Operation of CEBAF photoguns at average beam current > 1 mA

M. Poelker, J. Grames, P. Adderley, J. Brittian, J. Clark, J. Hansknecht, M. Stutzman

Can we improve charge lifetime by merely increasing the laser spot size? (distribute ion damage over larger area)

How relevant is CEBAF experience at 200 uA ave current and laser spot size ~ 500 um for operation at mA beam current?

Important questions for high current (> 1mA) photoinjectors at FELs, ERLs and proposed NP facilities like ELIC and eRHIC
Can increasing the laser spot size improve charge lifetime?

Bigger laser spot - same # electrons, same # ions

But QE at \((x_i, y_i)\) degrades more slowly because ion damage distributed over larger area (?)
Where do ions go? Reality more complicated

High energy ions focused to electrostatic center

We don’t run beam from electrostatic center

laser light IN

electron beam OUT

anode

residual gas

cathode

Which ions more problematic?

Ions create QE trough to electrostatic center

laser light IN

electron beam OUT

m. poelker, pst05, nov. 14-17, tokyo, japan
Experimental Setup

100 kV load locked gun

Bulk GaAs

NEG-coated large aperture beam pipe

Spot size diagnostic

1W green laser, DC, 532 nm

Faraday Cup Baked to 450C

Insertable mirror

Differential Pumps w/ NEG's

Focusing lens on x/y stage
Sensitive Pressure Monitoring Along Beamline

UHV ion pump vs. extractor gauge

Ion Pump Locations
\[ d = \frac{1.22 \lambda f}{D} \]

"old way"

342 \text{ um} \\
842 \text{ um} \\
1538 \text{ um}

Spiricon CCD camera + razor blade stepper motor scans (not shown)
Top View:
100 kV Load Locked Gun

- Activation Chamber
- Heating Chamber
- High Voltage Chamber
Side View: 100 kV Load Locked Gun

Mask to limit active area
“QE Scan” using lens attached to stepper motor x/y stage

<table>
<thead>
<tr>
<th>QE</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh Photocathode</td>
<td>18.406</td>
</tr>
<tr>
<td></td>
<td>16.102</td>
</tr>
<tr>
<td></td>
<td>13.798</td>
</tr>
<tr>
<td></td>
<td>11.495</td>
</tr>
<tr>
<td></td>
<td>9.191</td>
</tr>
<tr>
<td></td>
<td>6.887</td>
</tr>
<tr>
<td></td>
<td>4.583</td>
</tr>
<tr>
<td></td>
<td>2.279</td>
</tr>
<tr>
<td></td>
<td>1.134</td>
</tr>
</tbody>
</table>

Used 5 mm hole throughout experiment

- Electrostatic center
  - Value: 9.148
  - Value: 8.003
  - Value: 6.858
  - Value: 5.713
  - Value: 4.569
  - Value: 3.424
  - Value: 2.279
  - Value: 1.134
  - Value: 0.11

...
Is 5 mm active area well suited for gun geometry?

QE scan at 100 kV indicates beam from entire photocathode delivered to dump. Gun/beamline “acceptance” seems adequate.
Experiment:
Measure $1/e$ charge lifetime using different laser spot sizes. Strive to keep other operating conditions constant (e.g., orbit, position of laser spot on photocathode, starting QE, etc).

Details:
- Green light at 532 nm, DC Beam.
- Gaussian laser spots: runs at 342um, 842um and 1538um
- Bulk GaAs, initial max QE between 13 - 19%, 5 mm active area
- Gun vacuum w/o beam ~ $2 \times 10^{-11}$Torr
- Beam dump degassed at 450°C
- Beam current constant via feedback loop to laser attenuator
- Record ion pump current, laser power “pick-off” monitor.
- Charge extracted during each run between 10 - 200 C
- Five activations, one photocathode, total charge extracted 1345 C
- Ion damage restoration, typ. heat at 575°C for 24 hours
A “typical” set of runs: Record ion pump current at 7 beamline locations, laser power via “pickoff” detector, laser attenuator setting, beam current at dump.

\[ \frac{1}{e} \text{ Charge Lifetime} = \frac{\text{Charge Extracted}}{\ln \left( \frac{Q_{E_i}}{Q_{E_f}} \right)} \]

10 mA, 47C  
7.5 mA, 54C  
5 mA, 95C  
(portion of run at)

Y-scale: multiple variables

Time (hours)
Charge lifetime worse at high current. This makes sense - More electrons to ionize gas, and more gas to ionize (from beam dump and elsewhere).

Fit = \frac{a}{i^b}

Why? Why not?

Lifetime scales as \frac{1}{i^b}

where i is beam current.

Here \( b = 1.256 \)

Later, we see \( b \) ranged from 0.2 to 1.3 for entire set of runs. More later.
1/e Charge Lifetime vs Beam Current: 342μm, 842 μm and 1538μm
Very little, if any, lifetime enhancement with larger laser spots

Expectation:
\[
\left(\frac{1538}{342}\right)^2 = 20.2
\]
\[
\left(\frac{842}{342}\right)^2 = 6.1
\]
1/e Charge Lifetime: 1538um laser spot, from two locations

Location 2 further from electrostatic center by ~ 400um
342 um and 1538 um laser spots from same “good” location
Lifetime enhancement? YES, but not what simple picture predicts

\[
\left(\frac{1538}{342}\right)^2 = 20.2
\]
QE reduction at electrostatic center and overall
CEBAF 1/e charge lifetime similarly “random”

Charge extracted from CEBAF gun over 4 year period
“Obvious” Conclusions;
1) Some of the runs with 1538 um laser spot provided very good charge lifetime > 1000 C at beam currents to 10 mA! World record?
2) Good evidence for lifetime enhancement using larger laser spot. (Simple scaling argument likely not valid)
3) Charge density lifetime numbers with 342 um laser spot are comparable to CEBAF numbers with high polarizaiton material. > 2x10^5 C/cm2
4) Unfortunately (for those building high current guns), good charge density lifetime not maintained at large laser spot sizes (~ < 1x10^5 C/cm2)
“Not so obvious” Conclusions:
1) Simple exponential decay not always appropriate
2) Good charge lifetime not clearly correlated to good
   gun vacuum (at least gun ion pump current).
3) (so far) it has been difficult to identify conditions
   that lead to long charge lifetime. Spot location on
   photocathode seems to be very important. Radial
   position: further from EC is better. But not whole
   story.
4) When using simple \( \frac{a}{i^b} \) fit, \( b \) ranged from 0.2 to 1.3
   for entire set of runs. \( b = 1 \) implies strict current
   dependence (OK), \( b > 1 \) implies current + vacuum
   dependence. \( b < 1 \) significant?
5) Where do ions go? “Beaming”? Does the potential of the
   beam begin to play a role? Modeling required.
Dump Ion Pump Current scales with beam current

Not obvious that gun ion pump current scales with beam current

Best charge lifetime not necessarily associated with best gun vacuum (in this case, ion pump current)
QE recovery following heat treatment and reactivation

780 nm on GaAs (Damage=10.5 C)

- QE Min (ion damaged)
- QE Max (anywhere)
Ion Pump Power Supplies with nanoA Current Monitoring

"Free" pressure monitoring at 10^-11 Torr

**UHV ion pump vs. extractor gauge**

- Current (A)
  - 1.0E-02
  - 1.0E-03
  - 1.0E-04
  - 1.0E-05
  - 1.0E-06
  - 1.0E-07
  - 1.0E-08
  - 1.0E-09

- Pressure (Torr)
  - 1.0E-12
  - 1.0E-11
  - 1.0E-10
  - 1.0E-08
  - 1.0E-07
  - 1.0E-06
  - 1.0E-05

Pumps detect bad orbit and beamloss

- Gun chamber pump
- Wien filter
- Y-chamber
- Laser chamber

Ion Pump Locations