathode-cavity interface is the primary challenge at the moment, due to the need for high quality cleanliness. In addition, transverse emittance and longitudinal phase space measurements were performed, and agreed well with expectations from Astra simulations (Fig. 5).

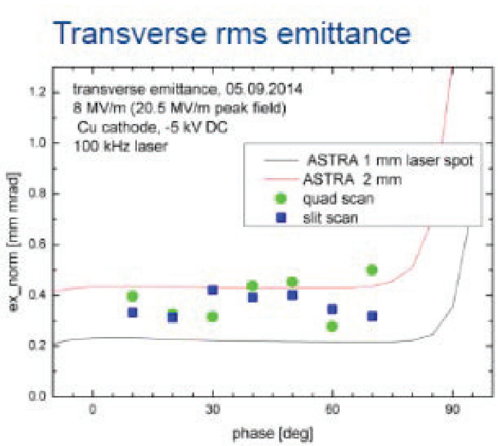

Figure 5: Transverse normalized emittance versus launch phase measurements using two methods with the SRF gun at ELBE.

CATHODES AND LASERS

Two talks were given on laser systems. First, during the plenary session, we heard a summary talk on the state of lasers for use in ERLs. Due to the existence of high quantum efficiency cathodes, drive lasers are now powerful enough for 100s of mA of beam current, and this is not a limiting factor any more. But, more work is still needed on long term stability, both in position and phase. More flexibility is also needed in the repetition rate and pulse structure, in order to have a method to raise beam current without affecting the e-beam optics.

We also saw a presentation on a new method to shape laser profiles using a spatial light modulator (SLM). Instead of making a phase grating, and exploiting diffraction to tune the shape of the laser beam, the SLM was used to manipulate the polarization of the light, on a pixel-to-pixel scale. A subsequent polarizer was then used to carve out the desired shape from the initial beam. Though inherently lossy, this method benefits from being both fast, simple, and potentially very accurate (Fig. 6).

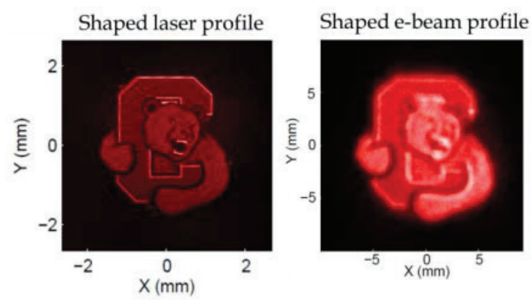

Figure 6: Example shaped laser and electron beam profile.

We heard two talks, related to an effort to understand and control the surface roughness on Alkali photocathodes. K2CsSb photocathodes have been regarded as a strong candidate for excellent electron sources. The traditional sequential growth method for this type of photocathode could result in a rough surface which will have an adverse influence on the beam emittance in the high gradient field used in most applications. Previous studies have revealed the evolution from crystalline Sb layer, to a K-Sb compound, and then to the crystalline K3Sb significantly increase the surface roughness. X-ray reflectivity (XRR) is a powerful non-destructive thin film characterization method and has been applied to the growth study of K2CsSb photocathode. In order to suppress the roughening phenomenon, they developed an alternating deposition method of Sb layer and followed by K-Cs sequential deposition, together with co-deposition of K and Cs, and sputtering. XRR analysis shows that co-evaporated K2CsSb may end up in a smoother surface with almost the same quantum efficiency compared to sequentially-evaporated photocathode (Fig. 7). Sputter deposition could result in a smooth photocathode with sub nm roughness and acceptable 1% quantum efficiency at the wavelength of green light.

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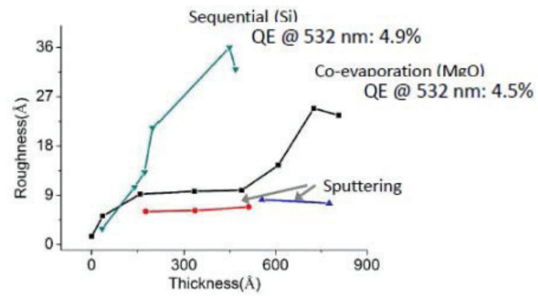

Figure 7: Cathode roughness as a function of thickness, for a variety of different growth methods.

We also heard of the development of a set of software to model the emission of electrons from an alkali photocathode. It used a 2D Monte-Carlo simulation based on Spicer's three step model. Agreement with measurement was striking (Fig. 8), and hopefully this will lead to the development of better understanding and control over these cathodes.

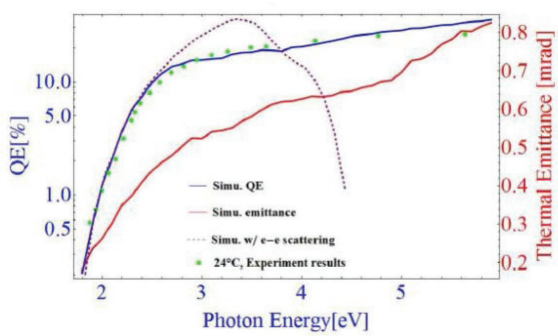

Figure 8: Simulated and measured QE and simulated thermal emittance of a K2CsSb photocathode.

There was a comparison between competing models of the activation of p-GaAs—the dipole layer model, and the heterojunction model. Longitudinal energy distribution measurements were performed periodically with a parallel plate retarding analyser during a long activation of the cathode, yielding data that agreed well with the heterojunction model (Fig. 9).

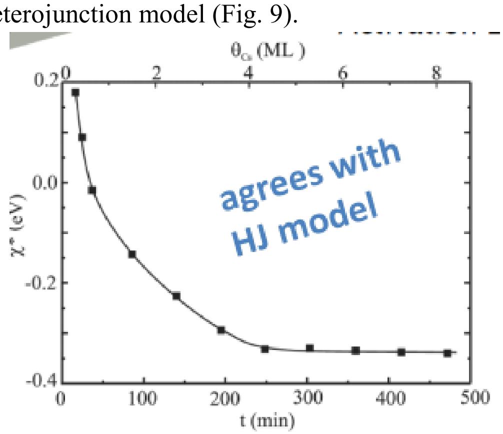

Figure 9: Effective electron affinity during cathode deposition. Measured data, and agreement with the heterojunction model.

At HZB, the commissioning of an advance photocathode preparation and analysis system is on-going. Figure 10 shows XPS spectra detected in-situ in-between sequential deposition steps of CsK2Sb photocathode.

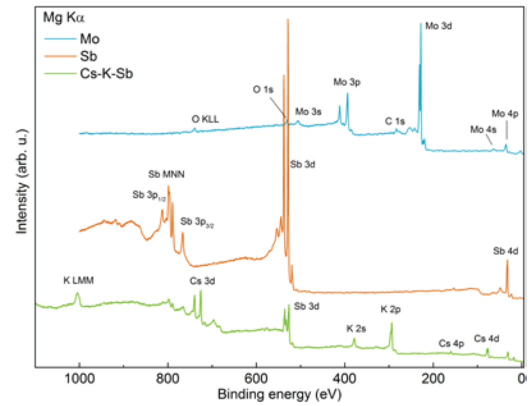

Figure 10: XPS data recorded in-situ during sequential deposition of a CsK2Sb photocathode.

Finally, Far-Tech also presented a novel design of a high peak and high average current source based on a triode-like thermionic cathode. A floating grid with a small biased dc applied field is placed inside of an RF cavity, thus preventing cathode emission during unwanted parts of the RF cycle. This electron source could potentially allow CW operation of a thermionic RF gun to generate high-peak and high-average current, small emittance beam. The source also has other potential advantages in its simplicity of structure and operation, robustness and reliability. This source is also much cheaper in fabrication and maintenance than that of a photocathode system. This source could be widely used in linac systems where high average current are needed, such as the ERL systems for electron cooling of ion beam, high average power free electron lasers, Terahertz sources.

CONCLUSION

The progress in injectors for ERLs is immense. The high average current achieved at Cornell and the high accelerating voltage achieved at JAEA and KEK is proof of the maturity of DC gun technology, and their viability for ERL use. SRF guns still need more demo and test experiments. New facilities are coming to life like the SRF gun at BNL with 200 uA average current and the new SRF gun (SRF gun II) at HZDR, but more results are needed to push the limits of the SRF gun concept. Lasers for ERLs have also become a mature field, and now mostly require further engineering to increase their stability and reliability—though the shaping of the laser, both transversely and temporally, is one important remaining area of work needed for optimal ERL operation. Photocathode R&D is now strongly benefiting from both material science methods and detailed simulation, and is using them to overcome the remaining challenges to maximizing their performance.

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