Photocathode and Laser

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C-AD electron-cooling
Outline of the talk

• **Multialkali photocathode development**
  – Measurements with 1\textsuperscript{st} generation deposition system
  – Design of 2\textsuperscript{nd} and third generation system

• **Laser system**
  – Requirements
  – Commercial availability
  – Modifications needed

• **Diamond amplifier**
  – Theoretical analysis
  – Gain measurements
  – RF testing
  – Capsule fabrication
    • Brazing
    • Metallization
Overview

Photocathode Requirements

• High Quantum Efficiency
• Visible light irradiated
• Multiple operating conditions
  20 nC/bunch, 9.4 MHz (mag)
  5 nC/bunch, 9.4 MHz (non-mag)
• Robust, long lived
• Capable of assembly into a photocathode secondary emission capsule

Laser requirements

• High Power (10’s of Watts)
• Picosecond pulse duration
• Variable output power
• Spatial and temporal beam shaping

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Photocathode Development

CsK₂Sb Deposition System

- 2-4% QE at 532 nm
- 12% QE at 355 nm
- Uniform emission over 1” diameter
- Long life time-months
- High Current density ~250 mA/cm²
- Initial high power laser testing completed
- mA current delivered, limited by space charge

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High Power studies

Excimer laser irradiated photocathode 352 nm

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0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

Field MV/m

QE vs time under high irradiation on Cu substrate

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

Charge (C)

QE %

QE vs time under high irradiation on Cu substrate

2 mA delivered with 3% QE using 532 nm light at 81.25 MHz, 10 ps pulse length- space charge limit

System is too large and cumbersome for our needs
- Packed powder samples cannot be heated quickly
- Time between deposition of different materials too long
• Second Generation
  - Smaller chamber, Less material, lower outgassing, better vacuum
  - Shorter source-substrate distance
  - Isolated SAES getter sources, quick to heat, fast photocathode prep
  - Co-deposition of cathode materials, better photocathodes
  - Metal or transparent substrate

• Third Generation
  - System designed to interface to 703 MHz SRF Gun
  - Similar technology to 2nd Generation system
  - Sample deposition occurs horizontally on fixed arm
2nd Generation Deposition system

- Shorter working distance
- Pre-made sources
- Transparent substrate
- Larger temperature range
- Adaptable for capsule fabrication

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Photocathode summary

Goal: To develop a high average current multi-alkali photocathode for use in a SRF photoinjector

Tasks accomplished:
- Uniformity of emission and lifetime studies under low power and high charge density completed successfully.
- High power test stand studies performed, cathode limitation identified and course of action established
- mA level current achieved

<table>
<thead>
<tr>
<th>Items to accomplish</th>
<th>Date</th>
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<tbody>
<tr>
<td>Successful transparent photocathode recipe developed</td>
<td>2Q 2006</td>
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<tr>
<td>High power testing, lifetime studies on transparent photocathode</td>
<td>3Q 2006</td>
</tr>
<tr>
<td>Design of a secondary emission capsule with multi-alkali photocathode</td>
<td>4Q 2006</td>
</tr>
<tr>
<td>Testing of above mentioned capsule</td>
<td>2Q 2007</td>
</tr>
<tr>
<td>Assembly and operation of 3rd generation deposition system</td>
<td>4Q 2006</td>
</tr>
<tr>
<td>Recipe development using 3rd generation system</td>
<td>1Q 2007</td>
</tr>
<tr>
<td>High power testing, lifetime studies on 3rd generation photocathodes</td>
<td>2Q 2007</td>
</tr>
</tbody>
</table>
Laser Requirements

- 9.4 MHz
- 532 nm, 355 nm
- 10 ps pulse length
- Synchronized to master RF clock
- Adjustable output power, oscillator, amplifier or other combination
- During ramp up 10^6 variation in power

<table>
<thead>
<tr>
<th>Power Requirement</th>
<th>Method</th>
<th>Process</th>
<th>Change</th>
</tr>
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<tbody>
<tr>
<td>Laser Wavelength</td>
<td>Power Requirement</td>
<td>Ramp up 10^6</td>
<td></td>
</tr>
<tr>
<td>532 nm</td>
<td>Lower Pump power</td>
<td>power supply control</td>
<td>~ x10</td>
</tr>
<tr>
<td>532 nm</td>
<td>Lower output power</td>
<td>Variable attenuator</td>
<td>x100</td>
</tr>
<tr>
<td>355 nm</td>
<td>Change repetition rate</td>
<td>Pulse picker</td>
<td>10^4</td>
</tr>
<tr>
<td>355 nm</td>
<td>Change micropulse</td>
<td>Pulse picker</td>
<td>x10</td>
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</table>

<table>
<thead>
<tr>
<th>Laser Wavelength</th>
<th>CsK₂Sb QE</th>
<th>SEY</th>
<th>Desired Current</th>
<th>Laser Power to Cathode</th>
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</thead>
<tbody>
<tr>
<td>532 nm</td>
<td>3%</td>
<td>0</td>
<td>50 mA</td>
<td>3.9 W</td>
</tr>
<tr>
<td>532 nm</td>
<td>3%</td>
<td>50</td>
<td>50 mA</td>
<td>.09 W</td>
</tr>
<tr>
<td>355 nm</td>
<td>10%</td>
<td>0</td>
<td>50 mA</td>
<td>1.8 W</td>
</tr>
<tr>
<td>355 nm</td>
<td>10%</td>
<td>50</td>
<td>50 mA</td>
<td>.03 W</td>
</tr>
<tr>
<td>532 nm</td>
<td>3%</td>
<td>0</td>
<td>200 mA</td>
<td>15.5 W</td>
</tr>
<tr>
<td>532 nm</td>
<td>3%</td>
<td>50</td>
<td>200 mA</td>
<td>0.3 W</td>
</tr>
<tr>
<td>355 nm</td>
<td>10%</td>
<td>0</td>
<td>200 mA</td>
<td>7 W</td>
</tr>
<tr>
<td>355 nm</td>
<td>10%</td>
<td>50</td>
<td>200 mA</td>
<td>.15 W</td>
</tr>
</tbody>
</table>

C-AD electron-cooling
Commercial Products

TBWP
Cheetah X

Lumera Laser GMBH

Coherent
Paladin

C-AD electron-cooling
C-AD electron-cooling

10 W at 1 MHz is now available, 20 W under construction

Multiplex or beam split to get 10 MHz

Sample system specification

<table>
<thead>
<tr>
<th>Specifications</th>
<th>RAPID</th>
</tr>
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<tbody>
<tr>
<td>Wavelength</td>
<td>1064 nm</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>&lt;15 ps</td>
</tr>
<tr>
<td>Average power</td>
<td>2 W @ 500 kHz</td>
</tr>
<tr>
<td>Pulse energy</td>
<td>30 μJ @ 10 kHz, 4 μJ @ 500 kHz</td>
</tr>
<tr>
<td>Pulse energy stability</td>
<td>&lt;1% rms at 500 kHz</td>
</tr>
<tr>
<td>Pulse energy contrast @ 500 kHz</td>
<td>&gt;200:1</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>0-500 kHz, TTL-trigger, pulse on demand</td>
</tr>
<tr>
<td>Beam quality M²</td>
<td>&lt;1.2</td>
</tr>
<tr>
<td>Polarization</td>
<td>p, 1000:1</td>
</tr>
<tr>
<td>Harmonics options</td>
<td>532 nm (p), 355 nm (s)</td>
</tr>
<tr>
<td>Electric supply</td>
<td>85-260 V, 50-60 Hz, 2 kVA</td>
</tr>
<tr>
<td>Control unit</td>
<td>W 553 x D 600 x H 612+70 mm³; ~80 kg</td>
</tr>
<tr>
<td>Laser head</td>
<td>W 440 x D 888 x H 117 mm³, ~46 kg</td>
</tr>
<tr>
<td>Beam position</td>
<td>H 67+ mm; IR 127, SHG 97 mm from left</td>
</tr>
</tbody>
</table>

System Specifications

<table>
<thead>
<tr>
<th>System Specifications</th>
<th>Paladin 355</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>355 nm</td>
</tr>
<tr>
<td>Output Power¹</td>
<td>&gt;4W</td>
</tr>
<tr>
<td>Paladin 355-4000</td>
<td>&gt;8W</td>
</tr>
<tr>
<td>Paladin 355-8000</td>
<td></td>
</tr>
<tr>
<td>Repetition Rate</td>
<td>80 MHz ± 1 MHz</td>
</tr>
<tr>
<td>Pulse Length</td>
<td>&gt;15 ps @ 1064 nm</td>
</tr>
<tr>
<td>Spatial Mode</td>
<td>TEM₀₀</td>
</tr>
<tr>
<td>M²</td>
<td>&lt;1.2</td>
</tr>
<tr>
<td>Beam Diameter</td>
<td>1 mm ± 10%</td>
</tr>
<tr>
<td>Beam Divergence</td>
<td>&lt;550 μrad</td>
</tr>
<tr>
<td>Beam Ellipticity</td>
<td>0.9 - 1.1</td>
</tr>
<tr>
<td>Pointing Stability</td>
<td>&lt;20 μrad/°C</td>
</tr>
<tr>
<td>Polarization</td>
<td>linear &gt;100:1, vertical</td>
</tr>
<tr>
<td>Noise (10 Hz - 2 MHz)</td>
<td>&lt;1% (rms)</td>
</tr>
<tr>
<td>Long-term Power Stability</td>
<td>±2%</td>
</tr>
</tbody>
</table>

Basic power requirements can be met, beam shaping will be system specific.

1. Average power calculated at 10 kHz.
Beam Shaping

- **Temporal Shaping:**
  - Gaussian- Near normal mode of laser operation
  - Flat Top- Chirp Pulse amplification-Routine for short pulse laser systems
  - Parabolic- Need to investigate

- **Spatial:**
  - Gaussian- Normal mode of laser operation
  - Flat Top-Aperture clip the edges of Gaussian-Very lossy

New Commercial product Pi shaper under investigation
Elliptical beam generation

- Generation of elliptical laser beam to meet emittance requirements
- Technique demonstrated for adaptive laser beam shaping (NIM A 557 (2006), 117)
- UV illumination of photocathode, 10 Hz repetition rate
- Tested multiple techniques
  - Microlens array to shape spatial profile
  - Deformable mirror
    - Requires genetic algorithm to adjust mirrors
  - Spatial light modulator for temporal shaping
  - Fiber bundle for both spatial and temporal shaping
    - Does not produce ideal spot size at cathode

- Suggested methods combine spatial and Temporal pulse shaping (NIM A 557 (2006), 106)
  - Spectral masking of chirped waveforms
  - Temporal stacking of multiple laser beamlets
  - Laser controlled spatial filtering

- To realize 3D ellipsoidal profile combine fiber bundle with adaptive optics to control the laser spatial distributions
- A great deal of work needs to be done to realize this complex laser beam shaping system
Laser summary

- Exact system configuration will be decided upon once photocathode, diamond secondary emitter and magnetized vs. non-magnetized cooling schemes are fixed, 4Q 2006
- Commercial systems today can deliver necessary power levels
  - Specifics of system will require some customization
- Multiple methods to modify both the output power will have to be installed, 2Q 2007
- Spatial and Temporal beam shaping will be one of the more complex requirements to implement
Secondary emission capsule concept

When High Charge/Current required

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Advantages

• Reduction of the number of primary electrons by the large SEY, i.e. a very low laser power requirement in the photocathode producing the primaries.
• Protection of the cathode from possible contamination from the gun, allowing the use of large quantum efficiency but sensitive cathodes.
• Protection of the gun from possible contamination by the cathode, allowing the use of superconducting gun cavities.
• Production of high average currents, up to ampere class.
• Expected long lifetime, due to the reduced current from the photocathode.
• **Issues**
  – Transit time and temporal spread
  – Heat generation and dissipation
  – Gain in transmission mode
  – Gain in emission mode
  – Testing in RF gun-JLab
  – Diamond Characterization-NSLS
  – Capsule fabrication
    • Design compatible with Chemical treatment
    • Metal diamond interface
    • Ohmic contact
    • Hydrogenation
Transit time and Temporal spread

Transit time:
Drift velocity $V_d = 10^5(0.2xE+0.55) \sim 2.7\times10^5\text{m/s for } E=2 \text{ MV/m}$
E instantaneous electric field in the range of a few MV/m
Time of flight through 10 µm sample = 110 ps

Temporal Spread:
Random walk broadening during transit:
Number of IMFP steps in 10 µm sample = 800
Number of EMFP steps in 10 µm sample = 1.7\times10^4
RMS broadening is negligible
Space Charge Broadening Negligible as long as field $> 2 \text{ MV/m}$
Straggling primary e w/ 10 keV energy $\sim 3$ ps
### Thermal load in W from different sources

<table>
<thead>
<tr>
<th></th>
<th>10mm</th>
<th>12.5mm</th>
<th>15mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>6.3</td>
<td>6.3</td>
<td>6.3</td>
</tr>
<tr>
<td>Secondary</td>
<td>7.6</td>
<td>7.6</td>
<td>7.6</td>
</tr>
<tr>
<td>RF</td>
<td>7.5</td>
<td>20.0</td>
<td>48.6</td>
</tr>
<tr>
<td>Replenishment</td>
<td>0.042</td>
<td>0.046</td>
<td>0.054</td>
</tr>
<tr>
<td>Total</td>
<td>21.4</td>
<td>33.9</td>
<td>62.5</td>
</tr>
</tbody>
</table>

This heat load can be handled by LN cooling.
Gain in Transmission Mode From Natural Diamond

Room Temperature

81 K

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High Current Performance in Transmission Mode

Max. current obtained 0.58 mA, current density .82 A/cm², limited by the power supply

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Gain in Emission mode From Hydrogenated samples

Gain of 50, still increasing W/ field, further investigation underway

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Testing in RF gun

Diamond can be attached to the insert for RF testing

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Oven and Nb-Diamond braze photograph

Diamond brazed to Nb at commercial outfit

C-AD electron-cooling
Metallization System Photograph

C-AD electron-cooling
Ohmic Contact Measurements
I-V curve of CVD single crystal diamond w/ 150 A° Ti-W Sputtering at Rutgers University

Performance need improvement: charging up- Still under investigation

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## Diamond Summary

### Requirements:
- Understand transmission and emission mode measurements
- Establish hydrogenation method
- Establish Ohmic contact
- Gain in emission mode of >50
- Transit time and temporal spread suitable for SRF photoinjector
- Capsule formation
  - Braze diamond to niobium
  - Attach niobium/diamond to multi-alkali photocathode
  - Test capsule photoemission performance

### Accomplishments:
- Transmission and emission measurements carried out
- Hydrogenation of multiple samples
- Gain of >50 obtained in emission mode measurements
- Brazing of Nb to diamond successful

### Work to be Done:
- Establish and better understand ohmic contact, **2Q 2006**
- Install pulsed electron gun and energy analyzer for transit time and temporal spread measurements, **2Q 2006**
- Complete capsule formation, **1Q 2007**
- Test capsule in photoinjector, **2Q 2007**

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**BROOKHAVEN NATIONAL LABORATORY**

**C-AD electron-cooling**
Photocathode, Laser and Diamond Overview

**Photocathode**
Photocathode R&D on schedule  
Good initial data obtained  
Confidence in system established  
Most key measurements made, only transparent photocathode needs to be proven out

**Laser System**
Laser System needed for electron cooling have been identified  
System specifics will be pursued once parameters are fixed  
Commercial systems are nearly at the level we need

**Diamond**
Suitable diamond candidates chosen- natural and high purity electronic quality poly crystalline  
High gain seen both in transmission and emission modes from natural diamond. Electronic quality sample will be investigated soon  
Testing of diamond in RF cavity is under preparation  
Brazing of diamond for capsule fabrication successful- chemical treatment will follow for testing compatibility with diamond processing  
Metallization process being tested  
New electron gun ordered to test temporal response  
Collaborating multiple vendors for sample production and evaluation

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Fabrication Sequence

Bottom Half

Top half

Complete Capsule

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