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  - Source (PKA2)
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Introduction - Motivation

- beam diagnostics for MESA
- 100 kV dc-electron gun
- normal conducting injector up to 5 MeV
- 1.3 GHz cw electron beam
- 155 MeV, 150μA polarized beam - EB-Mode
- 105 MeV, 1 mA (10 mA @ stage 2) - ERL-Mode
- bunch charge up to 8 pC (10 mA @ 1.3 GHz)
Important properties of the source/injector

- emittance must be much smaller than the acceptance of the accelerator \( \Rightarrow \varepsilon_n \leq 1 \mu m \)
- high extractable current
- long life time \( \Rightarrow \) stable photo emission
- reliable
- polarized an unpolarized beam
Introduction – Photo cathodes

Thermal emittance and response time measurements of negative electron affinity photocathodes

JOURNAL OF APPLIED PHYSICS 103, 054901 2008

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Thermal emittance and response time measurements of negative electron affinity photocathodes

JOURNAL OF APPLIED PHYSICS 103, 054901 2008 – I.V. Bazarov

Introduction – Photo cathodes

Measurement St. Petersburg – Y. Yashin

photon absorption in semiconductors

conduction band

bulk GaAs

valence band

532nm Laser

bulk GaAs

146±10 meV

113±8 meV

81±6 meV

53±4 meV

30±2 meV

photon absorption in semiconductors
Introduction – Photo cathodes

• charge life time of photo cathode \( Q \approx 700 \ C \) (our result)

• aver. electron current for experiment \( I = 1 \ (10) \ mA \rightarrow \dot{Q} = 3.6 \ (36) \ C/h \)

• phase acceptance of the accelerator \( \varphi_{acc.accept.} = 72^\circ \)

→ with dc electron source 80% of the charge is wasted

→ experimental time \( t_{\exp} \leq 40 \ (4) \ h \)

• with dc electron source 80% of the charge is wasted → pulsed source increase the operational time by a factor 5

MESA would need pulses with a length of 160 ps and a repetition rate of 1.3 GHz
Introduction – Space charge

- current limit
  \[ I_{sc,\text{lim}} = p_0 \frac{A}{d^2} U^{3/2} \]

- acceleration voltage
  \[ U = 100 \text{ kV} \]

- perveance
  \[ p_0 = 2.33 \cdot 10^{-6} \frac{A}{V^{3/2}} \]

- current limit with source parameters
  \[ I_{sc,\text{lim}} \approx 3 \text{ mA} \]

- current limit of the source fulfills MESA stage 1

- new 200 kV source in production
Components Overview of PKA2

Source 100 keV

Laser wavelength 405 nm and 520 nm

Quadrupol doublet

Solenoid doublet

Scanner 1

Quadrupol doublet

Horizontal

Vertical

Scanner 2

Alpha-Magnet

Quadrupol doublet

Scanner 3

Alpha-Magnet

Quadrupol doublet

Triplet

Resonator

Wien-Filter

Quadrupol doublet

PhD thesis M. Molitor

UHV suitable

Faraday-Cup (SiC)

Pulse length measurement

Laser wavelength ~800 nm
Components
Overview of PKA2

- scanner 1
- scanner 2
- scanner 3
- alpha-magnet 1
- alpha-magnet 2
- Wien-Filter
- electron trajectory
Components
UV-VIS laser system

- **laser diode**: 520 nm
- **laser diode**: 405 nm

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Laser Diode</th>
<th>Laser Power (mW)</th>
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<tbody>
<tr>
<td><strong>Anamorphic prism pair</strong></td>
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<td><strong>Dicrotic mirror</strong></td>
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<td><strong>Uncoated beam splitter</strong></td>
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<td><strong>Attenuator</strong></td>
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<td><strong>Shutter</strong></td>
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<td><strong>Variable telescope</strong></td>
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<td><strong>Virtual cathode</strong></td>
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<td><strong>Coupling mirror</strong></td>
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<tr>
<td><strong>Wave length</strong>: 405nm &amp; 520nm</td>
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<tr>
<td><strong>dc-beam</strong>: ( P_{\text{max}} &lt; 300 \text{ mW} )</td>
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<td>**P_{\text{av}} &lt; 3 \text{ mW} )</td>
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<tr>
<td><strong>Pulsed cw-beam</strong>: ( P_{\text{max}} &lt; 3000 \text{ mW} )</td>
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<tr>
<td>**P_{\text{av}} &lt; 3 \text{ mW} )</td>
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</tbody>
</table>

**Prisma**

- width: 279 μm
- width: 570 μm
- 4σ width

**Graphs**

- Injection current (mA) vs. Laser power (mW)
- Wave length: 405nm & 520nm
- DC-beam: \( P_{\text{max}} < 300 \text{ mW} \)
- \( P_{\text{av}} < 300 \text{ mW} \)
- Pulsed-beam: \( P_{\text{max}} < 300 \text{ mW} \)
- \( P_{\text{av}} < 3 \text{ mW} \)
- Pulsed cw-beam: \( P_{\text{max}} < 3000 \text{ mW} \)
- \( P_{\text{av}} < 3 \text{ mW} \)
Components – Deflecting cavity

- Deflecting cavity
- Solenoid pair
- Collimator
- Distance L
- Adjustable slit width w
- Electron bunch (20° ≈ 43ps)
- Continuous electron beam
- DC beam

Diploma thesis: V. Bechthold
Components – Deflecting cavity

**dc beam**

- $I_{inj} = 170 \text{ mA}$
- $I_{inj} = 180 \text{ mA}$
- $I_{inj} = 190 \text{ mA}$

**green laser diode**

- $\lambda = 520 \text{ nm}$
- $P = 120 \text{ mW}$
- $I_{th} = 120 \text{ mA}$

Transmission $\geq 95\%$ at $120^\circ$
Components - Scanner

- **Scanner 1**
  - Ce:YAG Ø = 25 mm
  - wire (W Ø = 40µm)
  - 21 hori. & 21 verti. slits
    (w = 25 µm / 250 µm)

- **Scanner 2**
  - Ce:YAG Ø = 25 mm
  - wire (W Ø = 40µm)
  - 21 x 21 holes (Ø = 25 µm / 250 µm)

- **Scanner 3**
  - Ce:YAG Ø = 25 mm
  - Ce:YAG Ø = 25 mm with hole Ø 2 mm
  - Ce:YAG Ø = 25 mm with hole Ø 3 mm

Ce:YAG – Yttrium-Aluminium-Granat
Results – Quadrupol-Scan

alpha-magnet

Ce:YAG screen

variation of the focus

quadrupol
variation of the current

e⁻-beam

mirror

vacuum window
limiting apperture

field of view
camera

drift space

- focus strength: 2.75 diopter
- focus strength: 0 diopter
- focus strength: -2.75 diopter
Results – Quadrupol-Scan

emittance measurement

2.25 mA beam current

2D gaussian – whole distribution x
2D gaussian – whole distribution y
1D gaussian – projection x
1D gaussian – projection y
Results – Quadrupol-Scan

Laser spot size:
- x: 570 μm
- y: 279 μm

20. april
Results – Quadrupol-Scan

Emittance (\pi \text{ mm mrad})

- Emitt. proj. x (\pi \text{ mm mrad})
- Emitt. proj. y (\pi \text{ mm mrad})
- Emitt. 2D gauss x (\pi \text{ mm mrad})
- Emitt. 2D gauss y (\pi \text{ mm mrad})

Current (mA)

Laser spot size:
x: 570 \mu m
y: 279 \mu m
Results – Quadrupol-Scan

21. April

29. April

20. April

Laser spot size:
x: 570 μm
y: 279 μm

Current (mA)
**Results – Slit mask**

- **Mask**: 25μm slit width
- **Ce:YAG**: 100μm depth

**Electron beam diagnostic at the ELBE FEL | P. Evtushenko - 2004**

**Space charge dominated bunch**

- **Phase space**
  - **Position (mm)**
  - **Divergence (mrad)**
  - **Emittance (π mm mrad)**

**Graphs**

- **Measured slit mask @ 0.5 mA**
  - **X**: 570 μm
  - **Y**: 279 μm

- **Beamlet evolution in a drift space**

**Beamlet profile measurements**

**Laser spot size:**

- **X**: 570 μm
- **Y**: 279 μm

**Additional Details**

- **Current** (mA)
  - **Emittance (π mm mrad)**
    - @ 600mA solenoid
    - @ 650mA solenoid
    - @ 700mA solenoid
summary & outlook

- diagnostic beam line is build up and ready to get used
- possibility to measure the two trans. phase spaces an the temporal distribution for different currents and beam diameter
- cross check between screen, wire and mask measurements
- three available laser wave lengths (405 nm, 520 nm & 780 nm)
- investigations of the beam halo with wires and perforated screens

- get final results for all laser wavelength
- closer look to helicity correlated asymmetries
- characterization if the bunches are suitable for 1 mA/0.8 pC (stage 1)

Thanks for your attention!
Introduction - Emittance

- 6 dimensional phase space
- transversal:
  - displacement and divergence
- longitudinal:
  - phase and energy spread
- TWISS-Parameters:
  - \( \alpha, \beta \) und \( \gamma \)

Emittance-ellipse \( \gamma x^2 + 2 \alpha xx' + \beta x'^2 = \varepsilon \)
possibilities to measure the emittance

- quadrupole scan (std. technique)
  - measure the beam profiles for different focus strength

- slit or hole mask (new technique in IKPH)
  - measure the position displacement & width of divergence distribution

Emittance-ellipse

$$\gamma x^2 + 2\alpha xxx' + \beta x'^2 = \varepsilon$$
Backup – Quadrupol-Scan

- beam diameter is linked to the Beta-Matrix

\[ r_{\text{rms}}^2 = x^2 = \varepsilon \beta = \xi_{11} \]

- Beta-Matrix with TWISS-Parameters

\[ M_{\text{Beta}} = \begin{pmatrix} \xi_{11} & \xi_{12} \\ \xi_{21} & \xi_{22} \end{pmatrix} = \varepsilon \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix} \]

- emittance calculation

\[ \varepsilon = \sqrt{\det(M_{\text{Beta}})} = \sqrt{\xi_{11} \xi_{12} - \xi_{12}^2} \]

- matrices for the drift & quadrupol

\[ M_{\text{Drift}} = \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix} \]

\[ M_{\text{Quad},-x} = \begin{pmatrix} \cos(\sqrt{k}s) & 1 \\ -\sqrt{k} \sin(\sqrt{k}s) & \frac{1}{\sqrt{k} \sin(\sqrt{k}s)} \end{pmatrix} \]

\[ M_{\text{Quad},x} = \begin{pmatrix} \cosh(\sqrt{k}s) & 1 \\ -\sqrt{k} \sinh(\sqrt{k}s) & \frac{1}{\sqrt{k} \sinh(\sqrt{k}s)} \end{pmatrix} \]

fit-function for the data of the quadrupol scan

\[
r_{\text{rms}}^2(k) = \xi_{11} \left( \cos(\sqrt{k}s) - L \frac{s}{k} \sin(\sqrt{k}s) \right)^2 \\
+ \frac{s^2}{k} \left( \frac{s}{k} \sin(\sqrt{k}s) + L \cos(\sqrt{k}s) \right)^2 \\
+ 2 \xi_{12} \left( \frac{s}{k} \sin(\sqrt{k}s) + L \cos(\sqrt{k}s) \right) \left( \cos(\sqrt{k}s) - L \frac{s}{k} \sin(\sqrt{k}s) \right) \]

k - focus strength
L - length of the drift
s - eff. length of the Quad.
\( \alpha, \beta \) und \( \gamma \) - TWISS-Parameter
\( \varepsilon \) - emittance
Backup – Quadrupol-Scan

- analog camera
- digital camera
- attenuator
- beam splitter 50:50
- translation table 25 mm way

Scanner 1
Scanner 2
Backup – Slit mask

- Example for a slit mask measurement
  - Fit function contains a sum of Gauss functions
    \[ F_{\text{Fit}}(x) = \sum_i \frac{A_i}{\sigma_i \sqrt{2\pi}} \exp \left( -\frac{x - x_{0i}}{\sigma_i \sqrt{2}} \right) \]
  - Elements of the Beta-Matrix
    \[ \xi_{11} = \sum_i x_i^2 w_i \]  
    \[ \xi_{22} = \sum_i x_i w_i \frac{x_{0i} - \langle x_0 \rangle - x_i}{L} \]
    \[ \xi_{12} = \sum_i w_i \frac{\sigma_i^2 + \left( x_{0i} - \langle x_0 \rangle - x_i \right)^2}{L^2} \]
    - RMS-beam width
    - Correlated and uncorrelated beam divergence
    - Correlation between beam width & divergence
  - Calculation of the emittance
    \[ \varepsilon_{\text{RMS}} = \frac{1}{L} \sqrt{\left( \sum_i x_i^2 w_i \right) \left( \sum_i w_i \left( \sigma_i^2 + \left( x_{0i} - \langle x_0 \rangle - x_i \right)^2 \right) - \left( \sum_i x_i w_i \left( x_{0i} - \langle x_0 \rangle - x_i \right) \right)^2} \]
Backup – Scattering in Ce:YAG

- Scattering width $\approx$ penetration depth
- penetration depth
  - Bethe-Bloch $< 48 \, \mu m$
  - „GEANT 4“ $< 45 \, \mu m$
  - „Casino“ $< 30 \, \mu m$
  - Crytur Inc. 38 $\mu m$

- first estimation: scattering is bigger than the hole diameter (25 $\mu m$)
Backup - γ detektor

Ce:YAG
25 mm diameter
20 mm high

Reflective foil

Light-tight Alu-housing

Mounted on Scanner 1

Igor Alexander
• investigation of the beam halo
• quadrupol-scan
• helicity correlated asymmetries
• high dynamic range of $10^3 – 10^4$

with MOPL-Programm

with Scanner-Kiste & Oszi
Backup – Deflecting cavity
Backup – UV-VIS laser system

RF MAMI-Master

directional coupler -20 dB

double stub Tuner

directional coupler -20 dB

bias-tee

laser diode

incoupled power
powermeter -20 dB

reflected power
Powermeter -20 dB

dc-current
Components - Source

- Vacuum manipulator
- Transport chamber
- Preparation chamber
- Source chamber
- Cover of the UV-VIS laser system
Components - Source

from source

[Image of an experimental setup with labels:
- alpha-magnet 1
- electron trajectory
- scanner 1
- scanner 2
- scanner 3
- alpha-magnet 2]
Components – Deflecting cavity

1.3 GHz deflecting cavity

first working rf component for MESA

38 cm

electron trajectory

SiC-Faraday Cup
2" Ce:YAG screen

beam line was build up with:
V. Bechthold (diploma thesis)
B. Ledroit (bachelor thesis)
Components
UV-VIS laser system

- Components:
  - UV-VIS laser system
  - 405 nm LD
  - 520 nm LD
  - anamorphic prism pair
  - shutter
  - attenuator
  - dicroitic mirror
  - 1.7 W of 1.3 GHz
  - shutter
  - attenuator
  - dicroitic mirror
  - 520 nm LD
  - anamorphic prism pair
  - injected RF power
  - reflected RF power
  - dc current in
  - beam splitter
  - var. telescope
  - CCD as virtual cathode
  - 405 nm LD
  - 1.7 W of 1.3 GHz
  - cw + dc to LD
  - dc current in

Igor Alexander
ERL - 11.07.2015
Components
UV-VIS laser system

for SLD3237VF
measurement with lin. defl. cavity @ 2.45 GHz

FWHM

$I_{inj} = 80 \text{ mA}$
$I_{inj} = 90 \text{ mA}$
$I_{inj} = 100 \text{ mA}$

unwanted beam - tail
Components - Scanner

holder for investigations of the electron scattering in YAG

slit mask

holder for YAG-screens

slit width 25 μm
slit distance 250 μm
number of slits 21
area 5x5 mm²
50 μm stainless steel

carriage of Scanner 3

mounted YAG-screens
Components - Scanner

all components are UHV suitable

with ITO coating
Results – Quadrupol-Scan

focus strength: 2.75 diopter

focus strength: 0 diopter

focus strength: -2.75 diopter
Components – IR laser system

improvement of the polarization optics:
diploma thesis of Chr. Matejcek

- laser diode
- anamorphic prism pair
- shutter
- 5 axis table
- pockels cell
- iris
- polarizer
- mirror
- attenuator
- 570 mm
Results – IR laser system

- Investigations on helicity correlated asymmetries for P2 experiment
- Switching helicity with 1 kHz instead of 50 Hz with RTP pockels cell
- Circular polarisation of 99.99%
- Loss 1.2% of measurement period

Diploma thesis: Chr. Matejcek

RTP: rubidium titanyl phosphate - RbTiOPO4