Polarized Electron Source: Gatling Gun

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Outline

* Photocathodes
  * Quantum Efficiency
  * Gallium Arsenide
* Gatling Gun
Motivation

- New accelerator-collider technologies are needed to advance our understanding of the subatomic world
- eRHIC requires 50mA of 70% polarized current
- Current technology only allows for 4mA to be extracted over 5.5 hours.
Photocathodes: Work Function

* Photocathodes will emit electrons if the energy of the incident photon is greater than the work function of that material via the photoelectric effect.

<table>
<thead>
<tr>
<th>Cathode Material</th>
<th>Work Function (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnesium</td>
<td>3.6</td>
</tr>
<tr>
<td>Lead</td>
<td>4.0</td>
</tr>
<tr>
<td>Niobium</td>
<td>4.38</td>
</tr>
<tr>
<td>Copper</td>
<td>4.6</td>
</tr>
<tr>
<td>CsBr:Cu (Coated)</td>
<td>2.5</td>
</tr>
<tr>
<td>GaAs</td>
<td>4.69</td>
</tr>
</tbody>
</table>
Photocathodes

* Quantum Efficiency (QE): Defined as the ratio of electron emission vs. incident photons

* Types:

  * Metallic: very durable but have low QE even for high intensity lasers

  * Semiconductor: Have high QE even for low intensity laser but are extremely fragile.
Photocathodes: QE vs. Lifetime

Photocathodes: Spicer’s Theory

* Photo excitation: electrons are stimulated by incoming photons and will move from the valence level to the conduction band

* Transport to surface

  * electron-electron scattering—metallic photocathodes
  * electron-lattice scattering—semiconductor photocathodes

* Escape to vacuum—Negative Electron Affinity
Spicer’s Theory
Photocathodes: Gallium Arsenide

* Commonly used in modern accelerator applications
* III-V family semiconductor with a direct band gap
* Benefits
  * Can create polarized electrons
  * Fast response time
  * Long photon absorption length
  * Long electron diffusion length
* Lifetime is severely limited by
  * Vacuum—requires $10^{-12}$ torr
  * Field Emissions—From high electrostatic fields causes desorption of gas
  * Ion back-bombardment—Current ionizes residual gas in the chamber; resulting ions hit photocathodes
Field Emissions

Image Credit: O. Rahman
Ion Back Bombardment

laser light IN
electron beam OUT

anode
residual gas
cathode

Image Credit: J. Lab
Ion Back Bombardment

Image Credit: J. Lab
GaAs:
Polarization of Electrons

Image Credit: E. Wang
Negative Electron Affinity

(a) GaAs Vac
(b) GaAs Cs Vac
(c) GaAs Cs$_2$O Vac

Image Credit: USPAS
GaAs Activation

* Photocathodes are activated in a chamber separate from the gun itself

* Heat Cleaning

* Cs-O deposition

  * Yo-yo

  * Co-deposition
Activation: Heat Cleaning

Image Credit: N. Chanlek

Image Credit: O. Rahman
Heat Cleaning
Activation: Yo-yo Method

* Alternates inputs of Cs and Oxygen

Image Credit: N. Chanlek
Activation: Co-Deposition

Image Credit: O. Rahman

Image Credit: M. Poelker
Gatling Principle

* Electron beam will be extracted from 20 individual cathodes illuminated in sequence. Each cathode contributes 2.5 mA

Image Credit: V. Litvinenko
Gatling Gun

* $P = 10^{-11}$ torr

* Main Components:
  
  * Cathode Magazine: holds 20 cathodes, 18 degrees apart
  
  * DC Gap: Accelerates beam across 45-55 kV potential
  
  * Beam dynamics: Dipoles and Combiner magnet alter beam trajectory
  
  * Beam Diagnostics: A Yttrium Aluminum Garnet (YAG) crystal visualize the beam
Gatling Gun:
Side View
Combiner Magnet

\[ I_D = I_{0D}\cos(\omega t + \Phi_D) \]

Image Credit: E. Wang
YAG Crystal
Thank you!
Dipole Magnet