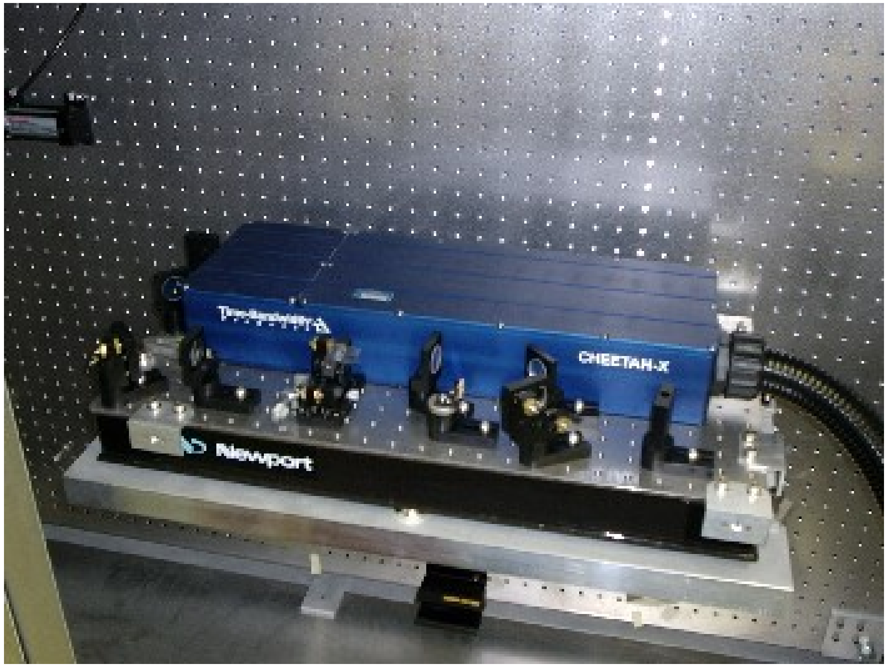
Photocathode and Laser



A. Burrill and T. Rao

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Outline of the talk

- **Multialkali photocathode development**
  - Measurements with 1st generation deposition system
  - Design of 2nd 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

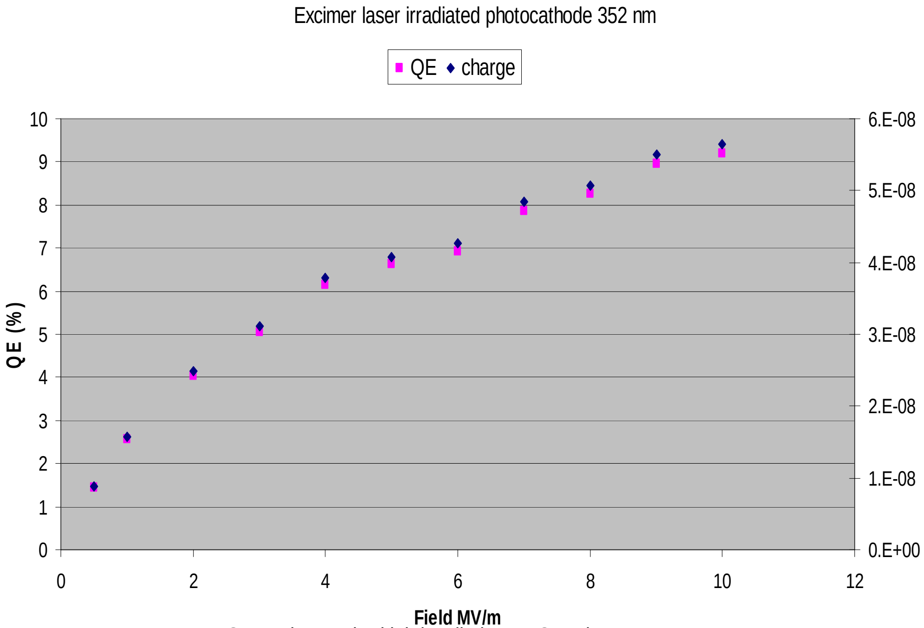
- High Power (10's of Watts)
- Picosecond pulse duration
- Variable output power
- Spatial and temporal beam shaping

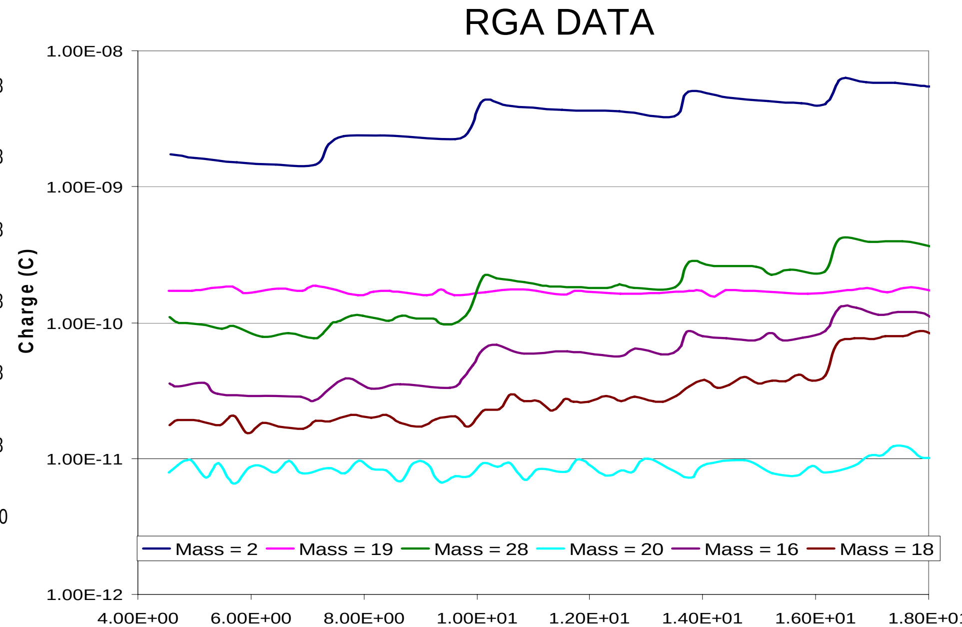
Photocathode Development

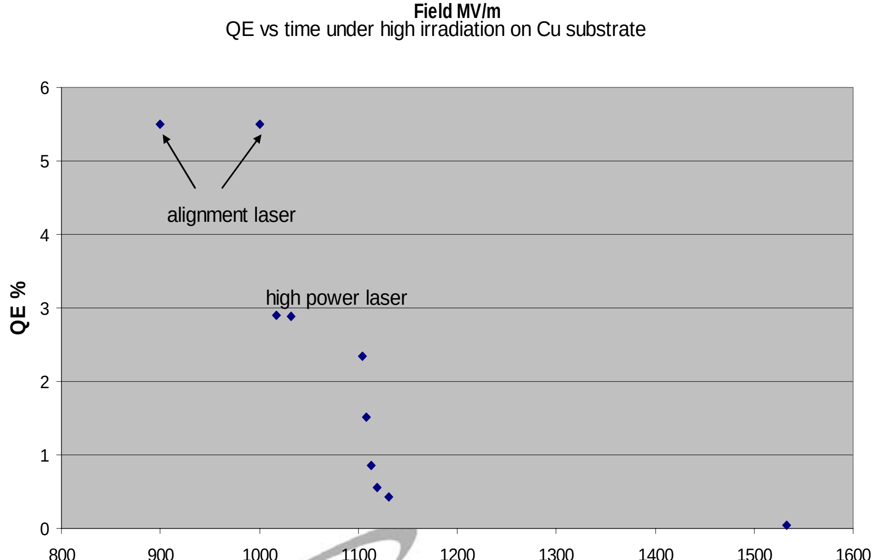
CsK_2Sb Deposition System

- 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/cm^2
- Initial high power laser testing completed
- mA current delivered, limited by space charge

High Power studies







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

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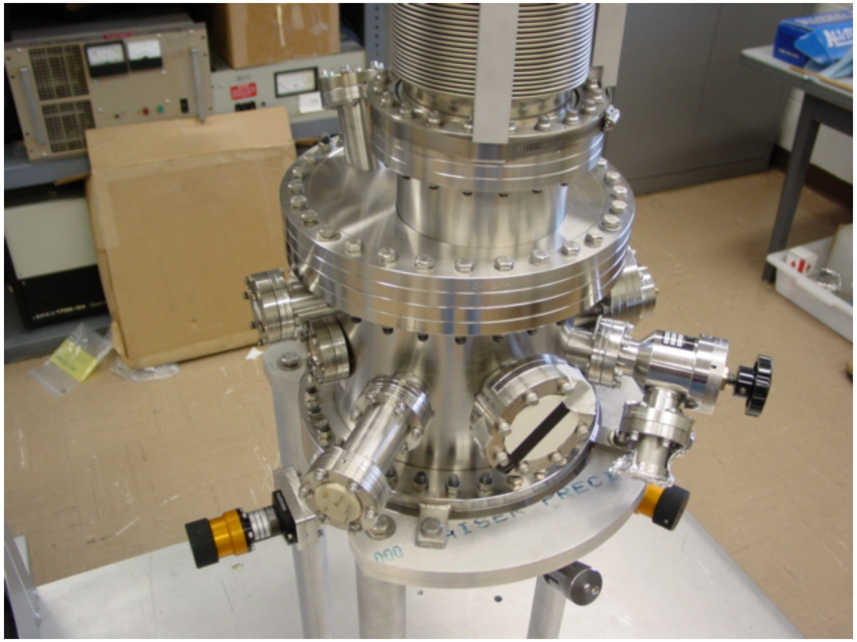
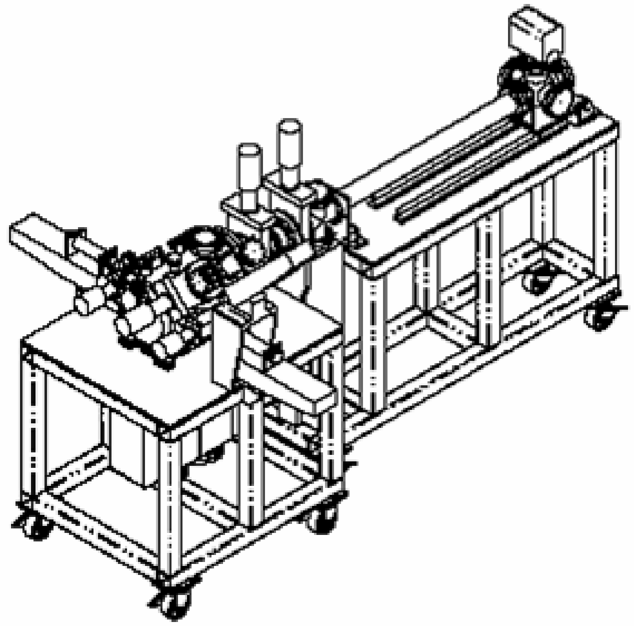
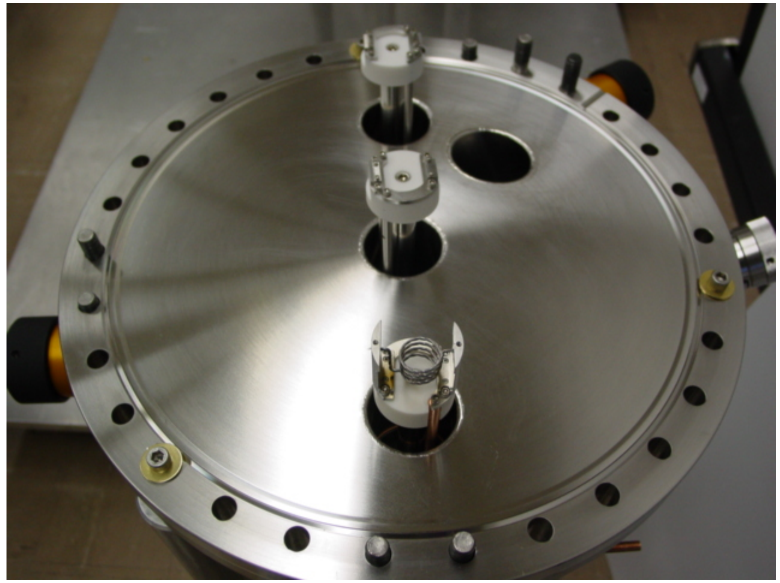
- Second Generation
  - ➢ Smaller chamber, Less material, lower outgassing, better vacuum
  - ➢ Shorter source-substrate distance
  - ➢ Isolated SAES getter sources, quick to heat, fast photocathode prep
  - ➢ Co-deposition of cathode materials, better photocathodes
  - ➢ Metal or transparent substrate



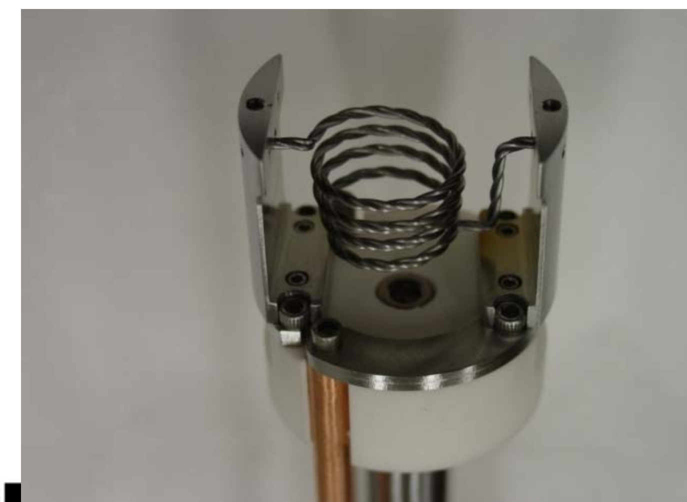


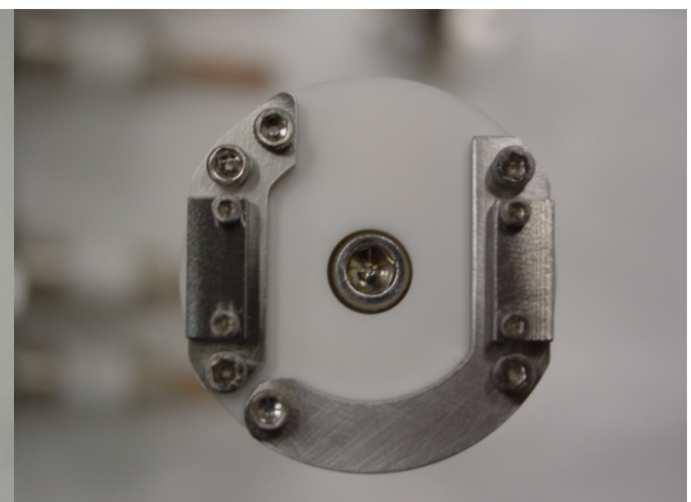
- Third Generation
  - ➢ System designed to interface to 703 MHz SRF Gun
  - ➢ Similar technology to 2nd Generation system
  - ➢ Sample deposition occurs horizontally on fixed arm

2nd Generation Deposition system



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





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

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

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 106 variation in power

Power Requirement

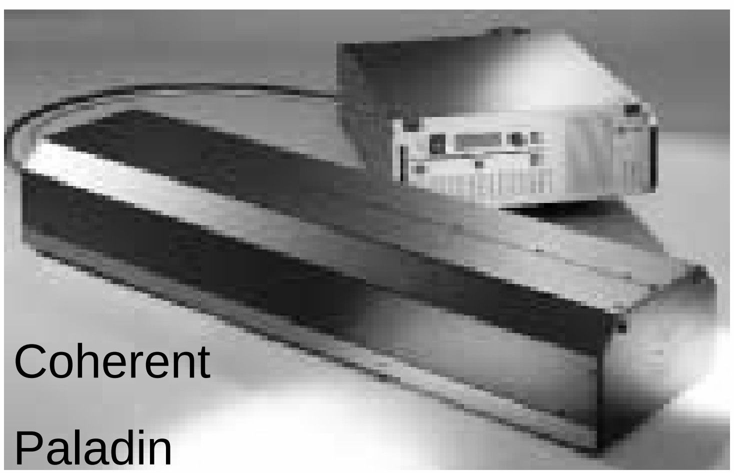
Laser Wavelength	CsK_2Sb QE	SEY	Desired Current	Laser Power to Cathode
532 nm	3%	0	50 mA	3.9 W
532 nm	3%	50	50 mA	.09 W
355 nm	10%	0	50 mA	1.8 W
355 nm	10%	50	50 mA	.03 W
532 nm	3%	0	200 mA	15.5 W
532 nm	3%	50	200 mA	0.3 W
355 nm	10%	0	200 mA	7 W
355 nm	10%	50	200 mA	.15 W

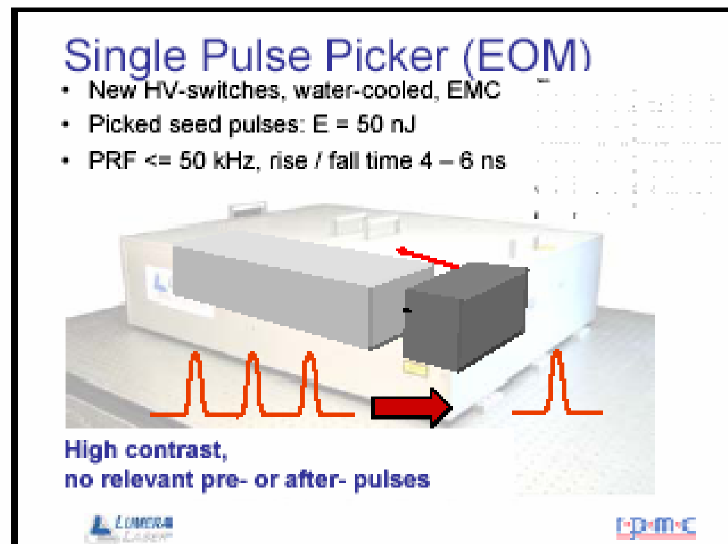
Ramping Process

Method	Process	Change
Lower Pump power	power supply control	~ x10
Lower output power	Variable attenuator	x100
Change repetition rate	Pulse picker	10^4
Change micropulse duration	Pulse picker	x10

C-AD electron-cooling

Commercial Products





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C-AD electron-cooling

Sample system specification

Specifications	RAPID
Wavelength	1064 nm
Pulse duration	<15 ps
Average power	2W @ 500 kHz
Pulse energy	30 µJ @10 kHz, 4 µJ @500 kHz
Pulse energy stability	<1% rms at 500 kHz
Pulse energy contrast @500kHz	>200:1
Repetition rate	0-500 kHz, TTL-trigger, pulse on demand
Beam quality M^2	<1.2
Polarization	p, 1000:1
Harmonics options	532 nm (p), 355 nm (s)
Electric supply	85-260 V, 50-60 Hz, 2 kVA
Control unit	W 553 x D 600 x H 612+70 mm^3; ~80 kg
Laser head	W 440 x D 888 x H 117 mm^3, ~46 kg
Beam position	H 67+ mm; IR 127, SHG 97 mm from left

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

Multiplex or beam split to get 10 MHz

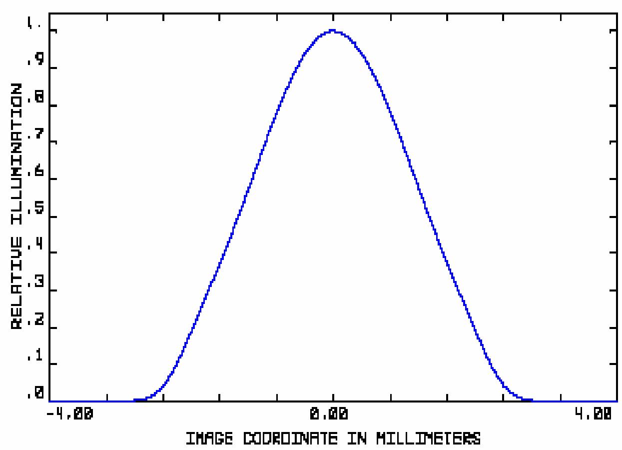
		Paladin 355
System Specifications	Wavelength	355 nm
	Output Power[1]	
	Paladin 355-4000	>4W
	Paladin 355-8000	>8W
	Repetition Rate	80 MHz ±1 MHz
	Pulse Length	>15 ps @ 1064 nm
	Spatial Mode	TEM_{00}
	M^2	<1.2
	Beam Diameter	1 mm ±10%
	Beam Divergence	<550 µrad
	Beam Ellipticity	0.9 - 1.1
	Pointing Stability	<20 µrad/°C
	Polarization	linear >100:1, vertical
	Noise (10 Hz - 2 MHz)	<1% (rms)
	Long-term Power Stability	<±2%

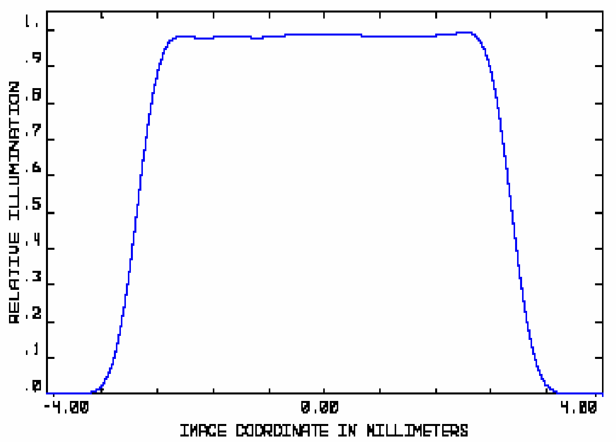
Basic power requirements can be met, beam shaping will be system specific

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





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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

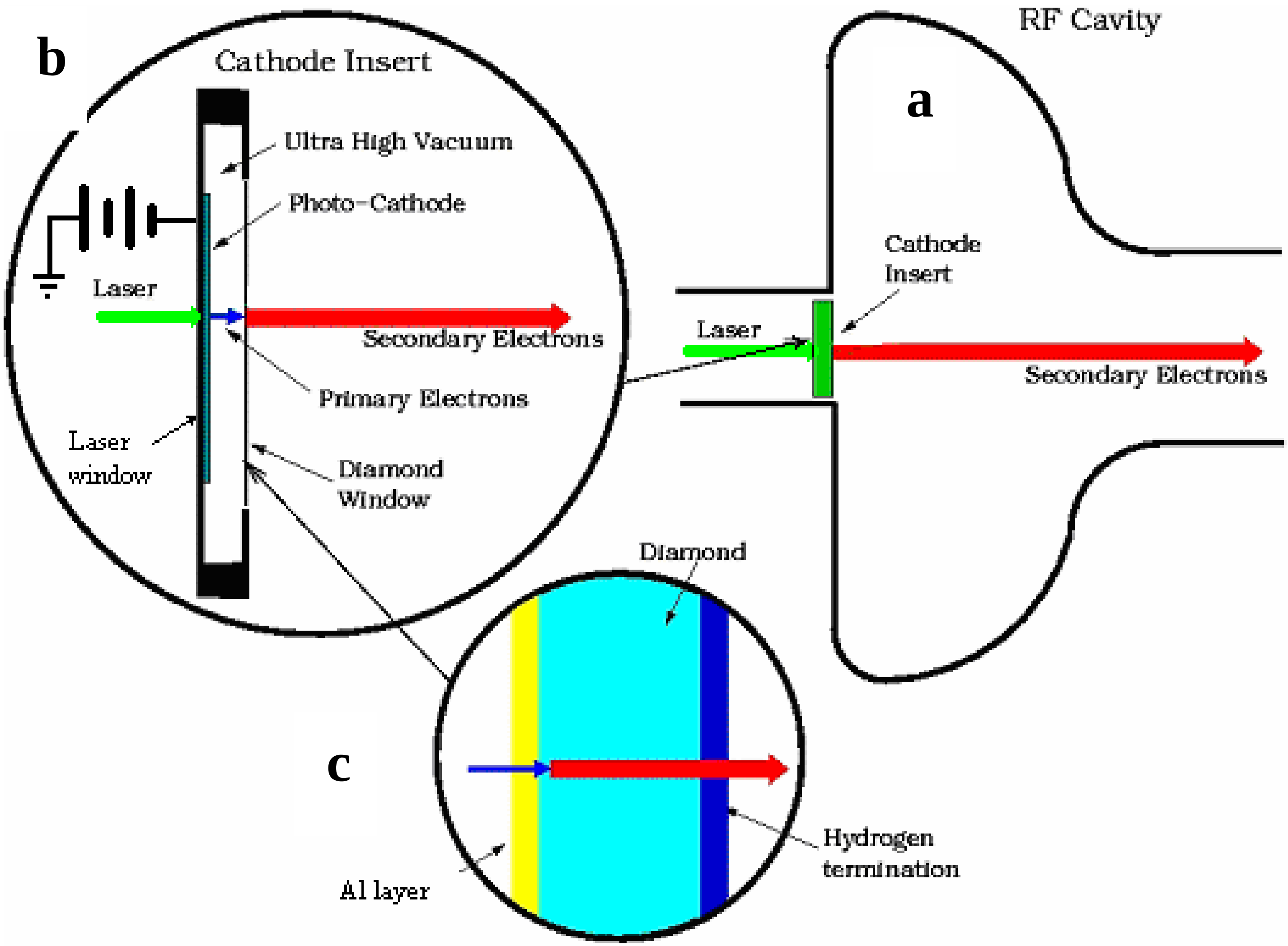
- Suggested methods combine spatial and Temporal pulse shaping (NIM A **557** (2006), 106)
  - Spectral masking of chirped waveforms
  - Temporal stacking of multiple laser beamlets
  - Laser controlled spatial filtering
- To realize 3D ellipsoidal profile combine fiber bundle with adaptive optics to 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



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 $V_d = 10^5(0.2xE+0.55) \sim 2.7x10^5$m/s for E=2 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=$1.7x10^4$

RMS broadening is negligible

Space Charge Broadening Negligible as long as field > 2 MV/m

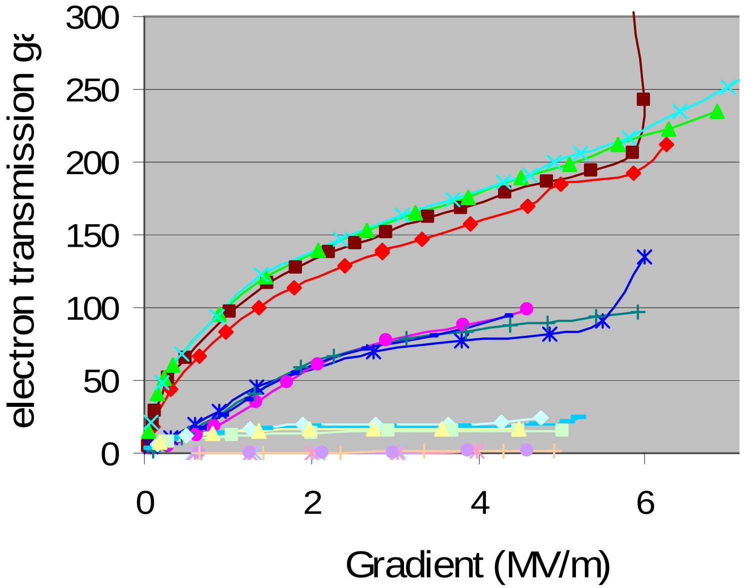
Straggling primary e w/ 10 keV energy ~ 3 ps

Thermal load in W from different sources

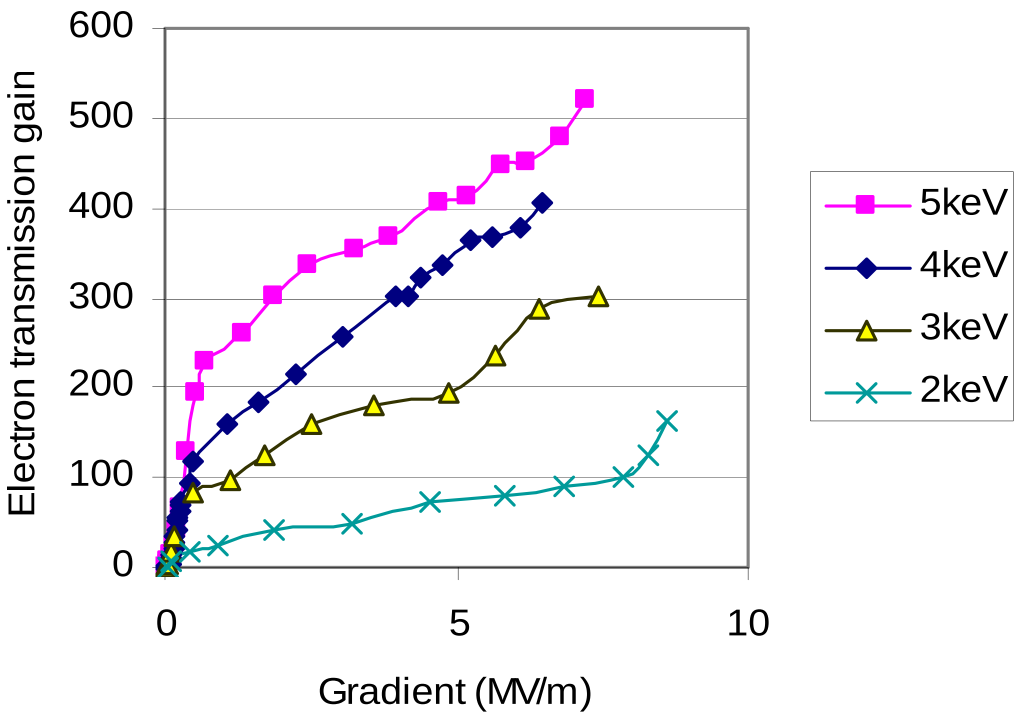
R	10mm	12.5mm	15mm
Primary	6.3	6.3	6.3
Secondary	7.6	7.6	7.6
RF	7.5	20.0	48.6
Replenishment	0.042	0.046	0.054
Total	21.4	33.9	62.5

This heat load can be handled by LN cooling

Gain in Transmission Mode From Natural Diamond



Room Temperature



81 K

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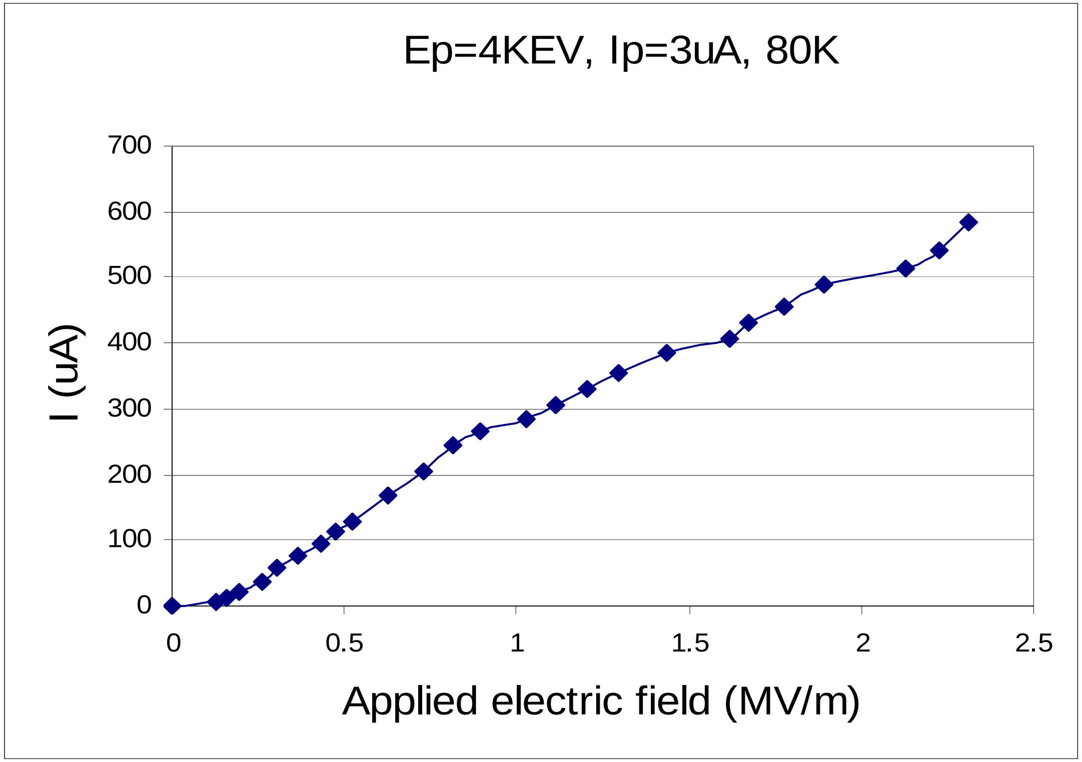
High Current Performance in Transmission Mode



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

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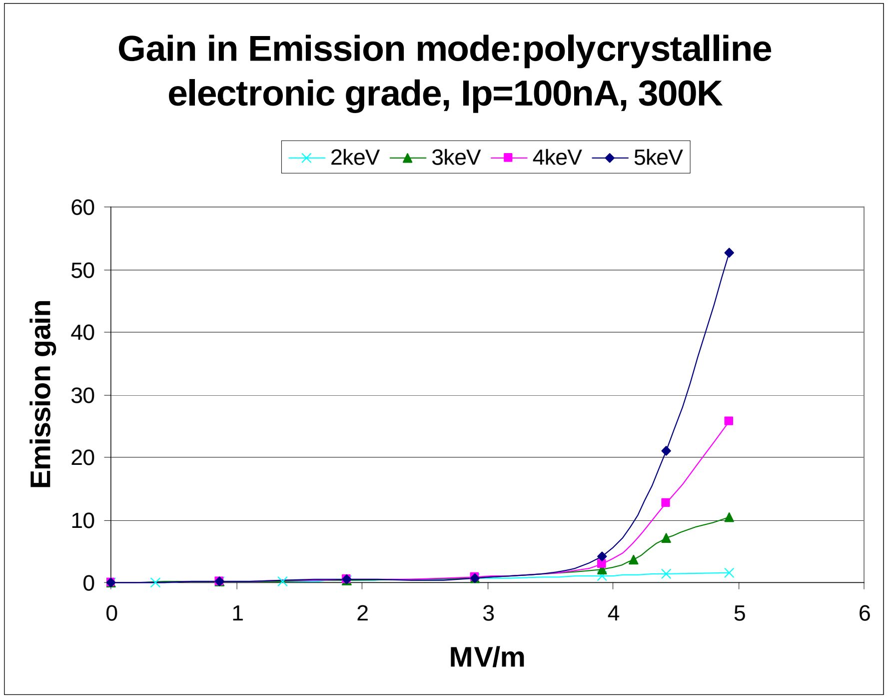
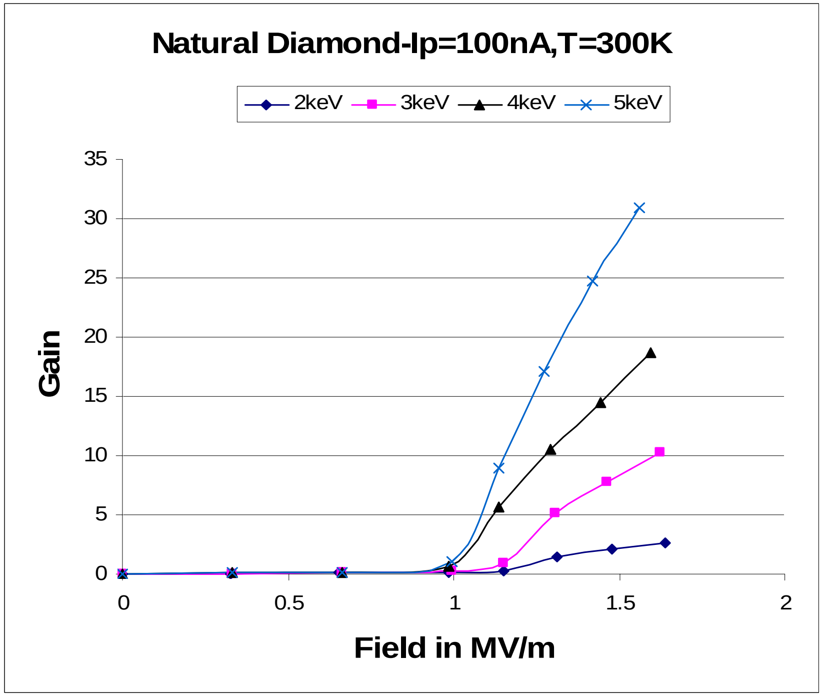
Gain in Emission mode From Hydrogenated samples





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

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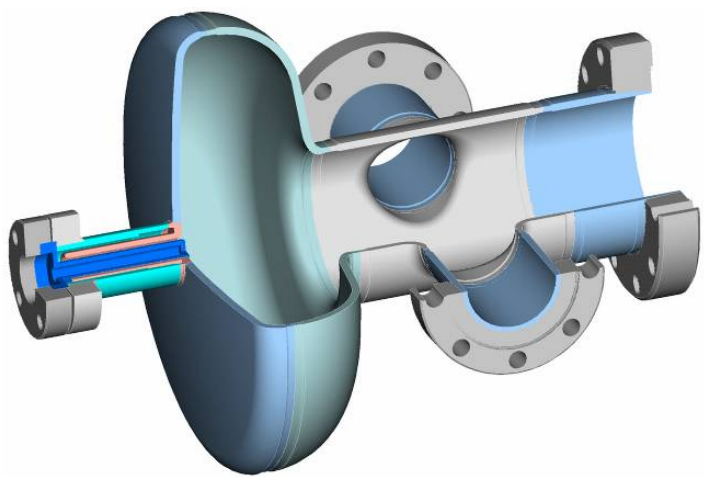
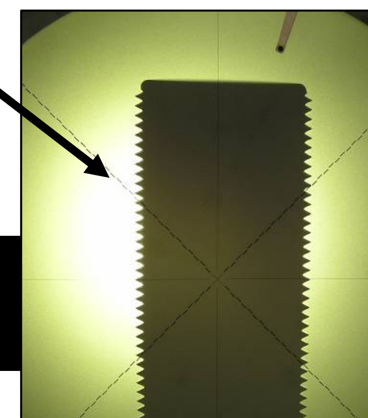
C-AD electron-cooling

Testing in RF gun



Diamond can be attached to the insert for RF testing



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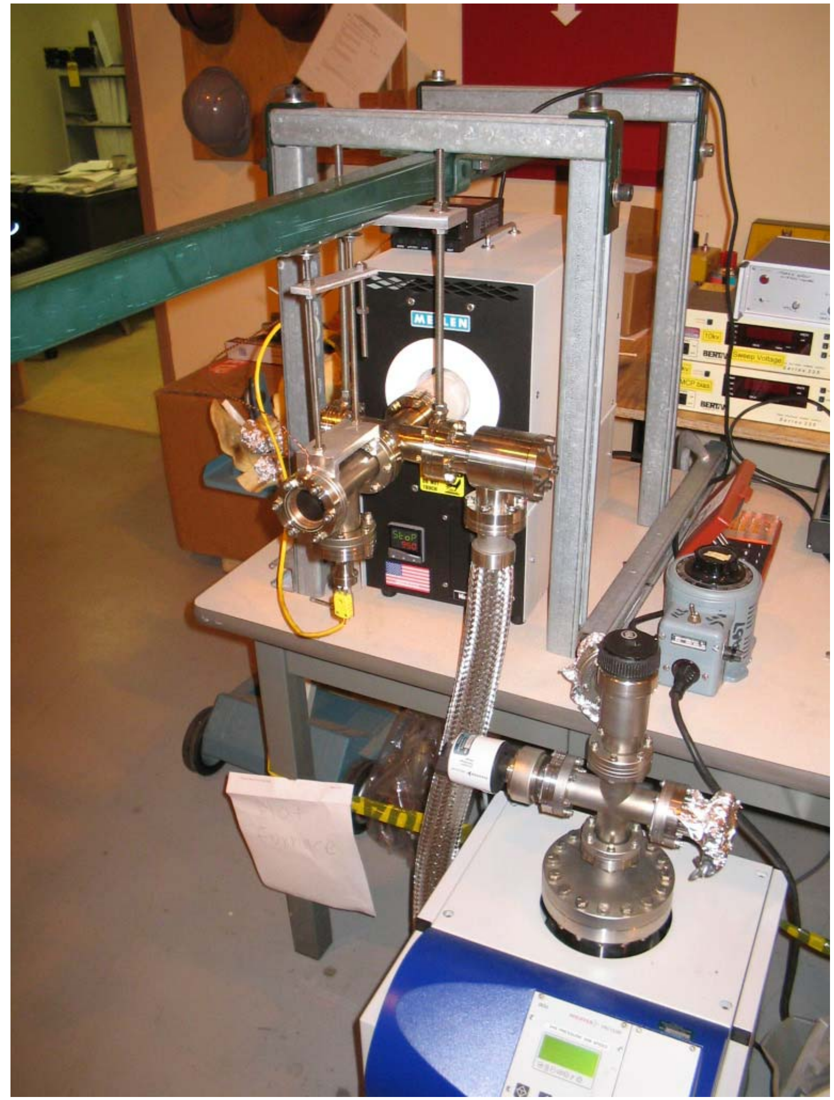
Oven and Nb-Diamond braze photograph



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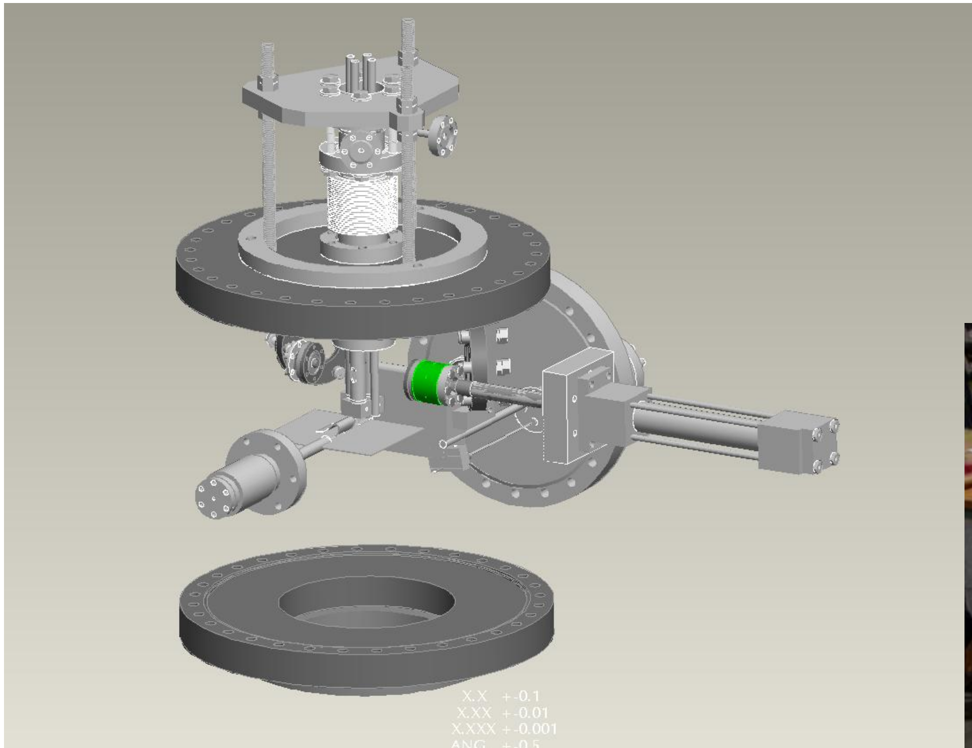
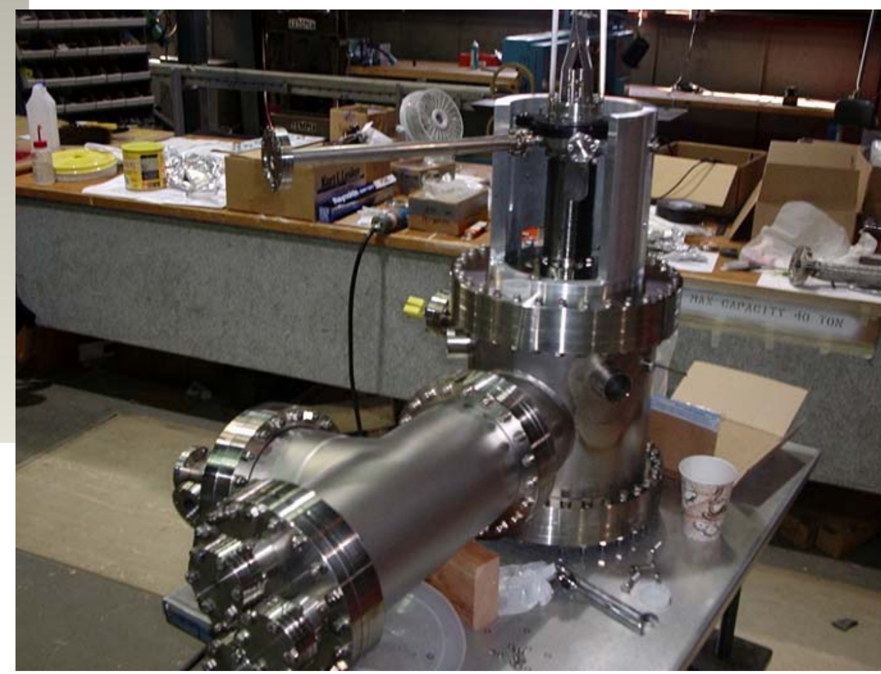
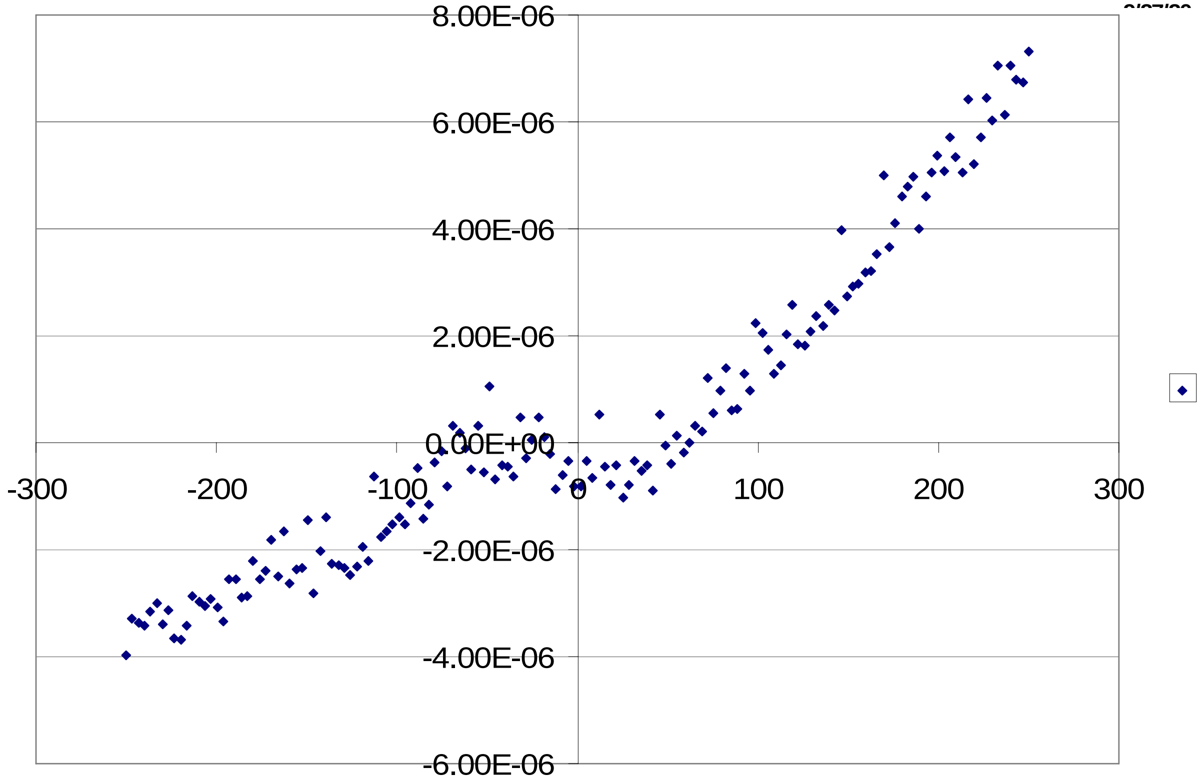
Metallization System Photograph





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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C-AD electron-cooling

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**

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

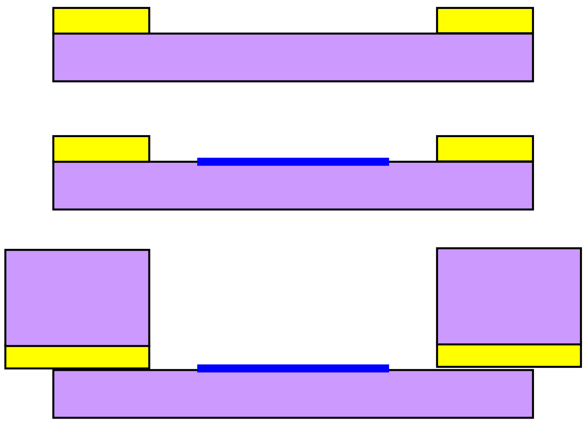
Metallization process being tested

New electron gun ordered to test temporal response

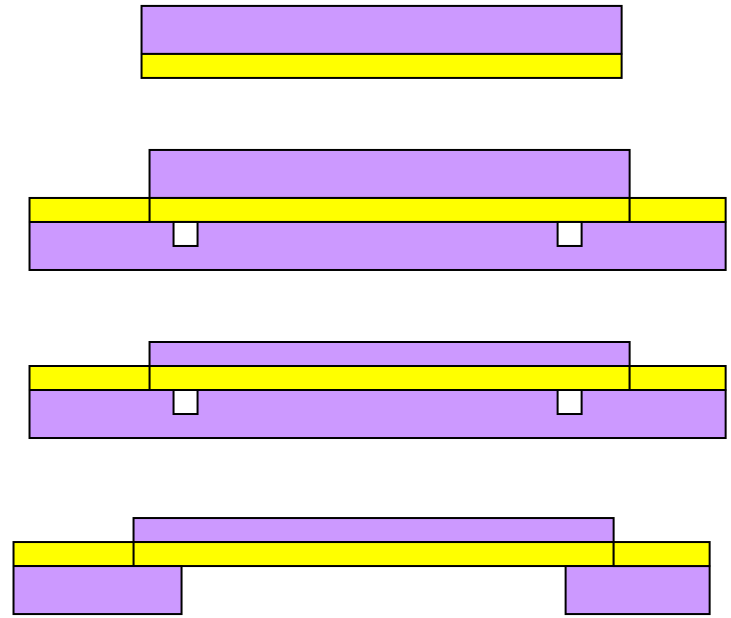
Collaborating multiple vendors for sample production and evaluation

Fabrication Sequence

Bottom Half



Top half



Complete Capsule