The MePS System at Helmholtz-Zentrum Dresden-Rossendorf and its special Capability for Positronium Lifetime Spectroscopy

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HZDR = Helmholtz Zentrum Dresden-Rossendorf

ELBE Facility (superconducting electron LINAC)

- electron beam repetition frequency $26/2^n$ MHz
- pulse width 5 ps
- $30 \text{ MeV}, 1 \text{ mA} \rightarrow 30kW$ (2 mA planned)
Ground plan of the ELBE hall
Concept of EPOS (ELBE Positron Source)

**MePS**
*Monoenergetic Positron Spectroscopy*
- Cave 111b / Lab 111d
- monoenergetic (slow) positrons
- pulsed system
- LT, CDBS, AMOC

**CoPS**
*Conventional Positron Spectroscopy*
- 4-tubes PALS digital spectrometer
  - CDBS, AMOC
  - using $^{22}$Na foil sources
  - He-cryostat
  - automated system
- SPONSOR: continuous slow-positron beam

**GiPS**
*Gamma-induced Positron Spectroscopy*
- Cave 109 (nuclear physics)
- Positron generation by Bremsstrahlung
- Information in complete bulky sample (up to 10 cm$^3$)
- all relevant positron techniques (CDBS, AMOC)

Information Depth:
- MePS: 0…5 μm
- CoPS: 0…200 μm
- GiPS: 0.1 mm …5 cm
• 30 MeV, 1 mA, 13 MHz repetition time in cw mode; lifetime, CDBS and AMOC with slow e^+
• Only possible due to superconducting LINAC
• Retain original time structure for simplicity and best time resolution
Simulation of Energy deposition

EPOS Density Energy Deposition (in MeV/cm²) for Distance = 10cm

Al beam dump
21 kW

W target
14 kW

primary beam
Kapton spectrum obtained at MePS

Tungsten+Water Target, 7.0 mm, \( E_0 = 40 \text{MeV}, 1 \text{mA} \)
Directly water-cooled Electron-Positron Converter

- stack of 50 pieces W-foils 0,1 mm separated by 0,1 mm → 13,5 l water at 1,5 bar (10 bar maximum pressure)
- foils cut by IR-laser in our workshop
Double-Slit Buncher

26 MHz double-slit buncher

~ 3 ns

accelerate decelerate

~ 200 ps

8 Wdg, 1.5 Cul
16 mm lang
c. 550 nH
Anzapfung bei 0.5 Wdg

Voltronics Trimmer
AT55HV (1.5-55pF)
600V DC max. 1200V DC

50 Ohm

AT55HV (1.5-55pF)
Buncher
35pF Glimmer
• Plate capacitor ≈ 1 pF
• 2 stages → delay of $e^+$ bunch ≈ 5 ns
• bias voltage of ≈ 100V keeps the beam deflected → chopper pulse kicks it in
150 V

3.8 ns
MePS characteristics

- Count rate @ 45 µA (1.35 kW): 30000 cps (maximum current 1 mA; in future 2 mA)
- time resolution today: 400 ps FWHM (but complex resolution function)
- signal-to-BG ratio: about $10^4$
- no spurious signals
- user-dedicated facility – user operation started in 2013
Effect of bent tube after accelerator

- reflected positrons are re-accelerated and have disastrous effect
- can be avoided by bent tube
- effect on resolution?
Kapton spectrum obtained at MePS

Kapton @ 11 keV with Chopper and buncher
- Measurement
- Fit: $\chi^2 = 1.2$
Avoid backscattered Positrons

- straight beamline
- accelerator is on
- strong side peak due to re-acceleration of backscattered positron

- bent beamline: 45°
- accelerator is on
- no side peaks
- less background $\approx 1 : 10^4$
- still no chopper in use
Annealed Cu single crystal

- $6.28 \text{ ps/ch}$, $\text{area} = 2.1 \times 10^6$
- $E_{e^+} = 2 \text{ keV}$
- Buncher $245^\circ / 210V$
Count Rate

- 2014: new W moderator (100μm W foil - flash lamp annealed)
- Electron beam power: 1.35 kW
- Possible power: 30 kW
Deterioration of first W Moderator

Counts per second (normalized to 100 µA)

- Count rate for 2 keV

18 month

Date

Necessary Repetition Time to measure 142 ns

- MC simulated lifetime spectra with 140 ns / 5%
- positrons survive from earlier bunches

<table>
<thead>
<tr>
<th>Repetition Time (ns)</th>
<th>Lifetime Component $\tau_3$ (ns)</th>
<th>Intensity $I_3$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>77</td>
<td>35</td>
<td>1.7</td>
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<tr>
<td>154</td>
<td>75</td>
<td>3.3</td>
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<tr>
<td>308</td>
<td>124</td>
<td>4.9</td>
</tr>
<tr>
<td>616</td>
<td>141</td>
<td>5.1</td>
</tr>
<tr>
<td>$\infty$</td>
<td>140</td>
<td>5.0</td>
</tr>
</tbody>
</table>

- lifetime analysis with LT 9
- 616 ns repetition time is sufficient
ELBE is able to operate in cw mode with 13 MHz and a bunch charge of 77 pC
- future plan at ELBE: increase of bunch charge to 123 pC at 40 MeV

results at $E_-$=30 MeV in 30 kW beam power (in future 64 kW)

we need only $\approx 2$ kW beam power for $\approx 50$ kcps

thus: we can use
- 1,625 MHZ = 616 ns repetition time at 8 kW cw beam power or
- 0,812 MHz = 1.23 µs at 4 kW

Conclusion: full count rate at very long repetition times
- with 616 µs $\rightarrow > 10^5$ cps expected
- ideal for Positronium Lifetime Spectroscopy
MePS: Study of low-k dielectric films

low-k matrix resin + porogen

initial cure template formation

final cure porogen volatilization

800 nm

spin casting

annealing

(1) “Low-k Dielectrics.”  http://fcs.itc.it/

CDO Matrix (SiOCH) + Porogen (C_nH_m)

UVTP – Ultraviolet Thermal Processing
Low-K dielectric layers

- Positrons are ideal tool for closed porosity in low-k layers
- Lifetime spectra of differently treated low-K layers
- Treatment:
  - untreated porous layer
  - plasma treatment for compactation
  - TiN cap layer

Differently treated low-K layers

Pore diameter 0.63 nm 1.05 nm
Low-K dielectric layers

- Dispersion of lifetime gives the size distribution of the pore system.
• MePS as part of EPOS is already now useful tool for porosimetry
• high counting rate: 30000 cps @ 1,3 kW electron beam power
• spectra free of spurious signals and $10^4$:1 Peak-to-BG
• problem of backscattered positrons solved by bended beam tube

Talk available: http://positron.physik.uni-halle.de

Thanks for your attention!
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many more ….

http://positron.physik.uni-halle.de
Workshop

Methods of Porosimetry and Applications

The workshop will treat aspects of the different methods of porosimetry, such as N\textsubscript{2}-Adsorption, Hg intrusion, SAXS, SANS and Positron Annihilation. Tutorial talks will be given about these topics. The limitations and possible applications of these techniques will be discussed. The workshop will be organized at the Institute of Radiation Physics at HZDR.

Dr. A. Wagner
Prof. D. Enke
Prof. R. Krause-Rehberg

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