Photocathode Choices, State of the Art

Triveni Rao
Brookhaven National Laboratory
Upton, NY 11973

ERL Cathode Requirements

- High, uniform QE preferably in fundamental of laser/visible
- Long life time- tolerant to contamination, ion bombardment
- Large charge deliverable
- Prompt response ~100 fs electron bunch (Jamie's talk)
- Short recovery time
- Operable in High Vacuum
- Operable in High Field
- Does not contaminate the injector environment
- Cryogenic operation
- Ease of preparation, transport, transfer

Photocathode Choices

Average current < 1 mA (a few mA)

- Metal photocathode (Mg, Pb) QE ~.3% @ UV
- Alkali telluride (Cs_2Te) QE ~ 3-6% @ UV in RF injector

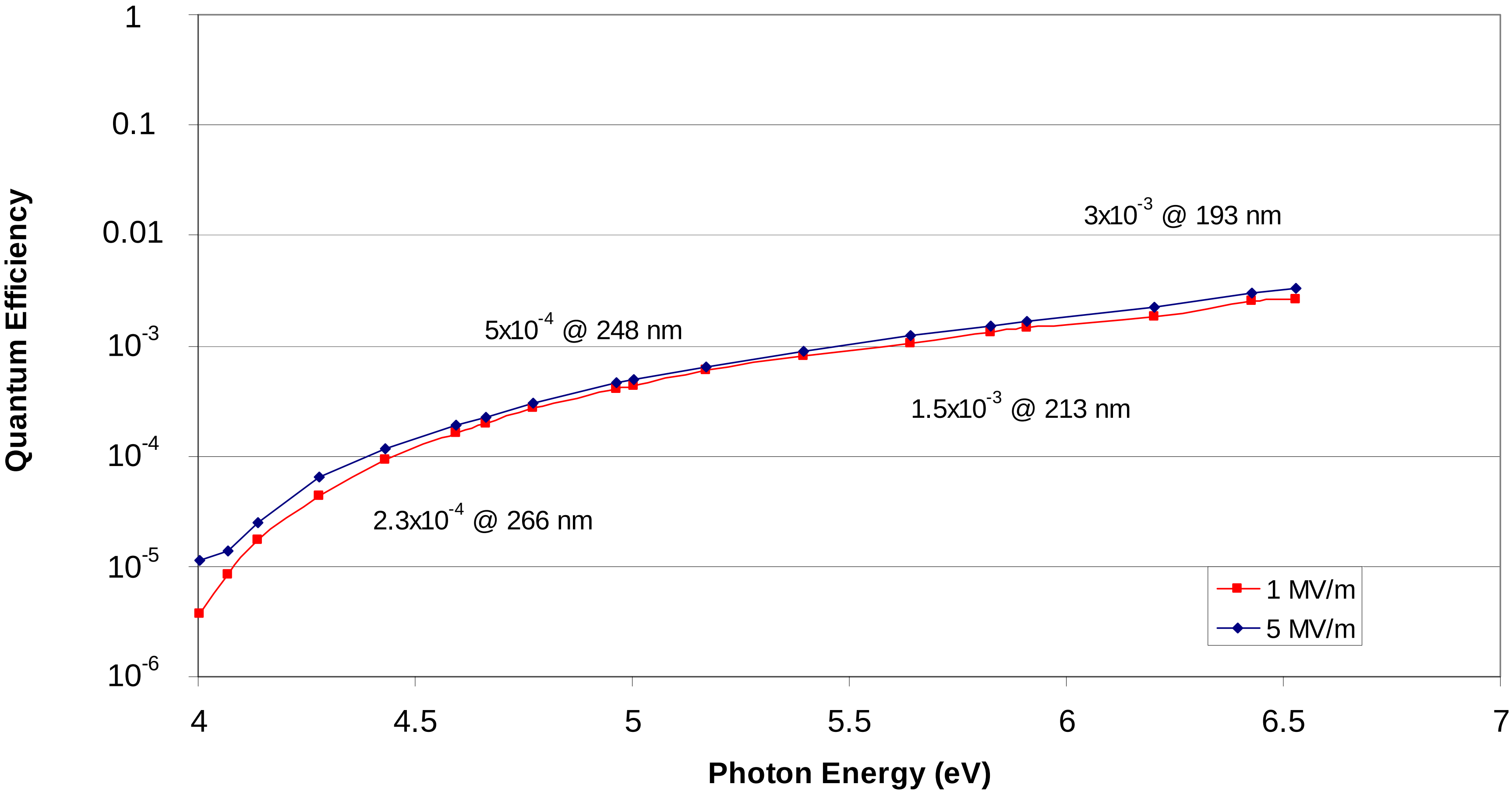
Average current > 1 mA

- Bi/multi alkali antimonides (Cs_3Sb, K_2CsSb) QE ~ 10% vis/UV
- NEA III-V (Cs:GaAs) QE ~6% vis

Novel

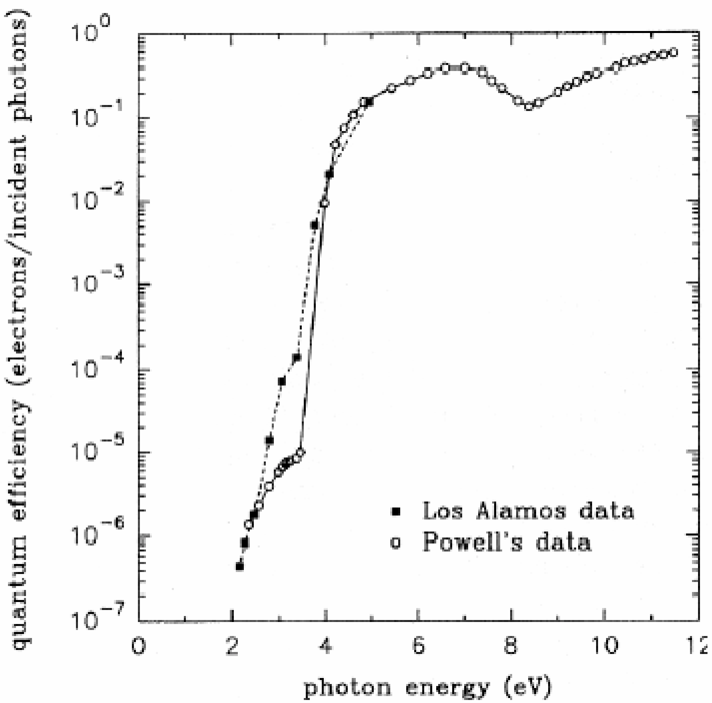
- Cs:GaN 50% QE @ 312 nm
- Photoassisted FE cathode
- Photoassisted Dispenser cathode

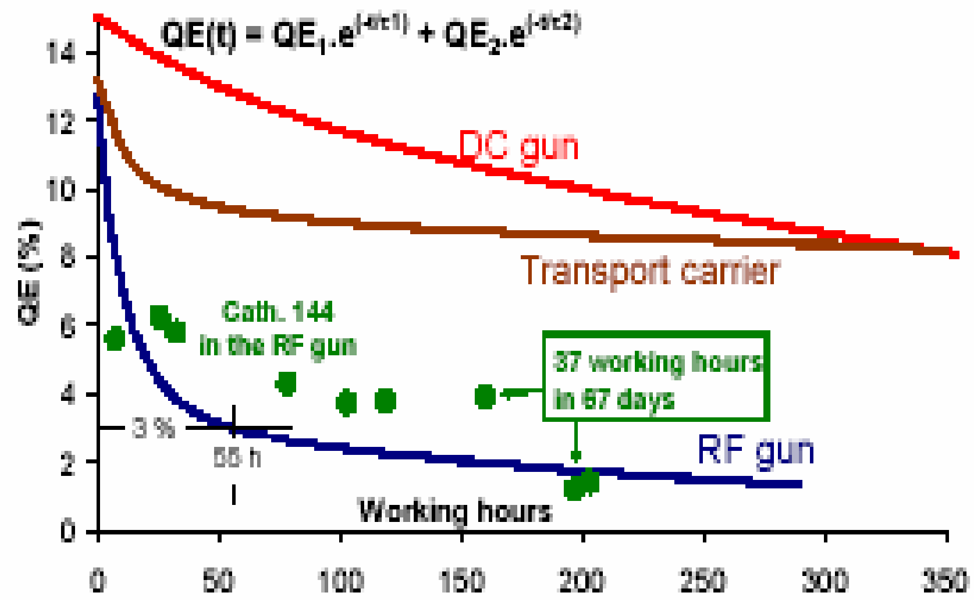
Pb cathode



Quantum Efficiency
1
0.1
0.01
10-3
10-4
10-5
10-6
4
4.5
5
5.5
6
6.5
7
Photon Energy (eV)
3x10-3 @ 193 nm
5x10-4 @ 248 nm
1.5x10-3 @ 213 nm
2.3x10-4 @ 266 nm
1 MV/m
5 MV/m

Cs_2Te





QE 1-10 % UV

Tested in RF injector

Dark current ~ Metal

UHV → **Load Lock**

Short life time → **Load Lock**

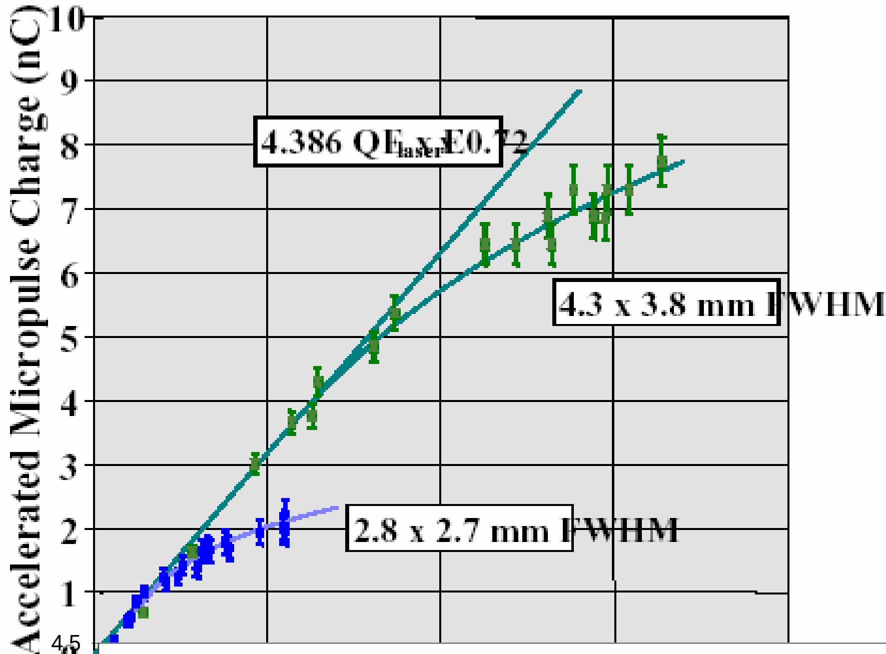
Cavity breakdown

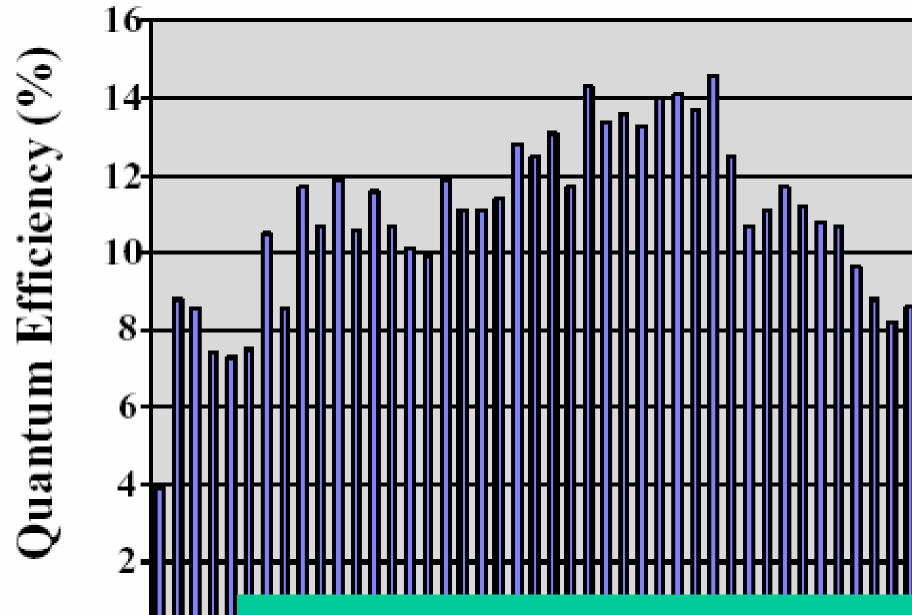
UV laser

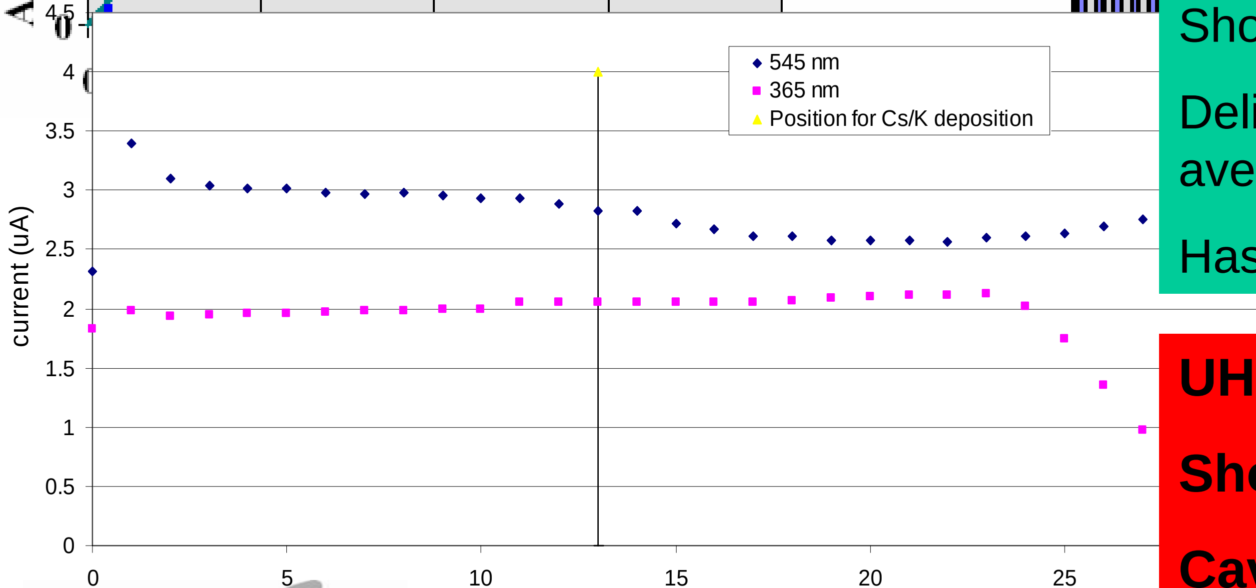
D. Nguyen, Workshop on Photo-injector for Energy Recovery Linac,January 22 & 23, 2001

G. Suberlucq, CERN, , Proceedings of EPAC 2004, Lucerne, Switzerland, 64

K_2CsSb







Shown QE > 10 % at ~ 530 nm

Delivered > 5 nC/bunch, 32 mA average current

Has been tested in an RF injector

UHV

Short life time

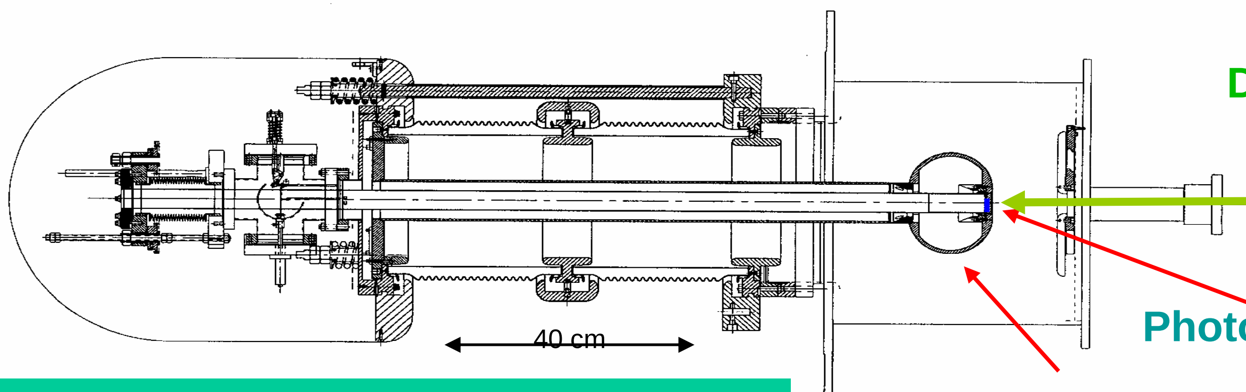
Load Lock

Cavity breakdown

D. Dowell, Workshop on Photo-injector for Energy Recovery Linac,January 22 & 23, 2001, BNL cathode research

Cesiated GaAs, GaN

Cs: GaAs performance at JLAB



Photocathode QE~6% after initial activation
Photocathode delivers ~400 C between re-cesiations
Typical day of operations draws ~35 Coulombs
About 96% of previous QE is recovered with each re-cesiation
12 activated cathodes and close to 40 re-cesiations performed on a single GaAs wafer in one year

UHV
Short life time
→ **Load Lock**
Cavity breakdown
Response time
Charge limit

Cs: Ga N

Concentrations of oxygen and carbon, expressed in monolayers, on the surface of GaN following immersion in a mixture of 4:1 sulfuric acid to hydrogen peroxide and annealing at 10 min at the temperatures indicated. The ammonia pressure was 2 mTorr.

Temperature		25 °C	590 °C	636 °C	700 °C	740 °C
Ammonia anneal	[O]	1.51	0.47	0.39	0.48	0.37
	[C]	0.32	0.23	0.13	0.01	0.01
Vacuum anneal	[O]	0.91	0.34	0.27	0.08	0.11
	[C]	0.74	0.14	0.05	0.01	0.01

Activation Process/Order of deposition	$I_{collected}$	QE	$\Delta\chi$	χ_s
1) GaN	0.01 nA	10^{-4} %	0.0 eV	3.6 eV
2) GaN/Cs	1.3 uA	50 %	2.4 eV	1.2 eV
3) GaN/O/Cs	1.2 uA	48 %	2.4 eV	1.2 eV
4) GaN/Cs/O/Cs	1.0 uA	40 %	2.0 eV	1.6 eV
5) GaN/Ba	0.3 uA	3%	-------	--------

FIG.
tion

F. Machuca et al. JVST B, 18, 3042, 2000, JVST A, 20, 1784, 2003

Photo assisted Field Emission Arrays

Spindt metal coated arrays

Si gated arrays

Carbon nanotubes

Carbon Nanotube based FE cathode

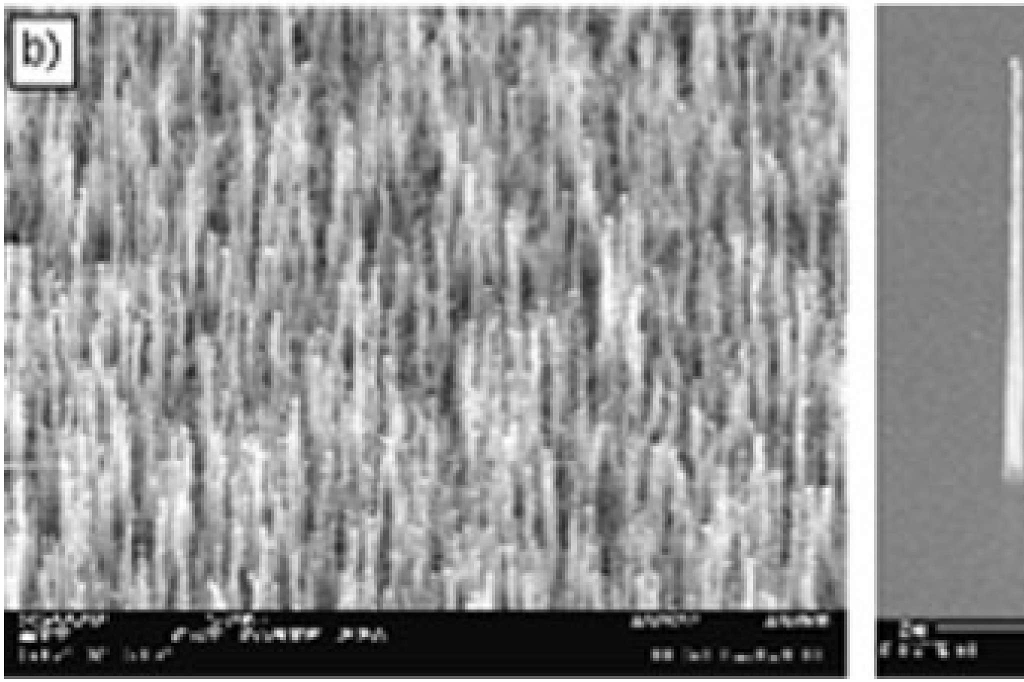
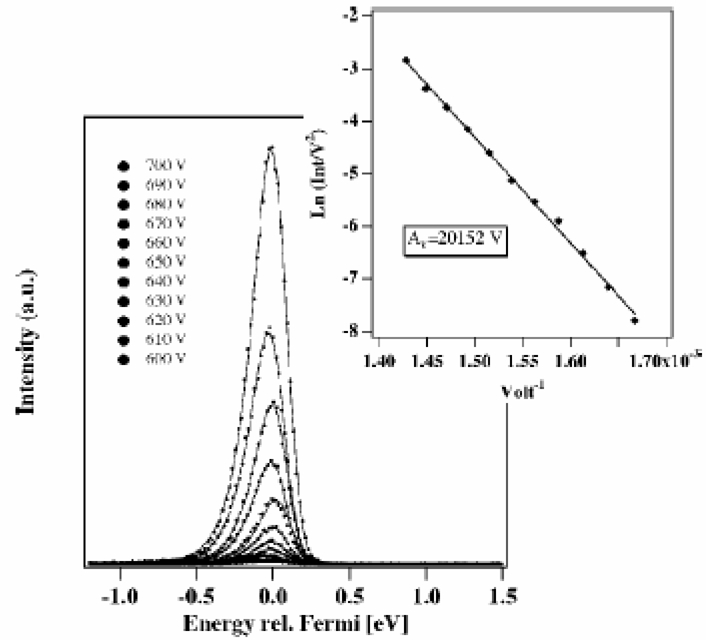


Fig. 3. Carbon nanotube thin films grown by: a) chemical vapor deposition (CVD); b) plasma enhanced chemical vapor deposition (PECVD).

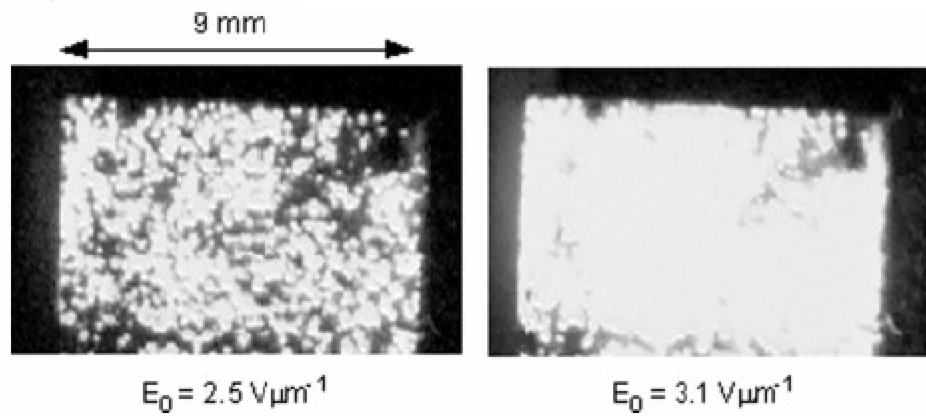


Narrow <1 eV energy distribution

Uniform emission ~ 100 nA/tip, 10^5 tips/cm^2

30x170 µm^2 Area

Current variation due to local variation in Φ, E, electronic structure and trans prob.



Groning et al. Advanced Engineering Materials, 5,541,(2003)

QE OF DISPENSER PHOTOCATHODES

- **B-TYPE: Sintered W w/Ba Ca Aluminate impregnated**
- **M-TYPE: B type w/ thin Osmium coating**
- **SCANDATE: Sintered W w/Scandium oxide impregnated**

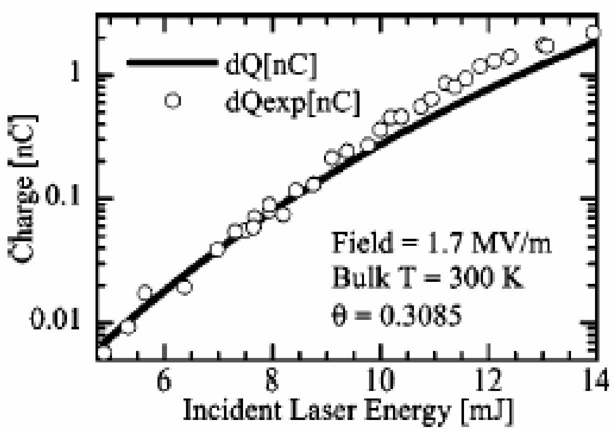
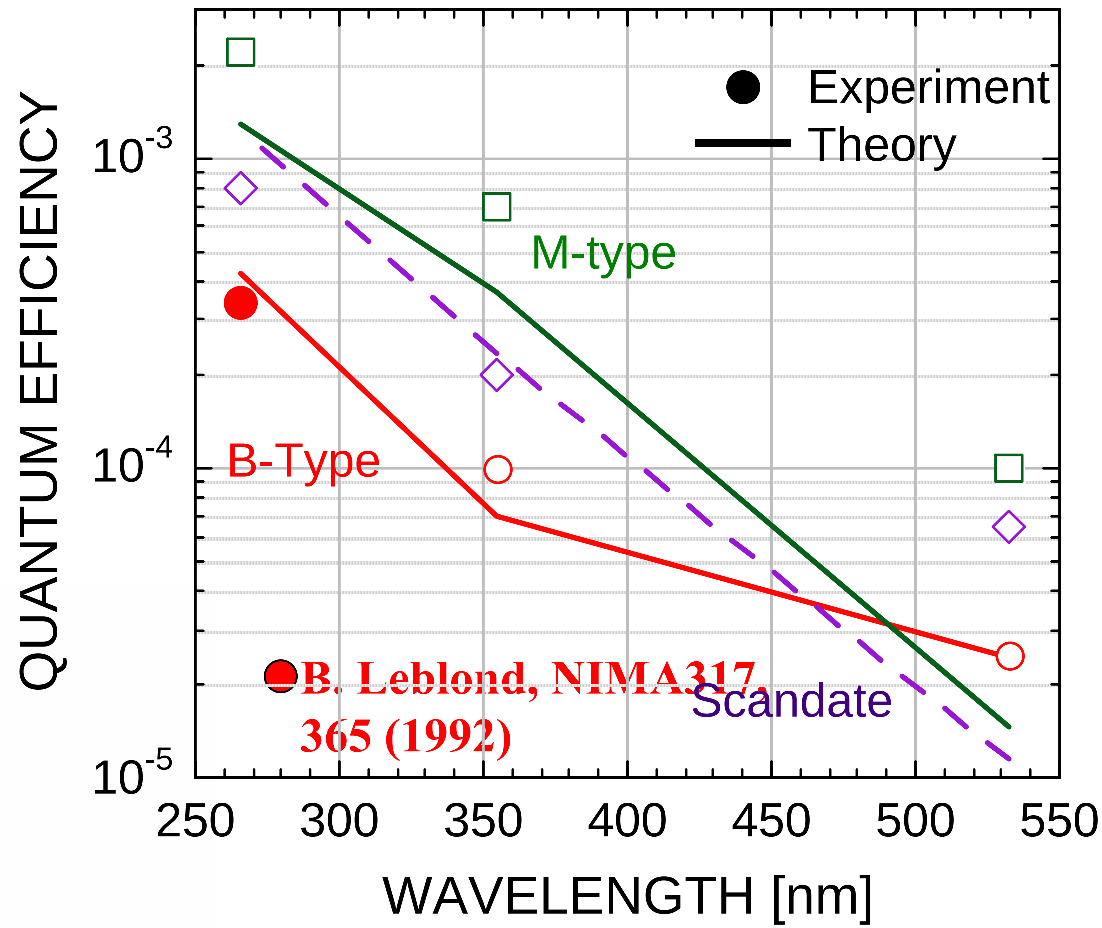


FIG. 1. Emitted charge versus deposited energy, taken as the time-integrated laser intensity over the area of the cathode. Cathode radius was roughly 1.25 cm. Fifty percent of incident laser light was assumed to be reflected.



Both QE and life time lie between metal and alkali photocathodes

D. Feldman, Univ. Maryland

Photocathode Summary

Photocathode	QE(%)	Pro	Con
Metal (Cu, Mg, etc)	.001 to .3 ~2 W/mA ~ 5 eV photon	Easy to obtain/handle, Widely used Rugged, does not require UHV Fast response, allows for pulse shaping Low dark current Tested in high field, RF Well understood	Requires UV
SC Metal (Nb, Pb etc)	.001 to .3 ~ 2W/mA ~ 6 eV photon	Easy to obtain/handle, Rugged, does not require UHV Fast response, allows for pulse shaping Low dark current Tested in SCRF Well understood	Requires UV

Photocathode	QE(%)	Pro	Con
Semiconductor (Cs_2Te, K_2CsSb etc)	1 to 30 25 W/A @ 2.5 eV	Responds to visible-UV light Tested in NCRF 25 mA, high duty factor	Requires UHV Sensitive to contamination Can contaminate injector Response time > metal Short life time Cryo preformance?
NEA (Cs: GaAs, Cs:GaN etc)	10 to 50 30 W/A @ 2 eV	Responds to near IR-UV light Possibility for polarized electrons Tested in DC 10 mA Variable band gap	Requires UHV Sensitive to contamination Can contaminate injector Response time >> metal Short life time Problem in RF injector Cryo perfromance

Photocathode	QE(%)	Pro	Con
Photon assisted Field emission tips		High brightness Technology-electronic industry	Not tested in injectors Improvement needed in o Reliability o Manufacturing o Scalability
Photon driven Dispenser		Commercial units In situ rejuvenation	Improvement needed in o Uniformity of emission

Improving Lifetime

Multiple surface: Jlab

Preparation technique

Overcesiation (P.Sen etal. J. Vac Sci Technol. B 16,1998, 3380)

Codeposition (G. Suberlucq, Proc. EPAC 2004, 64)

Protective layer

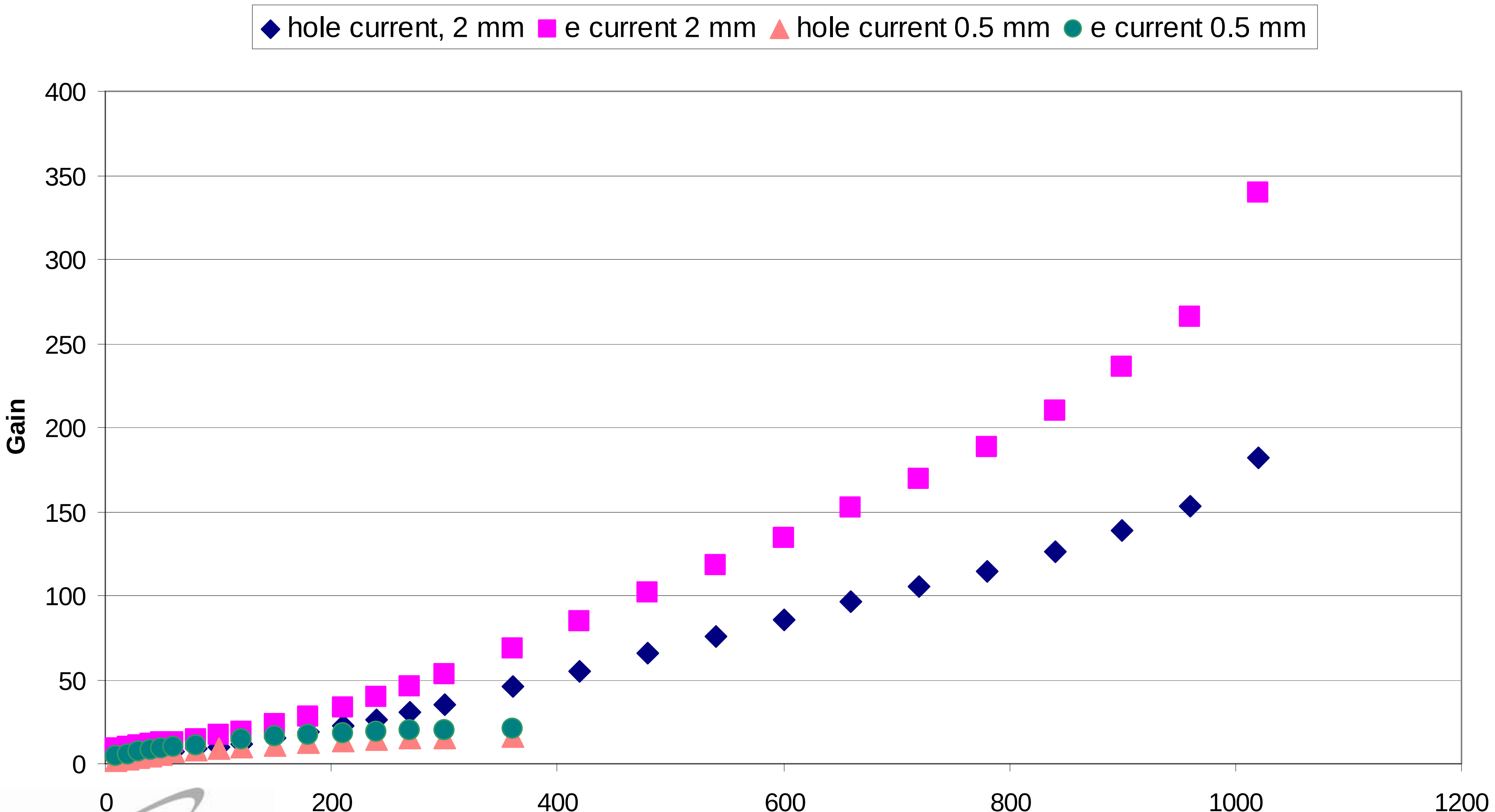
Diamond (BNL) - x 100 increase in yield (Chang, next talk)

CsBr (LANL) – Slight reduction in yield (D. Nguen)

Impregnated inert matrix

SiC (LANL), Dispenser cathode (UMD)

Diamond Secondary Emitter



BROOKHAVEN NATIONAL LABORATORY

Laser System For High Average Current Injector

Requirements

- Energy/wavelength required by cathode
- High rep rate (700 MHz)
- 10 ps pulse length
- Synchronized to master RF clock
- Adjustable output power

Platforms:

Solid state

Fiber

Schematic of the laser system

1064 nm
351/94/9.4 MHz
Few watts

Multi-pass
Multi-stage
Adjustable
output power to 80 W

2nd or 3rd Harmonic
40 W green
20 W UV

FORTIS™ SERIES

Mode-locked Thin-Disk Laser

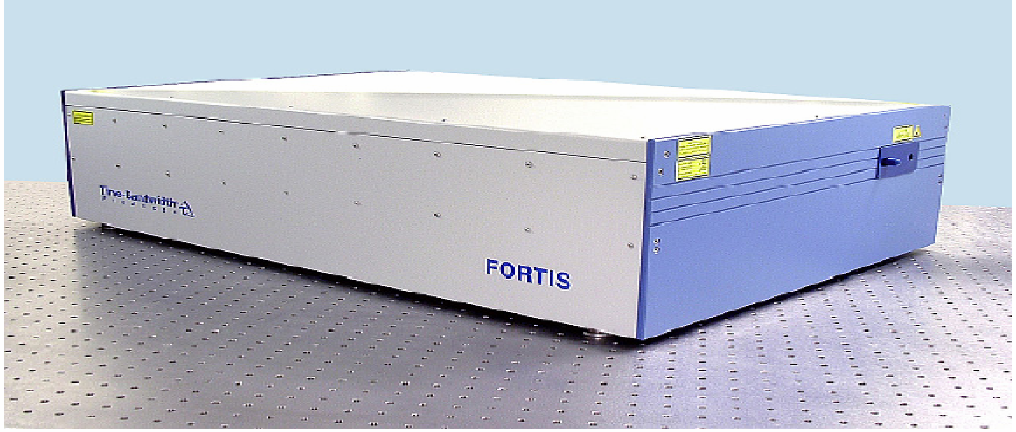
1 µJ per pulse with 50 W output power
Oscillator only, no amplifier
SESAM® Technology

Applications

- Extremly high repetition rate material processing and micromachining
- Waveguide fabrication
- RGB pump source
- OPO pumping

Features

- 50 W output power
- Oscillator-only design
- Turn-key operation
- Low maintenance
- Closed-loop water cooling



Options

- Second harmonic generation
- UV harmonic generation
- Clock synchronization
- Remote control / RS-232

50 W	output power
40 MHz – 60 MHz	repetition rate
1 µJ	per pulse
< 800 fs	pulse width
1 MW	peak power
1030 nm	wavelength
1.1	M^2 (TEM_{00})

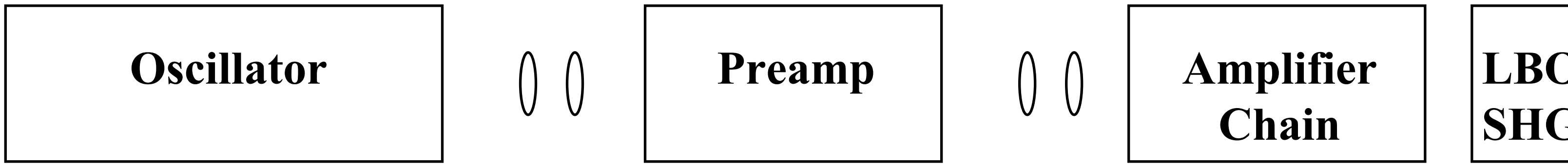
Made in Switzerland

Time-Bandwidth® Products

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

Coherent Inc, Paladin

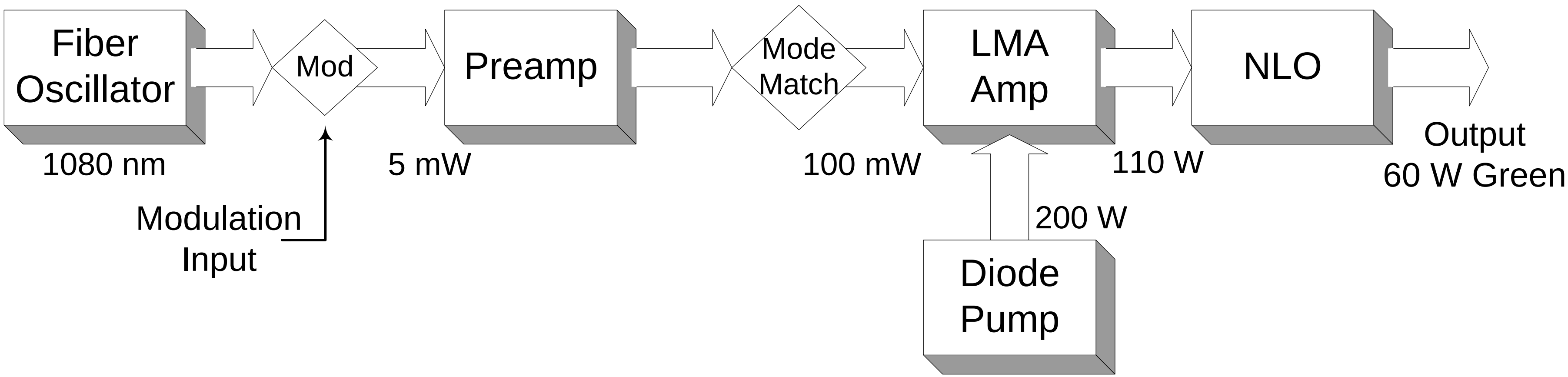
ADVANCED DRIVE LASER ARCHITECTURE



- We are building (under contract) a laser diode pumped MOPA (Master Oscillator Power Amplifier) system.
- Passively mode-locked oscillator (SESAM)
- Multipass amplifiers
  - $YVO_4{:}Nd^{3+}$ gain media
  - Can operate at our usual 74.85 MHz or 748.5 MHz

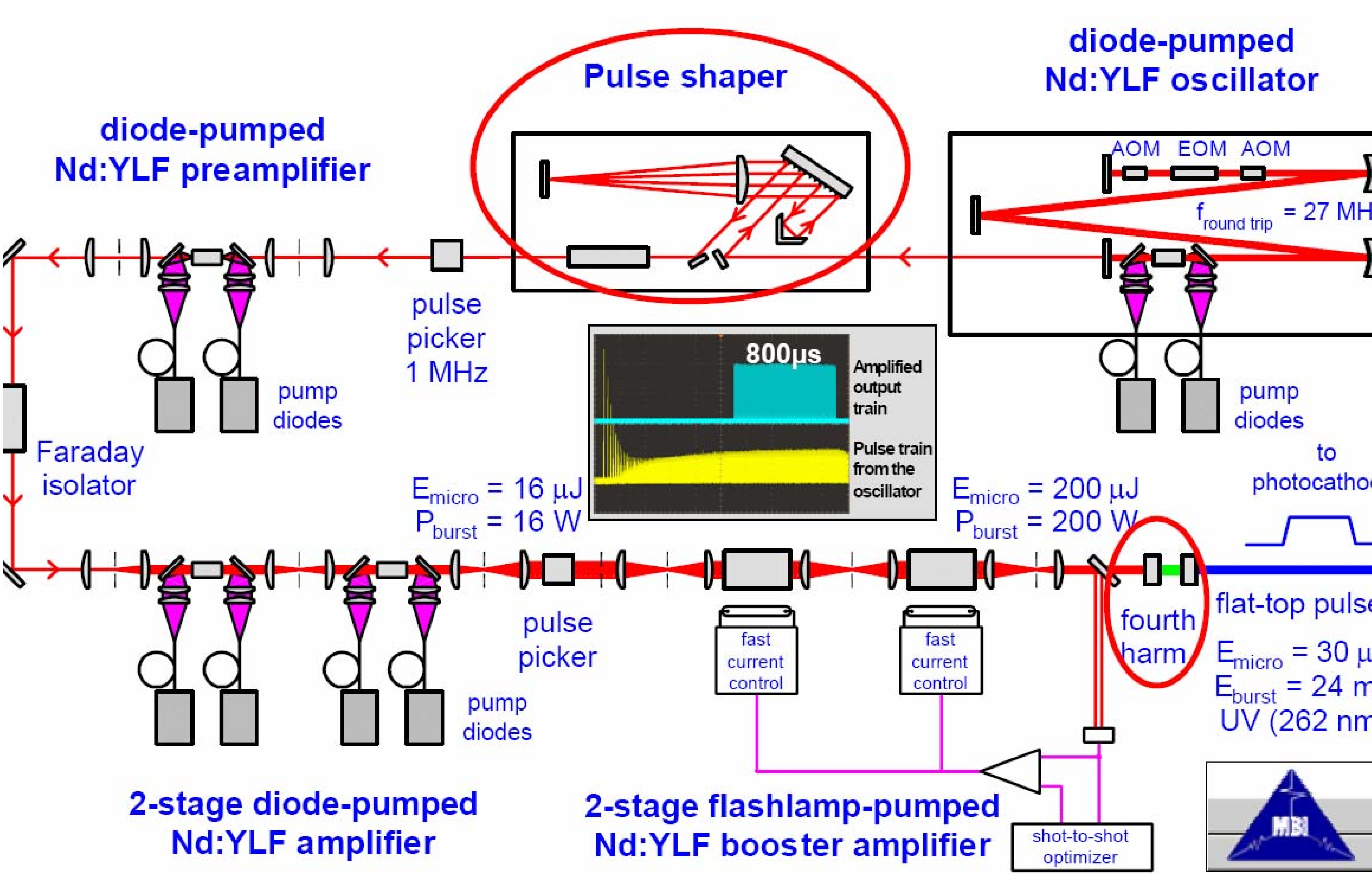
Parameter	Specification
IR output wavelength	1064 nm
IR output Power	~ 70 W
SHG output wavelength	532 nm
SHG output power	≥ 25 W
SHG amplitude stability	≤ 0.5 %
Timing stability	≤ 1 ps
Beam quality	Better than 3x diffraction-limited
Pointing stability	< 20 μrad
Beam profile	Circular (up to 25% ellipticity permitted)

Fiber Oscillator/Amplifier—
Key to High NLO Efficiency
Aculight Corporation



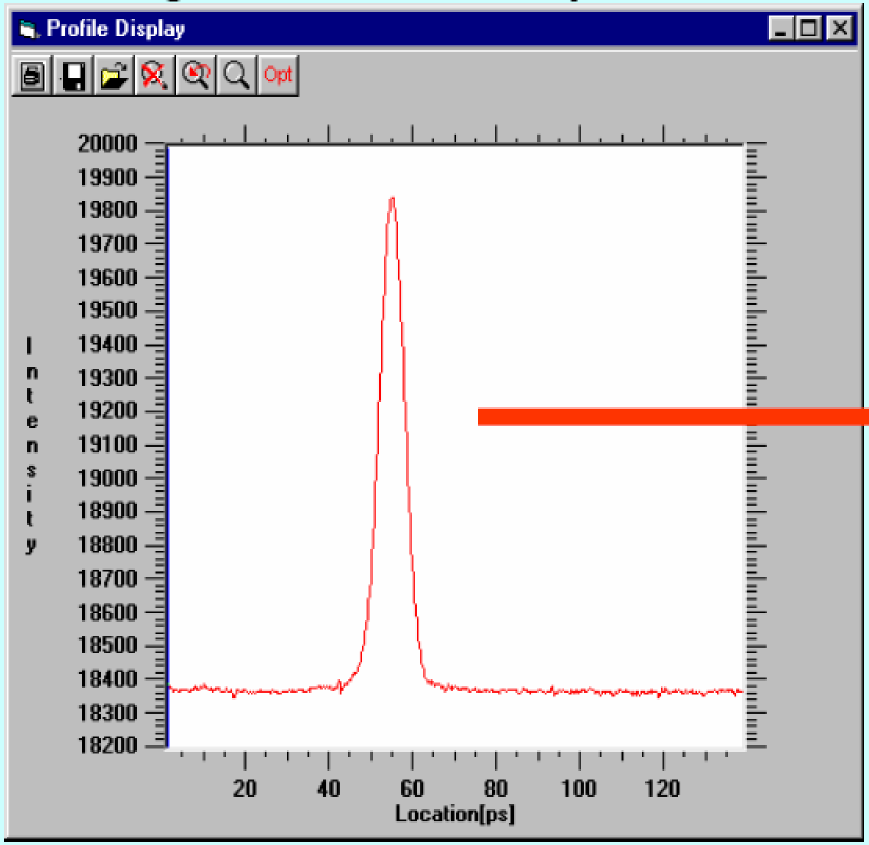
- 60 W green power output demonstrated at Aculight with $|M|^2 = 1.33$
- High repetition rate pulsing (>10 MHz) to increase NLO conversion
- Pulse format completely determined by modulator (not mode-locked)
- 10% electrical-to-optical (green) efficiency

ACULIGHT CORPORATION PROPRIETARY



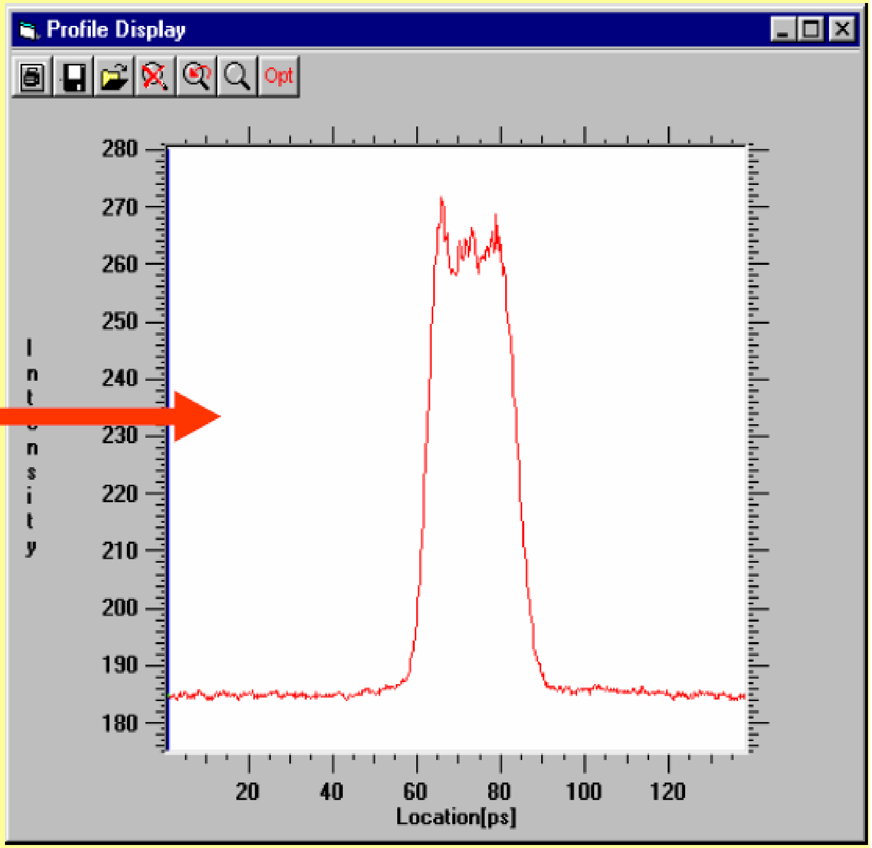
Pulse shaper
diode-pumped
Nd:YLF oscillator
AOM EOM AOM
$f_{round\ trip}$ = 27 MHz
diode-pumped
Nd:YLF preamplifier
pulse
picker
1 MHz
pump
diodes
800μs
Amplified
output
train
Pulse train
from the
oscillator
pump
diodes
Faraday
isolator
E_{micro} = 16 μJ
P_{burst} = 16 W
E_{micro} = 200 μJ
P_{burst} = 200 W
to
photocathod
pulse
picker
fast
current
control
fast
current
control
fourth
harm
flat-top pulse
E_{micro} = 30 μJ
E_{burst} = 24 mJ
UV (262 nm)
pump
diodes
2-stage diode-pumped
Nd:YLF amplifier
2-stage flashlamp-pumped
Nd:YLF booster amplifier
shot-to-shot
optimizer
MBI

Until 23.06.2003 - Gaussian longitudinal laser shape:



FWHM = 7 ± 1ps

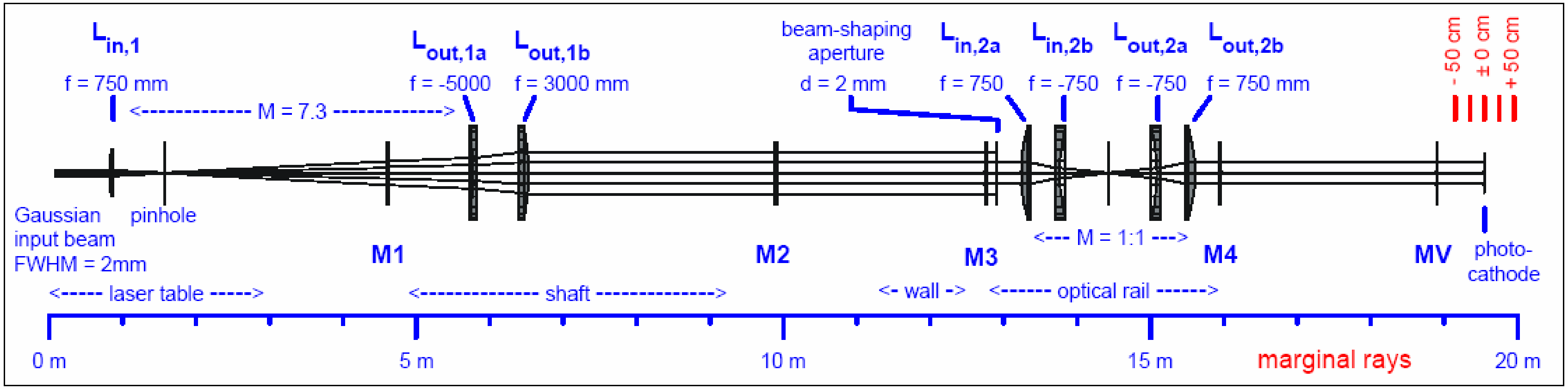
On 23.06.2003 longitudinal shape changed to flat top

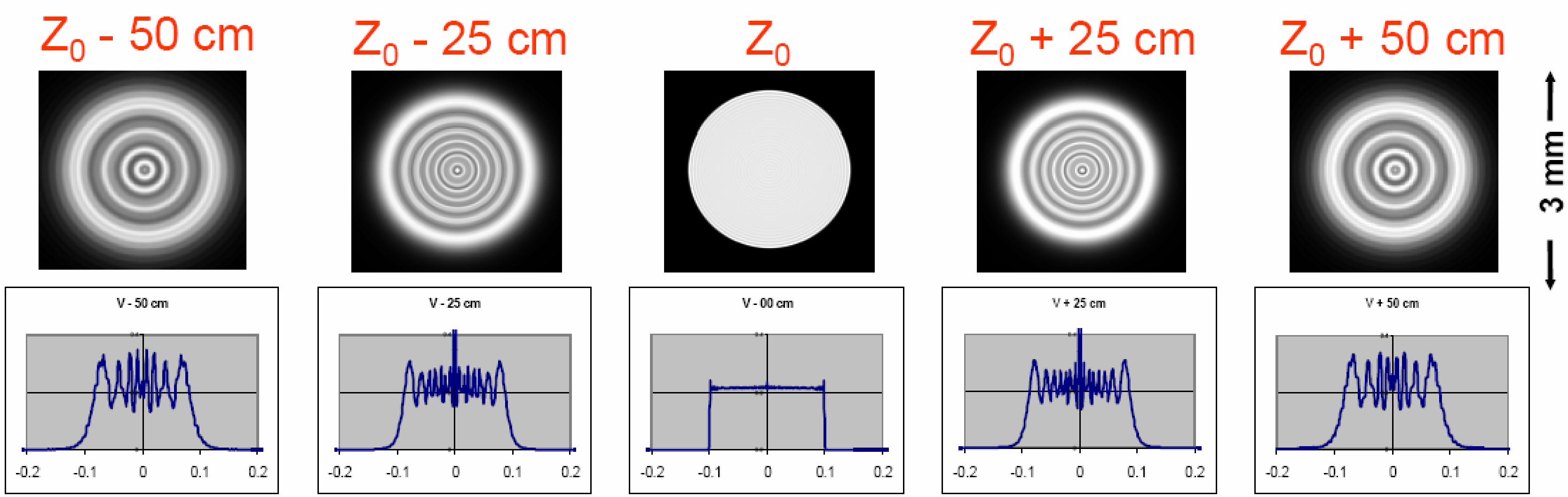


FWHM ≈ 18-23 ps

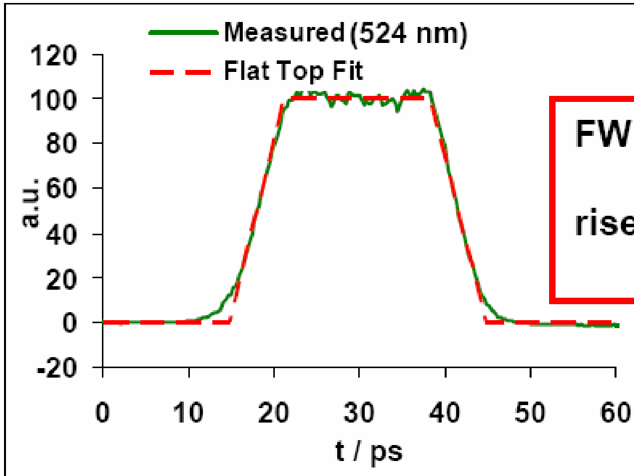
rise and fall time about 5-7 ps

first setup version realized, further upgrade in preparation

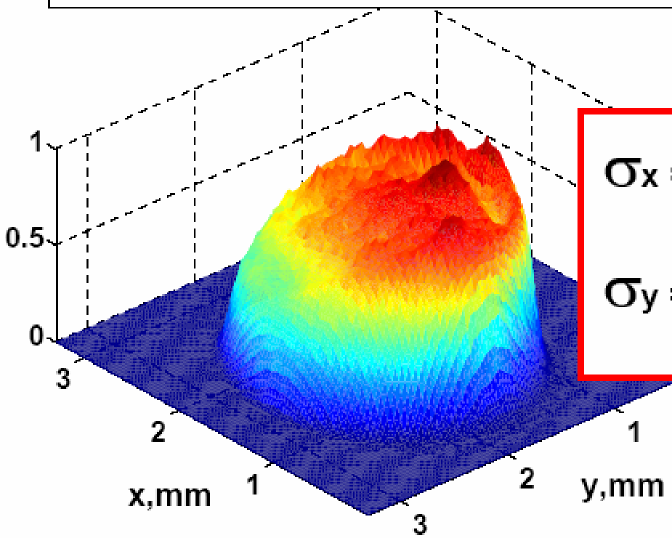




in 2003:



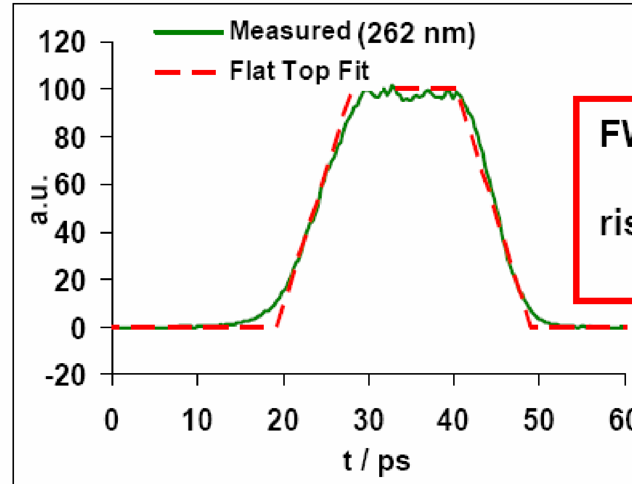
FWHM ≈ 18-23 ps
rise/fall ≈ 5-7 ps



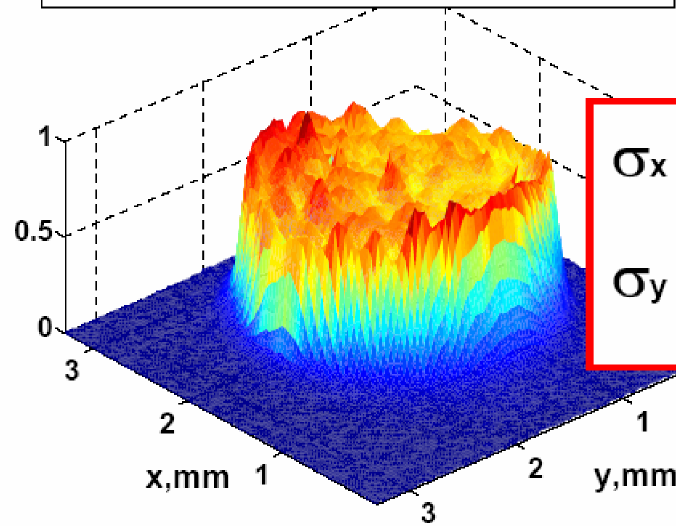
$\sigma_x = 0.51 \pm 0.02$ mm

$\sigma_y = 0.62 \pm 0.02$ mm

in 2004:



FWHM ≈ 19-24 ps
rise/fall ≈ 7-9 ps



$\sigma_x = 0.57 \pm 0.02$ mm

$\sigma_y = 0.58 \pm 0.02$ mm

BROOKHAVEN NATIONAL LABORATORY

Laser Systems

- Commercial systems are tantalizingly close to meeting a lot of the requirements
- Beam shaping, stability requirements may increase the requirements to beyond commercial systems
- Even if commercial systems are available, project specific custom modification will be needed