OPERATING A TUNGSTEN DISPENSER CATHODE IN PHOTO-EMISSION MODE*

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Abstract

The Stanford Synchrotron Radiation Laboratory (SSRL) operates a thermionic radio-frequency gun as part of its injector for the SPEAR 3 storage ring. In order to generate the high bunch charge required for top-off injection, it may be advantageous to operate the thermionic cathode as a photo-emitter. In this note we report on measurements of the wavelength dependence of the quantum efficiency of a tungsten dispenser cathode in a low-field environment, and on high-power tests of the injector in photoemission mode.

INTRODUCTION

The front-end of the SSRL injector for the SPEAR storage ring consists of an S-band radio-frequency (RF) gun with thermionic cathode, an alpha magnet, and a chopper [1] [2]. An S-band bucket of charge from the gun has a large energy spread and a near-linear longitudinal phase space, with the most energetic particles at the front of the bunch. These particles take a longer path in the alpha magnet, and the bunch that arrives at the first linac section is temporally compressed and suitable for energy compression when injected into the linac at the proper phase. Most of the charge produced in the gun during the $2\,\mu$s RF pulse is dumped at the chopper before the linac: the chopper sweeps 5 or 6 contiguous S-band buckets into the linac for acceleration, whereafter those buckets merge into a single booster RF bucket ($358\,\mathrm{MHz}$) before injection into the storage ring.

The RF gun is a 1.5 cell standing-wave structure that is geometrically similar to a photo-injector gun, but instead of a surface prepared for photo-emission at the end wall of the half cell the thermionic gun has a tungsten dispenser cathode in that position. The cathode emits electrons when heated to temperatures around $1000\,\mathrm{C}$. It turns out that the quantum efficiency (QE, number of electrons emitted per incident photon) of dispenser cathodes is suitable for photo-emission at ultra-violet and possibly green wavelengths [3], and in fact an RF thermionic gun at MAX-lab has been converted into a photo-injector [4]. Operating the SSRL gun in photo-emission mode has the potential to produce higher-charge bunches and to improve beam quality and injector performance by reducing beam loading and back bombardment on the cathode, and by eliminating the different angles imparted by the chopper should that component be eliminated. Another benefit is the reduction in radiation that comes from reducing beam losses.

As part of the injector upgrade for frequent top-off injection and higher stored current in the SPEAR storage ring, we are investigating running the gun as a photo-injector. The next section presents QE measurements on a dispenser cathode in a low-field test stand. The following section describes two photo-emission experiments on the SSRL gun, one using a very short laser pulse and the other using a pulse that spanned multiple RF buckets.

QE MEASUREMENT

The cathode in the SSRL gun is a barium dispenser cathode, a porous tungsten matrix with a formula of barium oxide dispersed throughout. It is not M type. An identical cathode was used for the measurements described in this section. QE was measured with the cathode biased $-86\,\mathrm{V}$ relative to a wire-loop collector at approximately $10\,\mathrm{cm}$. The cathode was illuminated by a Xenon arc lamp filtered by a monochromotor with $6\,\mathrm{nm}$ resolution. Photon intensity was measrured at the cathode position before installing the cathode. Current in the wire collector was measured with a picoammeter, with contributions due to thermal emission subtracted off by measurements with the arc lamp off. Measurements are shown in Fig. 1. The curve with small resistive heating indicates that a laser operating in the green may be sufficient for driving the cathode.

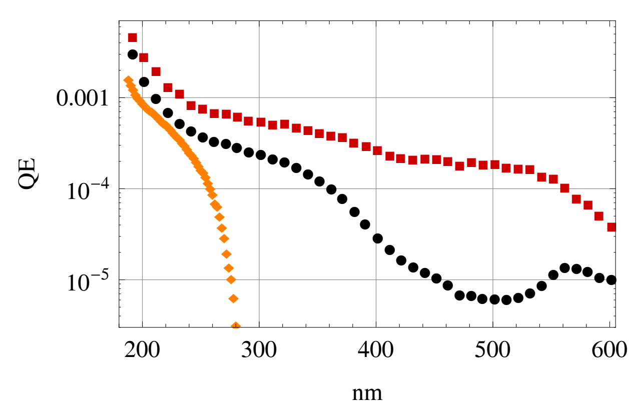

Figure 1: Test stand QE measurements. Circles and squares are data for the dispenser cathode, the former corresponding to zero cathode heating and the latter to $1.5\,\mathrm{W}$ in the resistive heating element embedded in the cathode. For reference, QE measurements on a copper cathode for the LCLS are shown as diamonds.

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For reference, also shown in Fig. 1 are QE measurements on a copper cathode for the LCLS [5].

SSRL GUN IN PHOTO-EMISSION MODE

Short Laser Pulse

This laser had a wavelength of $263\,\mathrm{nm}$. Its pulse length was short compared to the RF period (2 ps out of 350), so in this case it makes sense to speak of the launch phase of the electrons as they leave the cathode. The zero phase is defined by the RF zero-crossing (zero accelerating field) after which electrons are accelerated away from the cathode. Figure 2 shows a measurement of photo-emitted charge as a function of launch phase, for a laser-pulse energy of $5.4 \pm .5\,\mu\mathrm{J}$ at the cathode (mean and standard deviation). The charge measurement is the integral of a toroid signal on an oscilloscope. Each point in the plot is an average of 16 measurements with the laser beam on, minus 5 measurements with it off to remove offsets and charge not produced by the laser. (The cathode temperature was well below the threshold for significant thermal emission.) The peak charge corresponds to an effective QE of 5.7×10^{-4}. The standing-wave amplitude at the cathode was in the range 20–25 $\mathrm{MV/m}$.

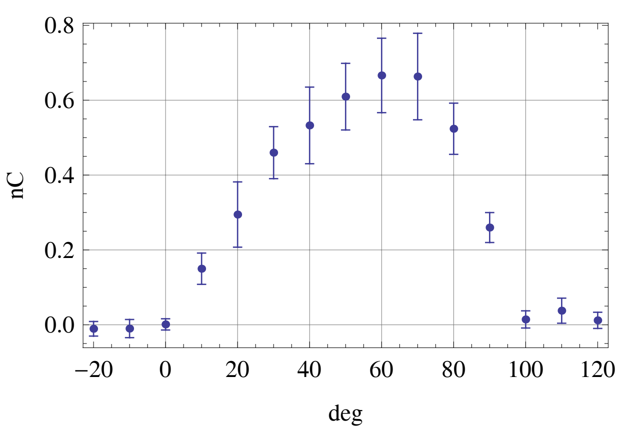

Figure 2: Photo-emitted charge vs. launch phase, with a laser-pulse energy of $5.4\,\mu\mathrm{J}$. The location of the zero phase is apporximate. Error bar half-height is one standard deviation.

The available laser-pulse energy was $100\,\mu\mathrm{J}$ at the cathode. Figure 3 is a plot of photo-emitted charge as a function of laser energy, with the launch phase held constant at approximately 60°. The data appears to show a striking space-charge effect. In addition to the measurements obtained by attenuating the laser, shown in the plot as circles, four independent measurements derived from phase scans (including the one in Fig. 2) are shown with error bars. The effective QEs range from $(7.4 \pm .8)10^{-4}$ at $1.8\,\mu\mathrm{J}$, to $(0.99 \pm .07)10^{-4}$ at $94\,\mu\mathrm{J}$.

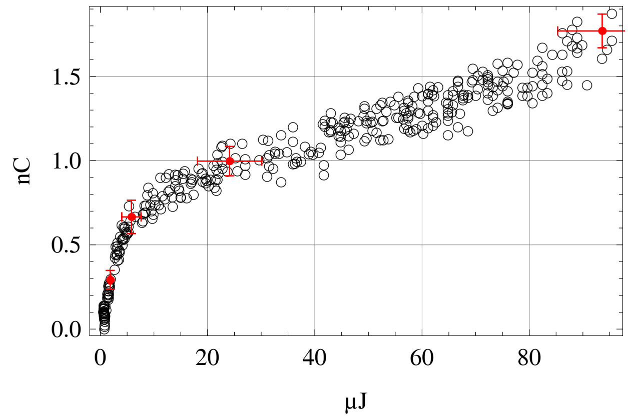

Figure 3: Photo-emitted charge vs. laser-pulse energy.

Long Laser Pulse

This laser had a wavelength of $266\,\mathrm{nm}$ and a pulse length of $7\,\mathrm{ns}$. The latter corresponds to 20 RF buckets, so like the thermionic case a bucket of electrons from the gun has a large energy spread that can be compressed by the alpha magent and linac, but beam loading and beam loss is small compared to a full $2\,\mu\mathrm{s}$ thermionic pulse. This one-day experiment was performed with full thermionic beam because there was little opportunity to tune the injection and the goal was to inject photo-current into the SPEAR ring. This we did, with beam currents and injection rates 3–4 times above normal operating values. With tuning it is likely these numbers could have been improved.

SUMMARY

We have seen that the SSRL gun can function as a photo-injector, and that its performance may thereby be improved. Next steps include identifying the laser best suited for this application, and to gain further experience operating in this mode.

We wish to thank the LCLS laser group for its support with personnel and loan of the “long pulse” laser.

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