Jefferson Lab polarized electron source

P. Adderley, M. Baylac, J. Clark, A. Day, J. Grames, J. Hansknecht, M. Poelker, M. Stutzman

SRF
September 25, 2002
Plan

- Basics of polarized photoemission
- Experimental setup:
  - photocathodes
  - guns
  - lasers
  - beam quality controls
- Laser for G0 experiment
- New generation of gun
- Conclusions & outlook
Polarized electron sources

Polarized electron beam to probe nuclear structure

⇒ development of polarized e- sources

First e- source on an accelerator: PEGGY, at SLAC (1978)

Semiconductor sources introduced in 1975 via optical pumping of GaAs

Introduction of strained GaAs to reach higher beam polarization in early 90’s (SLAC)

Nowadays, many accelerator facilities use strained GaAs sources:

   SLAC, MAMI, ELSA, CEBAF
Photoemission from GaAs

Optical pumping between $P_{3/2}$ and $S_{1/2}$

$E_{\text{gap}} < E_\gamma < E_{\text{gap+\Delta}}$

$P_e = \frac{3-1}{3+1} = +/- 50\%$
Photoemission from strained GaAs

Split degeneracy of $P_{3/2}$

& optical pumping between $P_{3/2}$ and $S_{1/2}$

$$P_e = +/- 100\%, \text{ with } E_{\text{gap}} < E_\gamma < E_{\text{gap}+\delta}$$
NEA Activation

- Electrons, pumped to the conduction band, must be emitted in vacuum
  \[ E_a > 0 \quad E_a \approx 0 \quad E_a < 0 \]

- Reduce surface \( \bar{e} \) affinity
  \[ \Rightarrow E_{\text{conduction}} > E_{\text{vacuum}} \]
  using alkali (Cs) and oxidant (NF3)

- Electrons emitted in vacuum & accelerated by some voltage
Polarized source requirements

• High QE and $P_e$ photocathode

• Gun

  Load and support photocathode

  Accommodate NEA activation of photocathode & optical port

  Hold high voltage

  Have good vacuum

• Light source

  • Polarization (>99%)

  • Beam quality controls (intensity, position)
Strained layer GaAs photocathode

Bandwidth Semiconductor (formerly SPIRE)

• MOCVD-grown epitaxial spin-polarizer wafer

• Lattice mismatch

$\Rightarrow$ split degeneracy of $P_{3/2}$

Strained GaAs

$GaAs_{1-x}P_x$

$\begin{align*}
x &= 0.29 \\
0 &< x < 0.29
\end{align*}$

p-type GaAs substrate
QE & polarization

Quantum Efficiency

0.2 % at 840 nm yields 1 $\mu$A/mW
1.0 % at 780 nm yields 6 $\mu$A/mW

Polarization

$P_e \sim 75$ % at 840 nm
$P_e \sim 35$ % at 780 nm

With laser polarization >99.5%, flipped at 30 Hz

$FOM \propto IP^2$
Photocathode preparation

- 3” wafer cleaved (15.5 mm)
- Reduce active area: anodization
  - ie: kill QE by anodizing in an electrolytic bath of weak phosphoric acid beyond a ~ 5 mm disk
- Mount sample on stalk
- Clean surface by a short exposure to atomic Hydrogen
JLab polarized gun design

- Laser
- e⁻
- Cs
- GaAs
- NEG coated beampipe
- NF₃
- HV insulator
- Non evaporable getter pumps (NEG)

-100 kV

Operated by the Southeastern Universities Research Association for the U.S. Depart. Of Energy
JLab polarized guns

- No load-lock system
  ⇒ bake after each wafer loading (3 days)

- Two identical guns
  switch within < 1 hour

- Excellent vacuum (Ion Pumps + NEG pumps)
  4 000 liter/s pumping speed ⇒ $5 \times 10^{-12}$ Torr
  excellent lifetime

⇒ Little downtime due to photocathode exchange
Lifetime (1/e)

Low current: lifetime ~ 600 C
beam to 3 halls for 3 months
with single activation

High current: lifetime ~ 300 C
uninterrupted beam for 3 weeks

One year with only 3 activations!
Two identical polarized guns
# Light source requirements

**Must satisfy 3 users simultaneously**

Reliable system, remotely controlled

<table>
<thead>
<tr>
<th>what</th>
<th>how</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light source</td>
<td>Laser</td>
</tr>
<tr>
<td>Control light intensity</td>
<td>Attenuator</td>
</tr>
<tr>
<td>Polarizing light</td>
<td>Pockels cell</td>
</tr>
<tr>
<td>Combining 3 beams</td>
<td>Beam splitter, dichroic mirror</td>
</tr>
<tr>
<td>Steering beams</td>
<td>Movable lens</td>
</tr>
<tr>
<td>Transport</td>
<td>Mirrors</td>
</tr>
</tbody>
</table>
Laser options

**Diode**
- easy, low maintenance, reliable
- low noise ~ 0.1% @ 30Hz
- low power < 100 mW
- wavelength fixed
- DC light => leakage

**Ti:Sap**
- high power ~500 mW
- wavelength adjustable
- higher maintenance
- homebuilt lasers were noisy (1%)
  now have low noise: 0.2% @ 30Hz

Diode lasers provide either high polarization (840 nm)
  or high current (780 nm)

Ti:Sap lasers provide both high polarization and high current
Dynamic laser configuration

3 experimental halls ⇒ 3 lasers

Each laser mode-locked at 499 MHz (or 31 MHz for G0)

Each laser to meet each hall specific needs:
- intensity
- polarization
- beam quality
Beam quality controls

Users ask for increasingly better beam quality:

As beam helicity is reversed, beam parameters (intensity, position) do not change

⇒ feedback systems to minimize those helicity correlations

Parity violation (PV) experiments measure $A_{exp} \sim 10^{-6}$ (1 ppm)

⇒ extreme constraints on helicity correlated beam parameters
  charge asymmetry $\sim$ ppm
  position differences $\sim$ nm

Independent control knobs for each hall

Level of control depends on the experiment
How we manage helicity correlations for PV

✓ Charge asymmetry

Pockels cell
- circular light (PC)
- correction (PITA)
- Rotatable 1/2-plate (correction) (RWP)
- Seed laser power modulation (correction) (TACO)

✓ Overall systematics

- Insertable 1/2-plate (systematic reversal) (λ/2)
Devices common to all lasers

- TACO
- Min.
- PC
- PITA
- RWP
- λ/2
- Days Min. Hour

Thomas Jefferson National Accelerator Facility
Operated by the Southeastern Universities Research Association for the U.S. Depart. Of Energy
## Some charge asymmetry results

<table>
<thead>
<tr>
<th>Experiments</th>
<th>Charge asymmetry (ppm) per physics run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hall B</td>
<td>w/o TACO &lt; 2000</td>
</tr>
<tr>
<td></td>
<td>w/ TACO &lt; 500</td>
</tr>
<tr>
<td>GEn</td>
<td>TACO &lt; 1000</td>
</tr>
<tr>
<td>GEp</td>
<td>&lt; 1000</td>
</tr>
<tr>
<td>GDH</td>
<td>RWP 300 to 1000</td>
</tr>
<tr>
<td>g2n</td>
<td>RWP &lt; 50</td>
</tr>
</tbody>
</table>
Independent parity devices

Installed upstream of the location where the 3 lasers are combined
Independent intensity control : IA

- Low voltage PC + $\lambda/10$
- Low insertion loss
- Compact footprint

Stable slope $\sim 200$ ppm/V

Tests : $A_i \sim 3 \pm 3$ ppm within 15 min.

(Tsentalovich, BATES)
GO experiment

- **Time structure**
  
  31.2 MHz versus standard 499 MHz (16th subharmonic)

- **Modest average current, but high peak current**
  
  40 uA @ 31.2 MHz = transporting 640 uA @ 499 MHz

  \[\text{ie: } 8.10^6 \text{ e}^-/\text{bunch}\]

  \(\Rightarrow\) **beam optics issues**

- **Parity quality beam**

- **Two other halls running simultaneously**

  \(\Rightarrow\) **mode-locked Ti:Sap Laser**
**Ti:Sap Laser for G0**

Homebuilt Ti:Sap
diode seeded
AOM

- pulse width too large

Commercial Ti:Sap laser bought
(TimeBandwith Product)

- FWHM ~ 70 ps
- phase noise < 1 ps

Installed early September, used since then for tests

40 μA to hall C & parity quality beam!
Load lock design goals

• Installation of cathode from air to HV in less than 8 hours

• Load-lock chamber at ground potential, no moving parts at HV

• Horizontal - compatible with tunnel configuration (15° bend)

• Maintain all good features of current horizontal guns
  Electrode material
  Electrostatic optics
  Excellent vacuum, pumping conductance
Best Technology Load Lock Polarized Electron Gun

3 Chambers:

- High Voltage Chamber
- Preparation Chamber
- Load/Heat/Hydrogen Chamber

and 2 manipulators
BTLLPEG under test

Installed in testcave in same configuration as production beamline

Instrumented beamline (viewers, BPM, harp scanner)

Plans for Wien filter, Mott Polarimeter

• Goal reached to load, Hydrogen clean, activate and bring to HV chamber within 8 hours with good QE

• Ready for beam
Conclusions

• Polarized source for production:

  Two operational guns

  high polarization (70-80%)
  high lifetime (300-600 C)
  high current (100 μA)

  Independent controls of beam quality for each hall
Outlook (1)

✓ 2002-2003 : high profile year for parity violation experiments at JLab (HAPPEx 2, G0)

♦ *Ti:Sap*
  commercial G0 laser appears to be good
  a 499 MHz model ordered for HAPPEx 2, etc...

♦ *Helicity correlations controlled at parity level*
  independent knobs validated for halls A & C

✓ This coming period will help us prepare the future of PV
Outlook (2)

- Test lab studies on Vertical gun to deliver $P_e > 80\%$
  
  *reliable and powerful Ti:Sap would help*

- Load lock gun studies to improve lifetime

  *Qweak experiment asks for 200 $\mu$A in 2006*

  *high $P_e$ and parity quality beam*