Polarized source applications

Kurt Aulenbacher – 12.09.2019
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz
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Outline

- Introduction – Applications of polarized beams
- Advantages of “polarized”-Photocathodes
- Limitations and challenges – surface photovoltage, charge lifetime, fluence lifetime
- Summary and outlook
Future (challenging) applications of polarized beams

- Solid state physics with magnetic interaction
  - high brilliance beams (microscopy) & high time resolution
    (e.g. Spin polarized ultrafast e-diffraction, “SUED-beams”)
    typical application: \( E_{\text{source}} \approx \text{keV-MeV}, t_p << 1\text{ps}, \varepsilon_{\text{norm}} < 1\mu\text{m} \)
    QB>pC, \( f = \text{kHz-MHz} \)
- Particle physics – spin interaction at “fundamental” scales
  - medium (peak) brilliance, high average current sources
    e.g. ERL-based double polarized e-ion collider (eRHIC, LHeC) \( E_{\text{source}} \approx 200-500\text{keV,} \)
    cw. operation, current average mA – 50mA
<table>
<thead>
<tr>
<th>Experiment</th>
<th>Mode</th>
<th>$E$ (MeV)</th>
<th>$I$ (mA)</th>
<th>Data taking (h)</th>
<th>Polarisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2</td>
<td>EB</td>
<td>155</td>
<td>0.15</td>
<td>15000</td>
<td>0.85, mandatory</td>
</tr>
<tr>
<td>MAGIX</td>
<td>ER</td>
<td>105</td>
<td>1-10</td>
<td>?</td>
<td>0.85, if possible</td>
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**Strained Superlattice-cathode**

GaAs/GaAsP”Strained Superlattice” :
SL causes shift of Band gap energy wrt GaAs and removal of degeneracy
: Gradient doping

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**SLAC/SVT — Superlattice**

<table>
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<tr>
<th></th>
<th>5 nm</th>
<th>(p=5 \times 10^{19} \text{ cm}^{-3})</th>
<th>(p=5 \times 10^{17} \text{ cm}^{-3})</th>
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<td>GaAs/GaAsP SL</td>
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Strained Superlattice vs “strained layer”:
SL causes shift of Band gap energy wrt GaAs and removal of degeneracy
→ “Band structure engineering” (e.g. frequency double telecom lasers…)

Absorption enhanced by DBR-Reflector causing active region to be a cavity with enhanced absorption at resonance → increased QE. 6% @ 770nm (>30mA/Watt) @ >80% Pol.
Further Advantages of SL

1. Due to low doping in small active region: large mean free path $\lambda \approx d_{active}$  
   $\Rightarrow$ fast $t << 5$ps
2. almost 100% “sink” at surface  
   $\Rightarrow$ no tail (see talk by N. Scahiil tomorrow)
3. Huge “gradient” doping at surface  
   $\Rightarrow$ high current density and/or fluence possible in spite of “photovoltage”
4. (Quite) low transverse energy due to NEA-near band gap operation

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expected response without exp. resolution
Limitations of Spin-polarized Photocathodes
Limitations of Spin-polarized Photocathodes

SLAC pulse-measurements for increasing laser intensity

![Graph showing SLAC pulse-measurements for increasing laser intensity](a)

I/a.u.

How that?
Trapped electrons in surface region create “Photovoltage” which reduces NEA
Model: Thermal equilibrium is NEA-state, but current diffusing to surface
charges “condenser”, hole current discharges towards equilibrium

Consequence:
- current density limit in steady state
  (may be much lower than vacuum space-charge limit)
- typical time constants of $\tau \sim \text{ns}$ lead to “charge limit” for bunches $< \tau$
  – high fields, high doping level favorable

$$I_e = \frac{Q E_0}{A} \frac{\lambda_L P}{h c A} \left[ 1 - \frac{E_0}{\tilde{\chi}} \ln \left( 1 + \frac{Q E_0}{j_p} \frac{\lambda_L P}{h c A} \right) \right]$$

Model used by
steady state-current measurements with the MESA-source 2.5MV/m, doping level $1-2 \times 10^{19}$

For practical purposes it is obviously important to avoid reduction of q.e.
Difficulties of Spin-polarized Photocathodes

Another illustration from MESA-source operation:

Observation: Beam losses are (highly) detrimental. Field emission counts as beam loss (or worse) empirical: loss of 100nA reduces lifetime to 100 hours several tricks allow to reduce losses below $10^{-6}$ in the vicinity of the source note finite lifetime without operation → chemical (thermal) decomposition?
Difficulties of Spin-polarized Photocathodes

Good heat conductivity is essential!
Good example: U. Weigel et. al achieve $\Delta T = 15$K/W

\[ \frac{1}{\tau} = \sum_i \frac{1}{\tau_i} \]

Besides the contributions already discussed there is **ion backbombardment**.

**excentrically started**

**Electron-beam**

causes back traveling ions

**Experimental finding**

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**PhD thesis Aulenbacher**
Mainz 1994, see also Andresen et al. SLAC pub
However….

\[ \frac{1}{\tau_{\text{Obs}}} = \sum_{i} \frac{1}{\tau_{i}} \]

Besides the contributions already discussed there is **Ion backbombardment**. Example from MAMI-beam-times

Charge lifetime:
\[ C_\tau = I^* \tau_{\text{obs}} = Q = \text{const!} \]

Here \(~200\)C!

Fluence lifetime:
\[ F = \frac{C_\tau}{A_{\text{beam}}} \sim 10^5 \text{ C/cm}^2 \]

Note: \( \varepsilon_{\text{norm}} \sim 100\)nm in these experiments
(150\(\mu\)m Laser spot rms)
\(\Rightarrow\) can Charge lifetime be increased to \(>>1000\)C at \(\varepsilon \sim 1\mu\)m?
Careful experiments have been done at JLAB: achieved >1000C with green light illumination at about 9mA current. Open question: other contributions become non negligible (Heating, non-linear transmission loss?)

Note that (non-linear space charge may create halo...)

Charge lifetime

Fluence lifetime

J. Grames et al.
PHYS. REV. ST.-AB 14, 043501 (2011)
GaAs/GaAsP superlattice cathodes offer high polarization (>85%), high QE (>1%) fast response (probably <1ps) and low tail (see N. Scahill’s talk tomorrow) as well as low thermal emittance.

They seem well suited to fulfill materials-science applications needs like SUED. However, high voltage limitations have to be taken into account (d.c. fields < 5-10MV/m?)

The so far achieved charge lifetimes of about 1000 C limit practical current to about 1mA. (Cathode regeneration every 300 hours).

Projects like ERL based colliders require more R&D to shift the limit: Control of Ion backbombardment, (non-linear) transmission loss and cathode heating are pressing issues.

SRF gun could improve on most of the problems mentioned
Thank you for your attention!