Optical Diagnostics

March 13, 2006

Design Specifications & Restriction

- high radiation area
- tight environment
- non-serviceable area
- passive components
- optics only, no active electronics
- transmit image through flexible fiber bundle

Optical Layout

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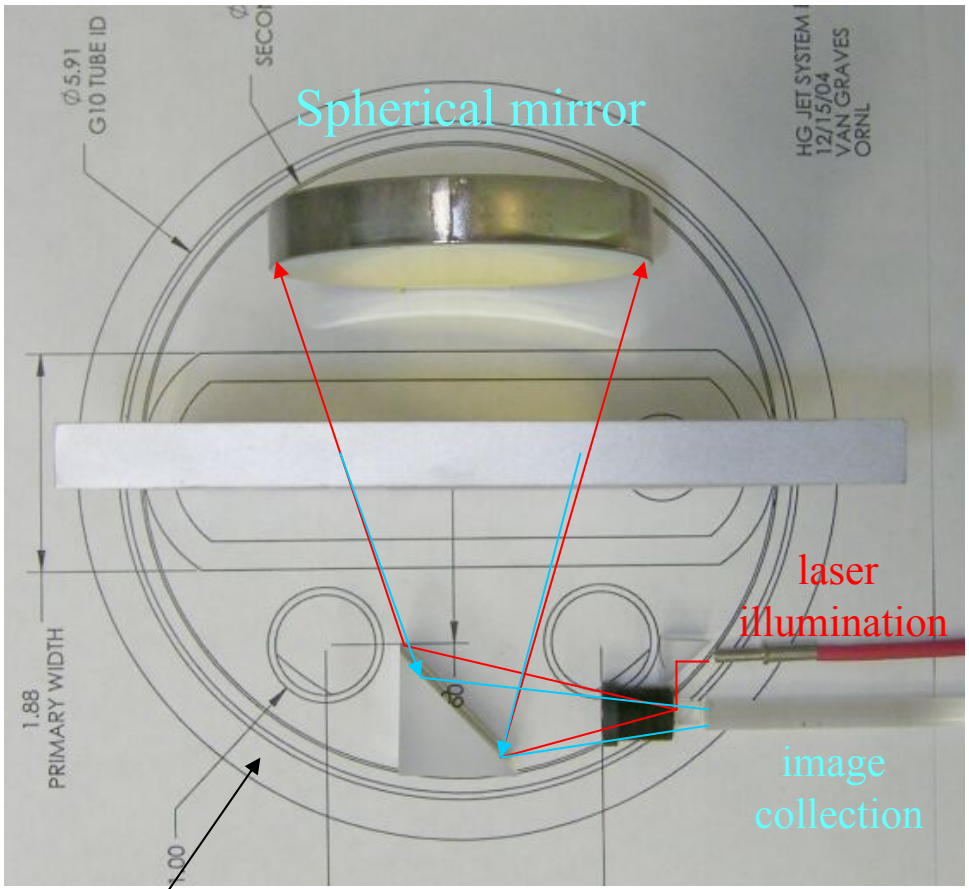

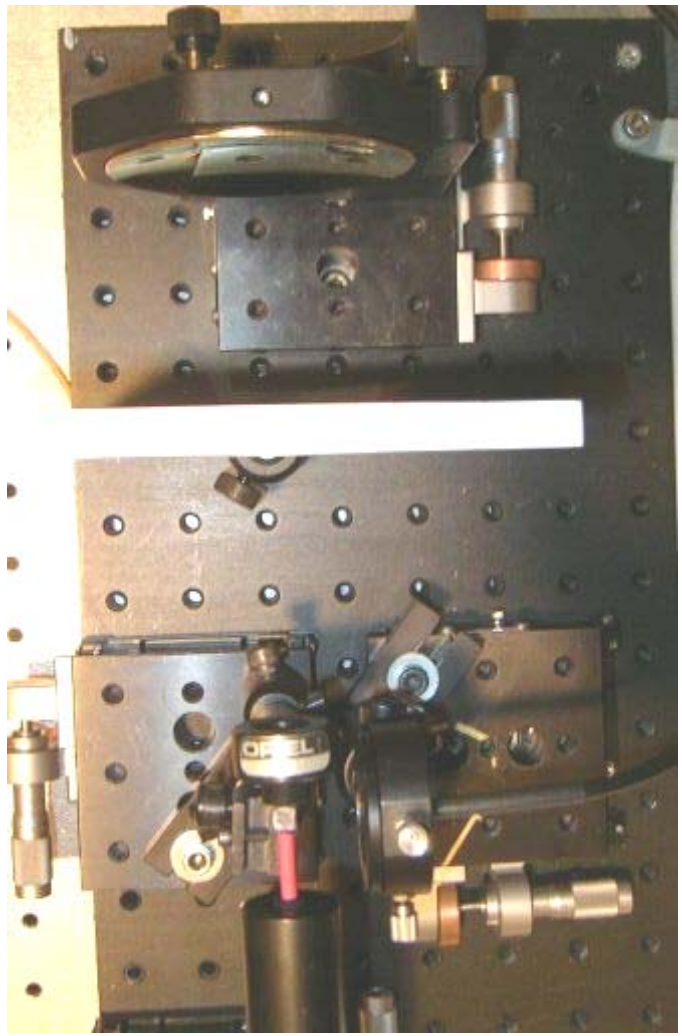

Ø6'' Secondary Containment

Works OK in this tight environment

Experimental Setup

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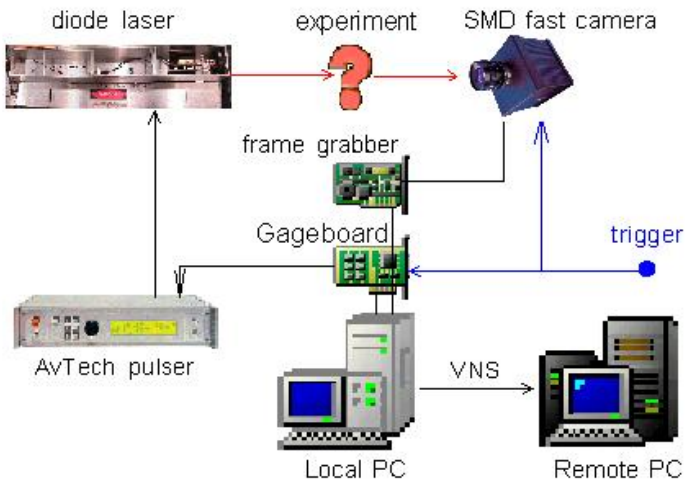

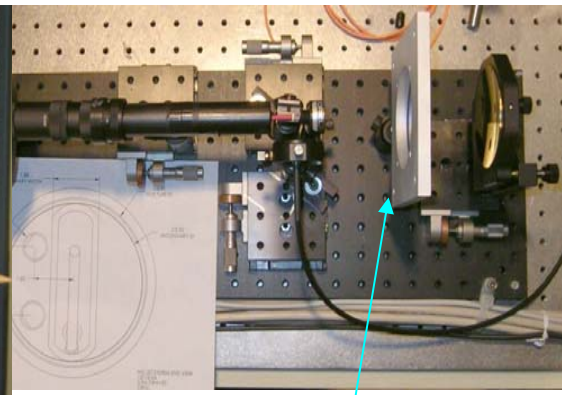

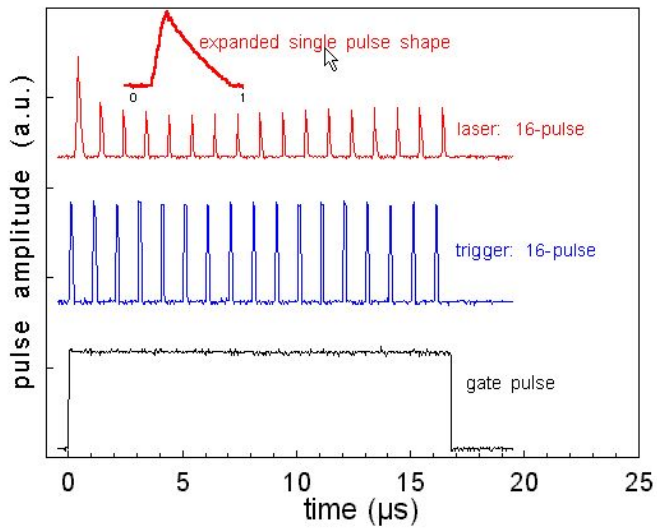

Optical Components

- 50/50 beam splitter: Edmund, 0.5 cm cube
- spherical mirror: Edmund, f=3-in, D=3in< Au coated
- small prism mirror: Edmund, 1x1x1.4 cm, Au coated
- large prism mirror: Edmund, 2.5x2.5x3.54 cm. Au coated
- imaging fiber Edmund: ⅛-in diameter, 12-μm core, 0.55 NA
- illumination fiber: ThorLabs, 0.22 NA, SMA-905 840 -μm core
- imaging lens: Sunex, f=0.38-cm, f/# 2.6, diagonal FOV 54°, φ1.4-cm x 2.0 cm

Cameras & Glass Imaging Fiber

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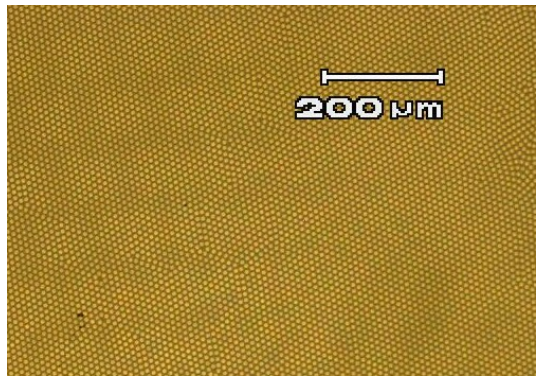
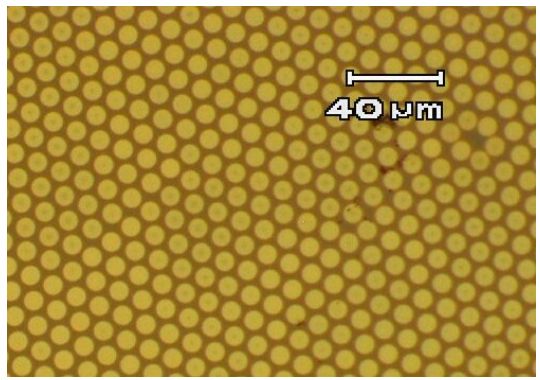
SMD 64KIM camera
CCD size: 13.4 x 13.4 mm
Pixels: 960x960
Single frame: 240x240 pixels
57,600 picture elements
frame rate: 16 frames up to 1 μs/frame
Reduced pixel size: 56 x 56 um

FastVision
CCD size: 15.4 x 12.3 mm
Pixels: 1280x1024
Single frame: FPGA programable
1.3 M picture elements
Frame rate: 500/s @ full resolution
500k/s @ 1x1280

CERN Olympus Encore PCI 8000S
4 kHz recording rate, 25 us electronic shutter

glass imaging fiber bundle
Core size: 12 μm, diameter: 1/8”





Total fiber counts ~50,000 in 3.17 mm diameter
Imaging ~243 x 243 fibers on 960 x 960 CCD array

~1 imaging fiber on ~4x4 pixels on full frame

~1 imaging fiber on ~1 pixel on a single frame

Laser Sources

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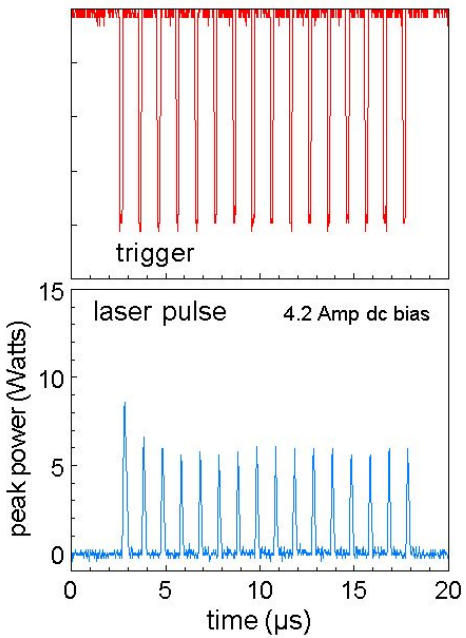
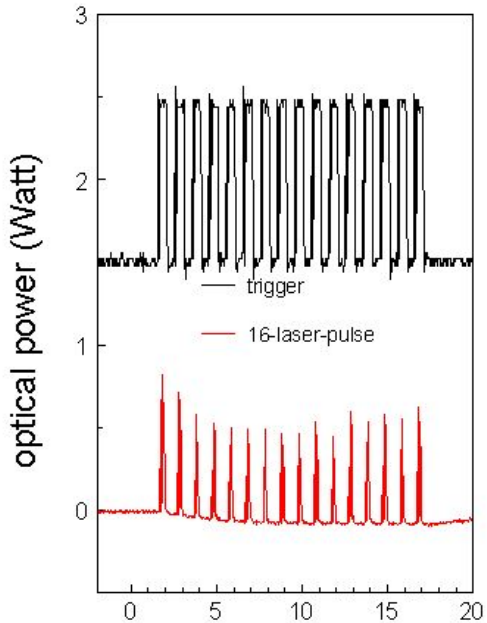
Laser diode, SLI 15-W, Class IV
Power = 15 Watts
I_{th}= 4.5 Amp
λ -= 808 nm

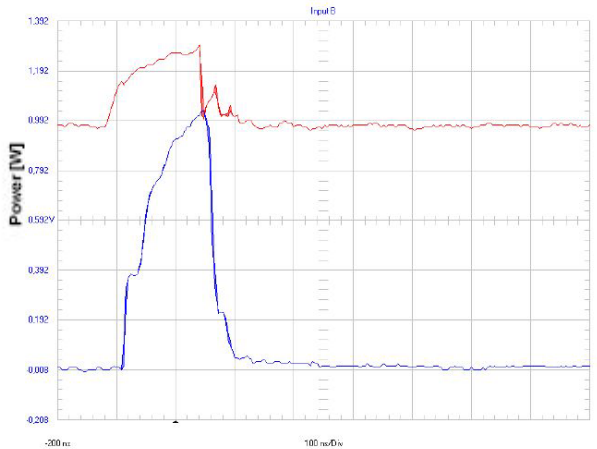


JDS Uniphase
Laser diode, SDL-2300-L2
Power = 1 Watts
I_{th}= 0.3 Amp
λ -= 850 nm



BrightSolutions
SOLUZIONI LASER INNOVATIVE

BDL20-808-F6
s/n: 05091745



Input A: Current 20 A/div
Input B: Optical Power 4 W/div

Parameter	Value	Unit
Temperature	25	°C
Rated power	20	W
Current at rated power	35.38	A
Maximum current	41.63	A
Threshold current	9.2	A
Center wavelegth	808.6	nm
Linewidth FWHM	2.64	nm

Stationary images of NIR laser illumination

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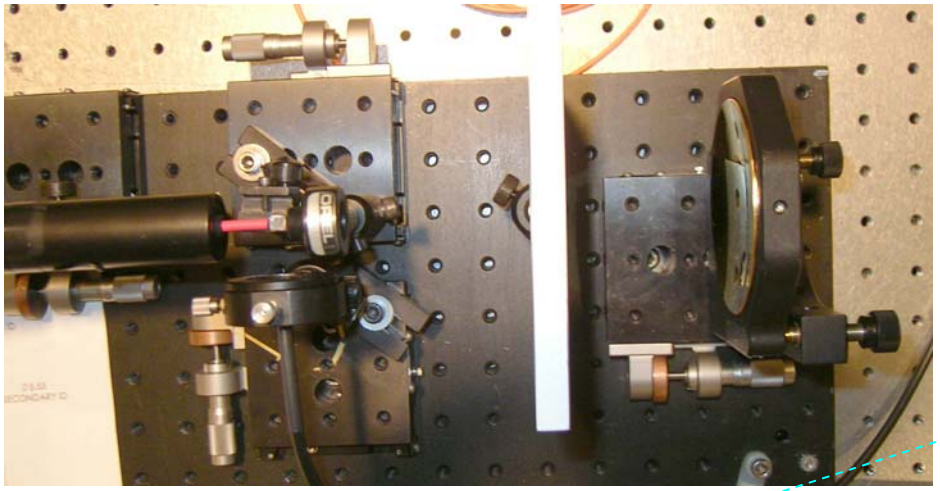

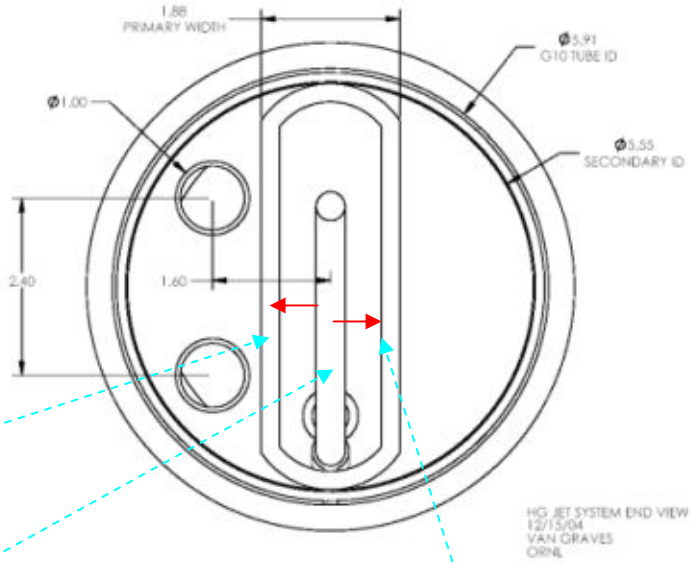

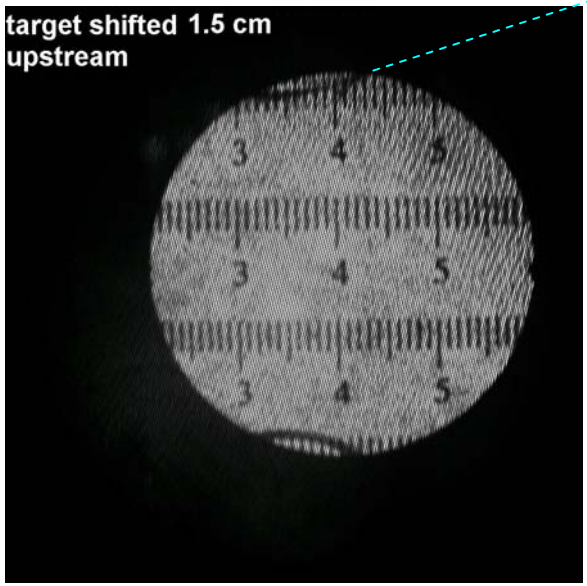

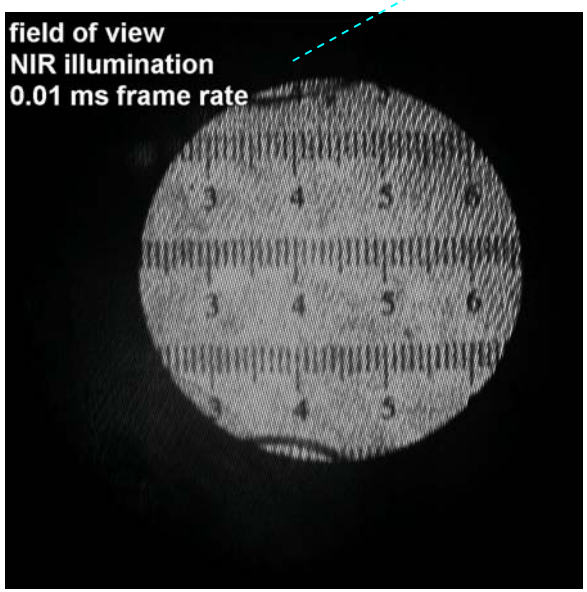

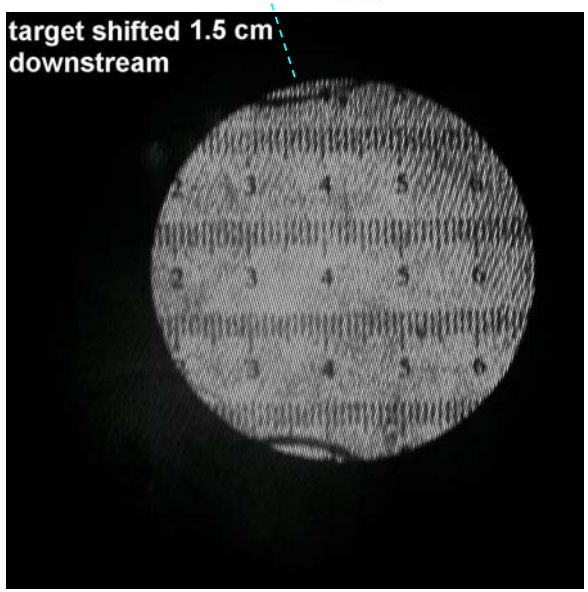

Chopper Image In Motion @ 4 kHz

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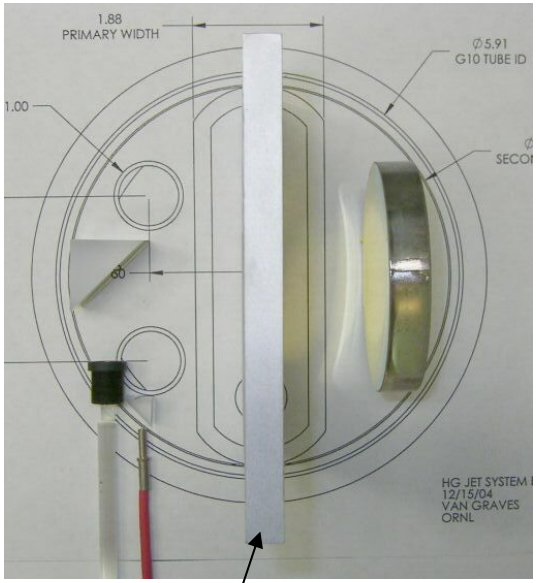
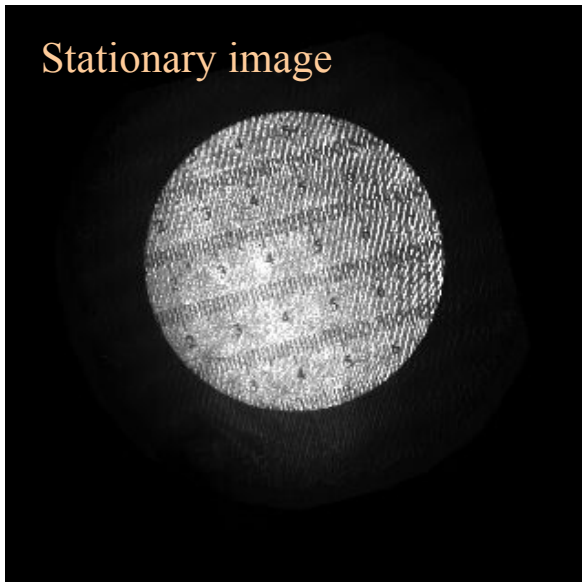
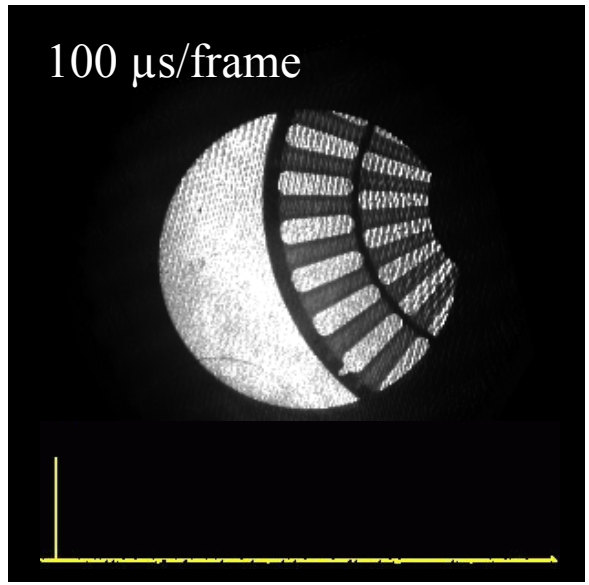
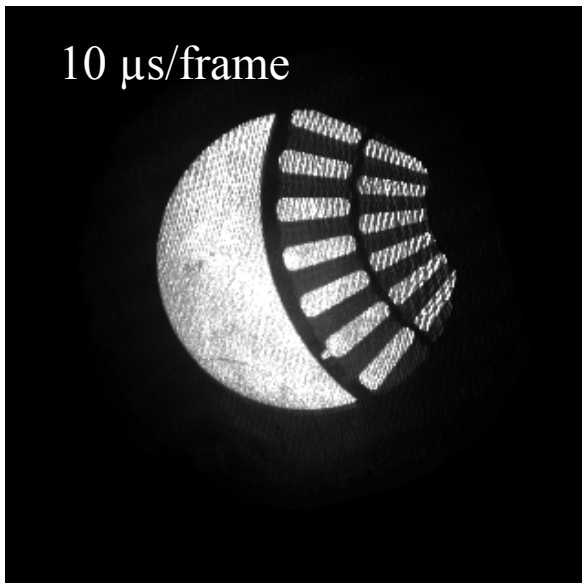
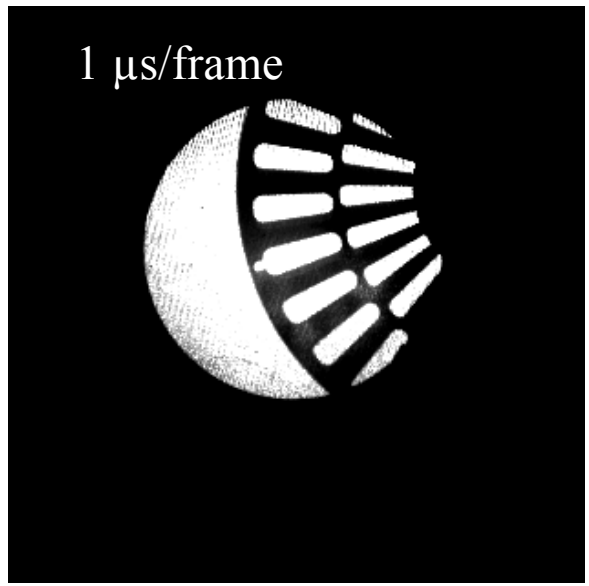


Linear Velocity @ ~40 m/s









Optical Diagnostics System Design In Secondary Containment

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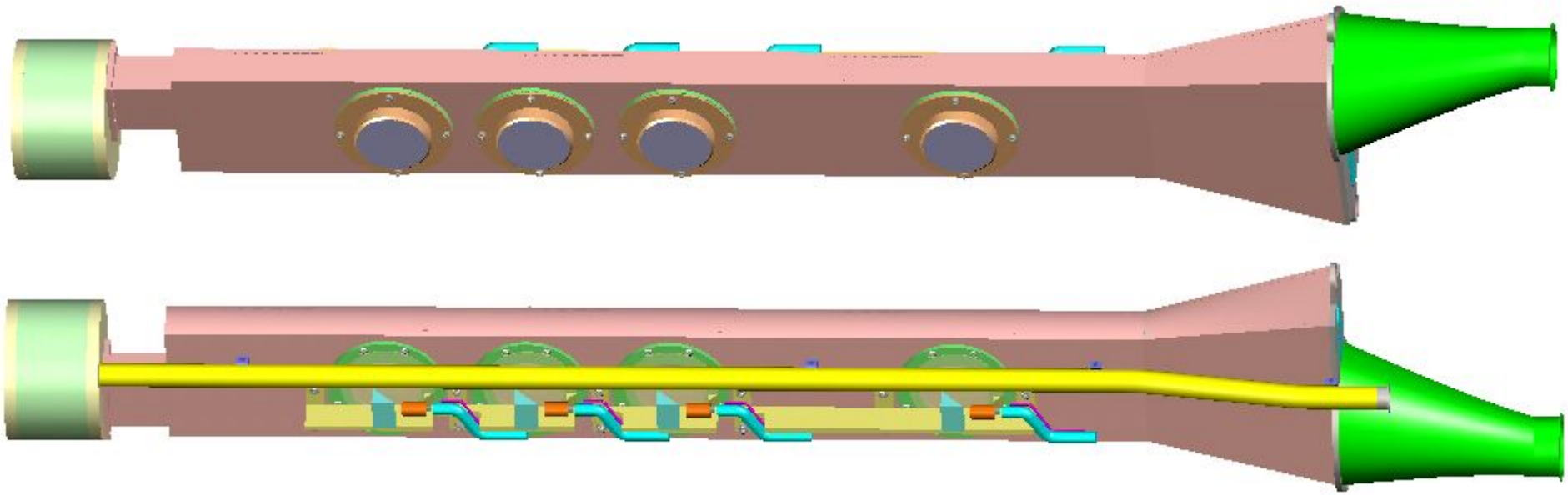

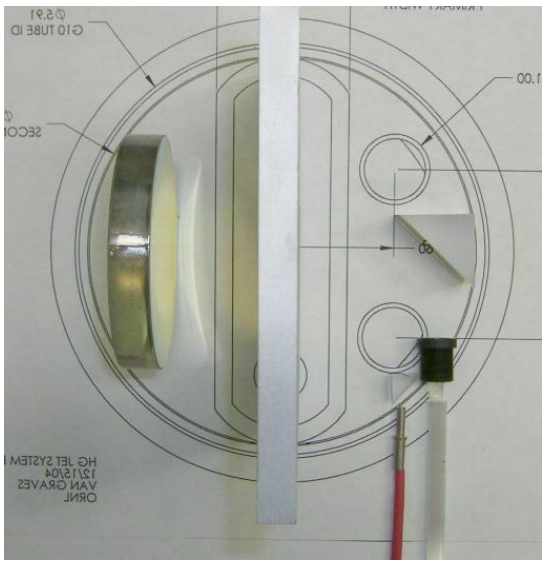

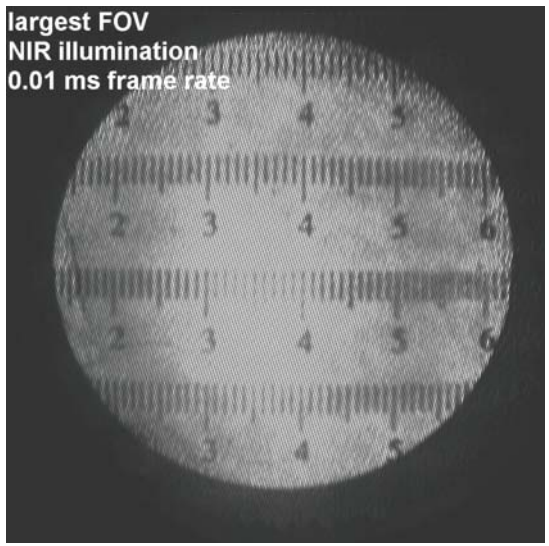

One set of optics per viewport

Conceptual design completed

Irradiation Studies of Optical Components - I

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Instrumentation Division Ultrafast Laser Laboratory

CERN, ~ April 15-24, 2005
Irradiation Condition :
1.4 GeV proton beam
4 x 10^{15} proton
Irradiation dose: equivalent to
40 pulses of 24 GeV proton beam
28 TP/pulse
total of 1.2 x 10^{15} proton

Received radiation dose:
3231 Gy, ~ 323 krad

Schott glass imaging fiber is not good

	A	B	C	D	E
1		13-Jul-2005			
2		Results of optical components irradated at CERN on April 15, 2005			
3		proton beam energy: 1.4 GeV			
4		no. of protons: 4x10^15			
5		transmittance and reflectance measured at the HeNe wavelength			
6					
7	**item #**	**components**	**before**	**after**	**results**
8	2	Large gold mirror reflectance	0.910	0.920	no change
9	3	Small gold mirror reflectance	0.930	0.940	no change
10	4	50/50 beam splitter: transmittance	0.450	0.360	drop 20%
11	4	50/50 beam splitter: reflectance	0.530	0.423	drop 21%
12	5	imaging lens: transmittance	0.880	0.610	drop 31%
13	6	1-mm thick sapphire plate	0.863	0.867	no change
14	7	1-mm thick fused silcia	0.914	0.859	drop 5%
15					
16	1	3-fleet long imaging fiber	0.394	0.000	no measureable light transmitted
17					at the HeNe or 800 nm wavelengths
18					

Irradiation Studies of Optical Components - II

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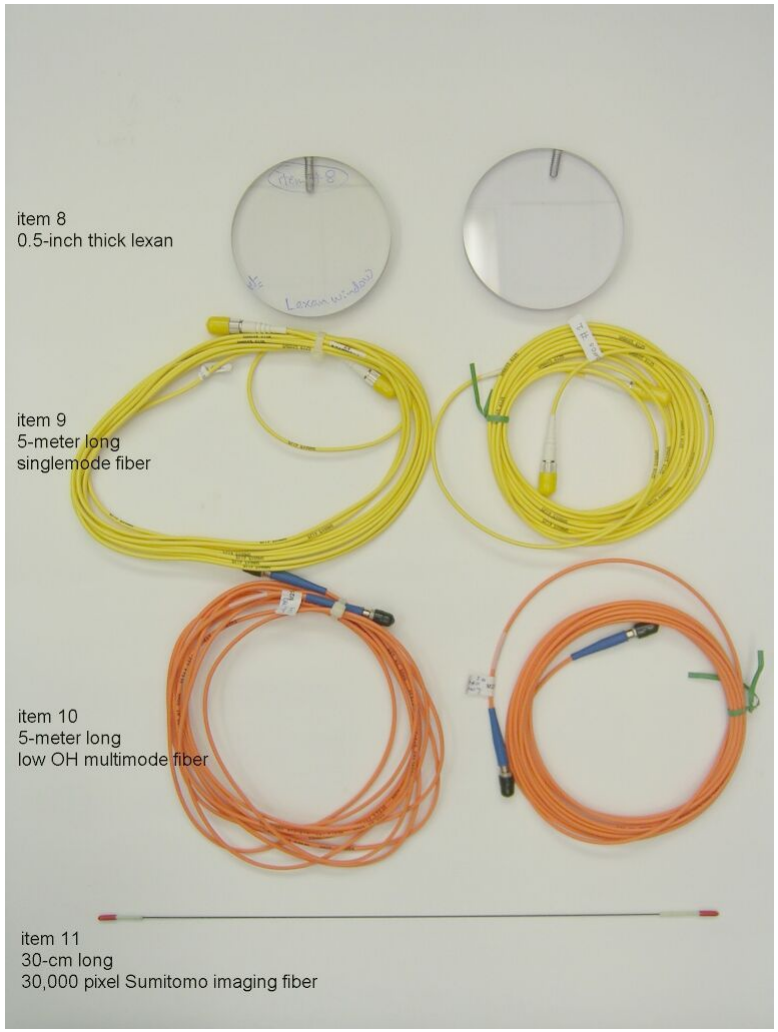

CERN, ~ Oct. 24, 2005
Irradiation Condition :
1.4 GeV proton beam
5 x 10^{15} proton
Irradiation dose: equivalent to
40 pulses of 24 GeV proton beam
total of 5 x 10^{15} proton

28-Dec-2005
Results of optical components irradated at CERN on Oct. 24, 2005
proton beam energy: 1.4 GeV
no. of protons: 5x10^15
transmittance measurements at 650 & 850 nm wavelengths

		wavelength @ 650 nm			wavelength @ 850 nm		
item #	components	before	after	results	before	after	results
8	0.5-inch thick Lexan window	0.840	0.830	no change	0.940	0.900	drop 4%
9	5-meter singlemode fiber	0.600	0.022	drop 96%	0.420	0.330	drop 22%
10	5-meter multimode low-OH fiber	0.830	0.850	no change	1.000	1.020	no change
11	30-cm long Sumitomo imaging fiber	0.850	0.640	drop 25%	0.670	0.710	no change

overall radiation activity ~ 3 times above background on dec 16, 2005

Sumitomo fused silica imaging fiber is good

Sumitomo Imaging Fibers

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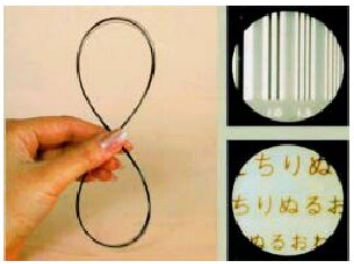
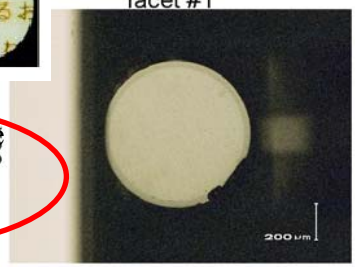
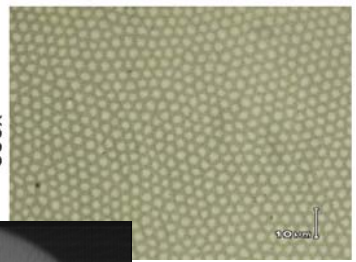
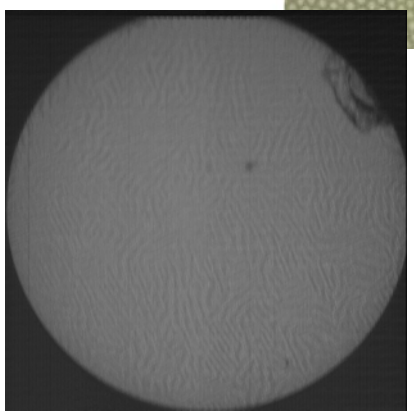
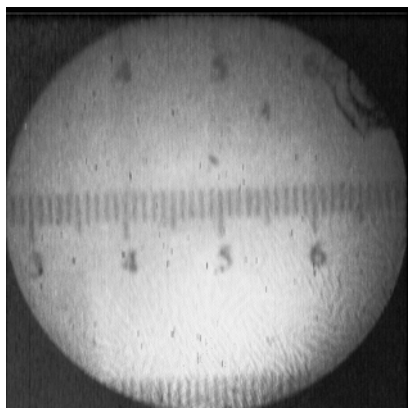


IGN-08/30 sample
0.3-meter
30,000 pixels









SEI

Product Lineup

	IGN-02/03	IGN-028/06	IGN-035/06	IGN-037/10	IGN-05/10	IGN-08/30	IGN-15/30	IGN-20/50
Number of picture elements	3,000	6,000	6,000	10,000	10,000	30,000	30,000	50,000
Jacketing diameter (um)	200	280	350	370	500	800	1,500	2,000
Picture elements area diameter (um)	180	252	315	333	450	720	1,350	1,800
Coating diameter (Primary) (um)	250	340	420	450	590	960	1,900	2,400
Coating diameter (Secondary) (um)	---	---	---	---	---	---	2,500	3,000
Circularity	>= 0.93							
Core material	GeO2 Containing Silica							
Cladding material	F Containing Silica						Pure Silica	
Coating material	Silicone						Silicone + PFA	
Numerical aperture	0.35						0.30	
Lattice defect (%)	<= 0.1							
Allowable bending radius (mm)	10	15	15	20	25	40	75	100
Allowable max temp. (C)	150							

SUMITOMO ELECTRIC

Cost per foot	**$78**	**$158**	**$305**
Cost in 10 meter	**$2574**	**$5214**	**$10065**
Total cost for 4 fibers (40 meter)	**$10.3k**	**$20.8k**	**$40.3k**

continuous
10-20 meter
available

continuous
10 meter
maybe available

Fujikura Imaging Fibers

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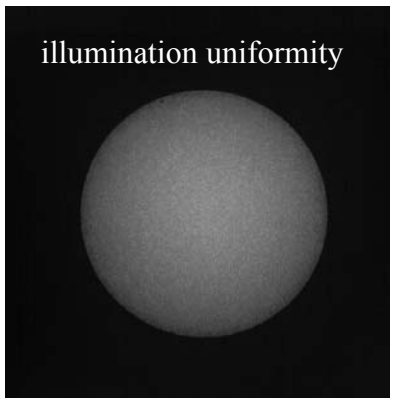
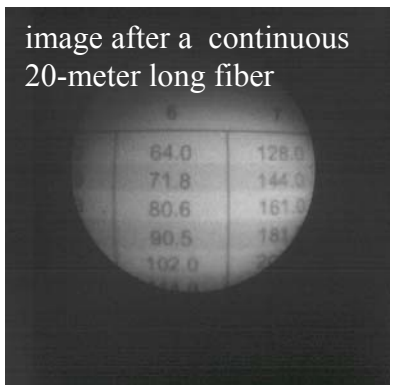
Fujikura data, FIGH-30
A continuous 20-meter fiber
30,000 pixel imaging fiber





ULTRATHIN IMAGEFIBER SPECIFICATIONS
(FIGH series N-Type 50k-100k)

Table 3

Item	FIGH-30-850N	FIGH-50-1100N	FIGH-70-1300N	FIGH-100-1500N
Number of picture elements(nominal)	30,000	50,000	70,000	100,000
Imagecircle diameter (um)	790 ± 50	1,025 ± 80	1,200 ± 100	1,400 ± 120
Fiber diameter (um)	850 ± 50	1,100 ± 80	1,300 ± 100	1,500 ± 120
Coating diameter (um)	950 ± 50	1,200 ± 100	1,450 ± 100	1,700 ± 150
Minimum bending radius (mm)	90 *1 _50 *2 _	110 *1 _80 *2 _	150 *1 _100 *2 _	200 *1 _130 *2 _
Coating material		Silicone resin		
Lattice defect (%)		< 0.1		
Uncirculality (%)		< 5		
length/pc		Maximum length of 1pc : 10ft Cut and rough polish are available. Cut length of 1pc : Customer order		

Cost per foot	$85	$250		$540
Cost in 10 meter	$2805	$8250		$17.8k
Total cost for 4 fibers (40 meter)	$11.2k	$33k		$71.8k

unofficial price info

Cost/foot	**$210**	**$371.4**		
Cost in 10 meter	**$6,935.65**	**$12,256.7**		
Cost in 20 meter	**$15,607.9**			
Total cost for 4 fibers (40 meter)	**$27,742.6**	**$49,026.8**		

official price info

Uniformity of Imaging Fibers

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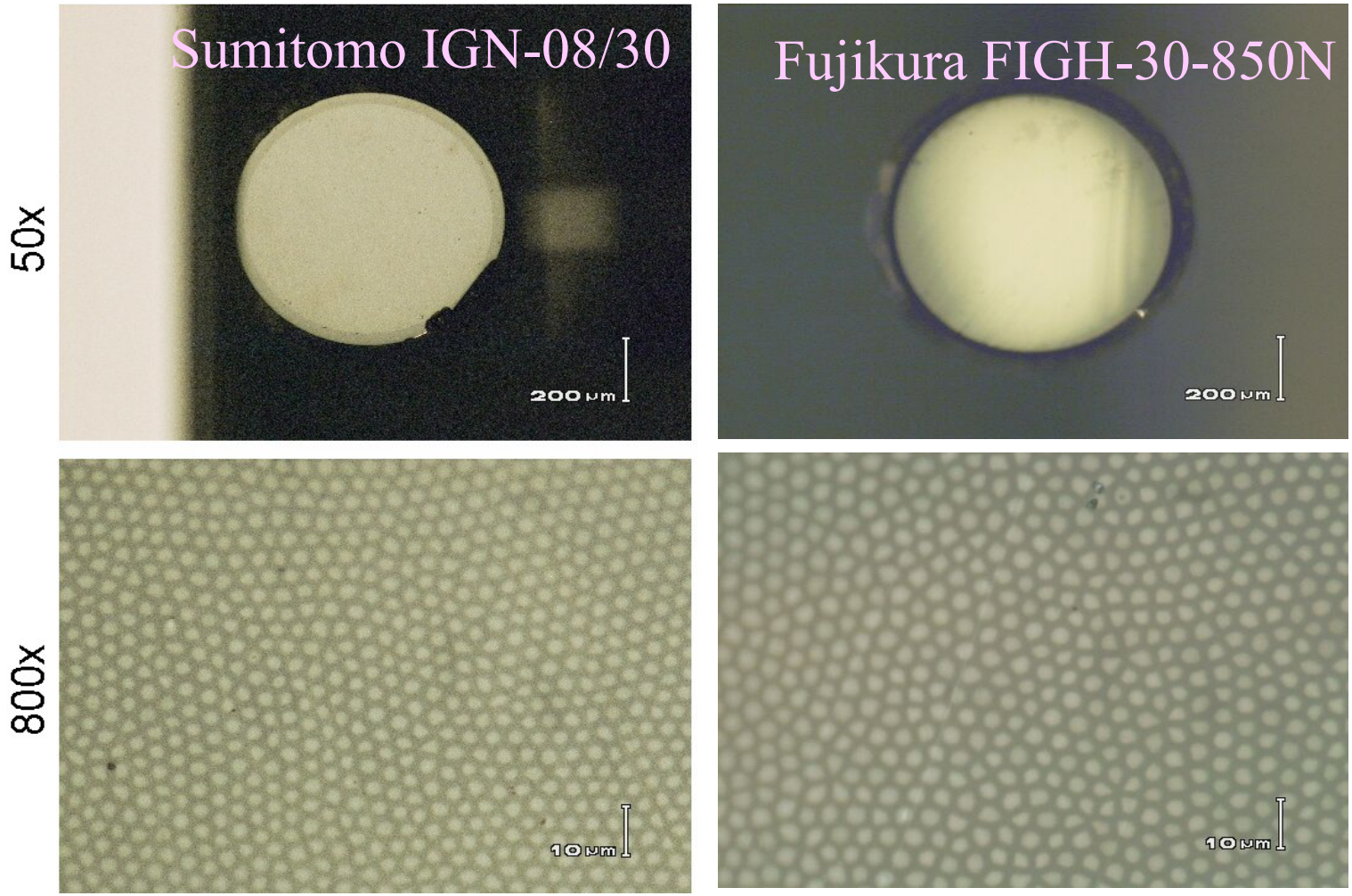
30,000 picture elements



NO significant difference in the uniformity of imaging fibers

Image Quality Comparison

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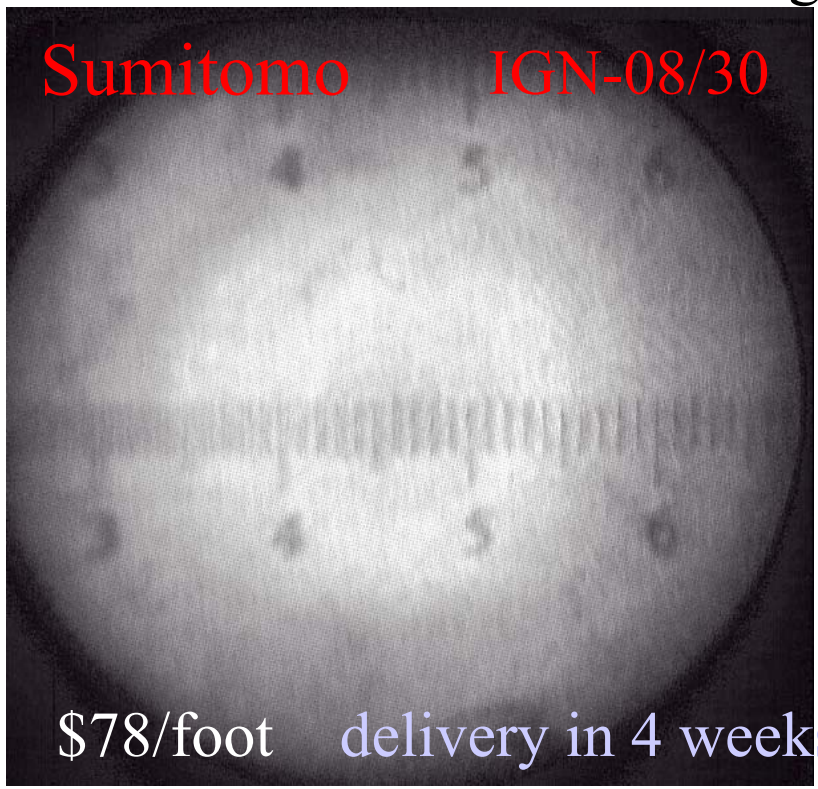
30,000 pixels, 1-mm diameter

25 cm long

30 cm long



camera SMD illumination
NIR pulse, 10 us/frame

NO significant difference in image quality
Should go with Sumitomo fibers
(20 meters have been ordered)

All-In-One Optical Setup

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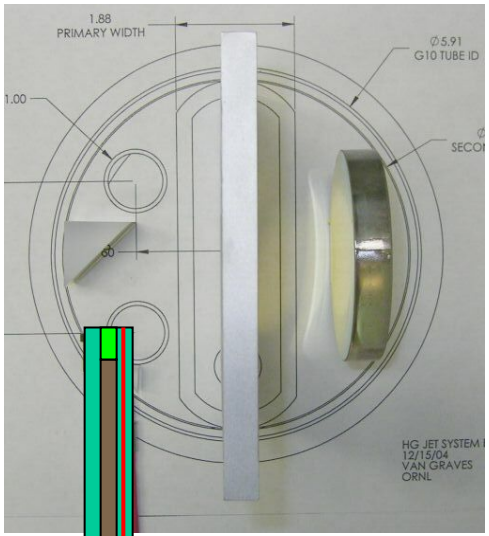
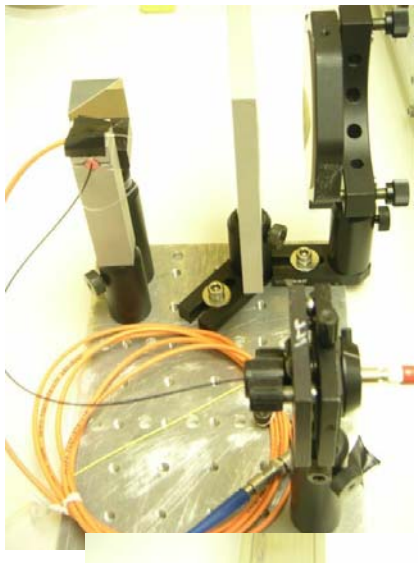
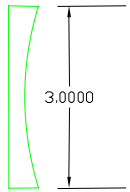
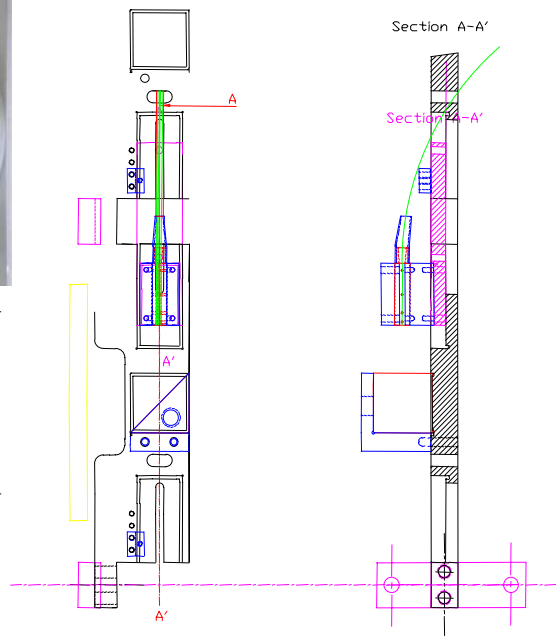
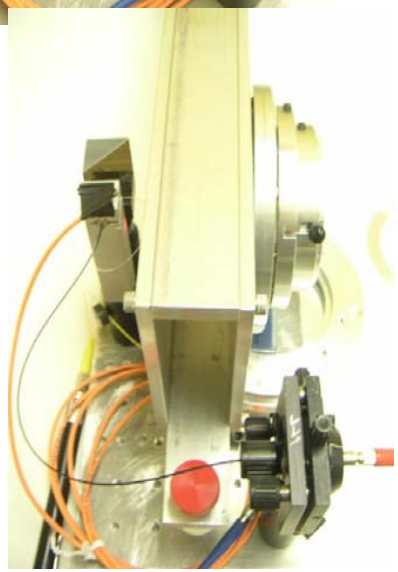
The implementation of the new setup depends on the irradiation test

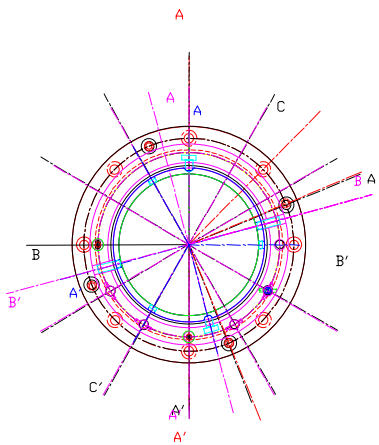


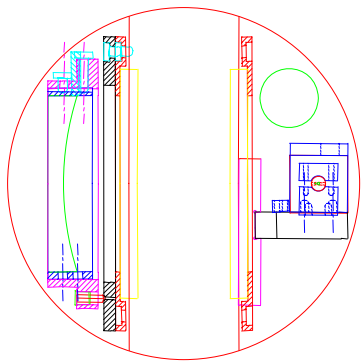












lens
imaging fiber – 1 mm
illumination fiber
fiber holder

Image Capture in All-In-One Optical Layout Setup

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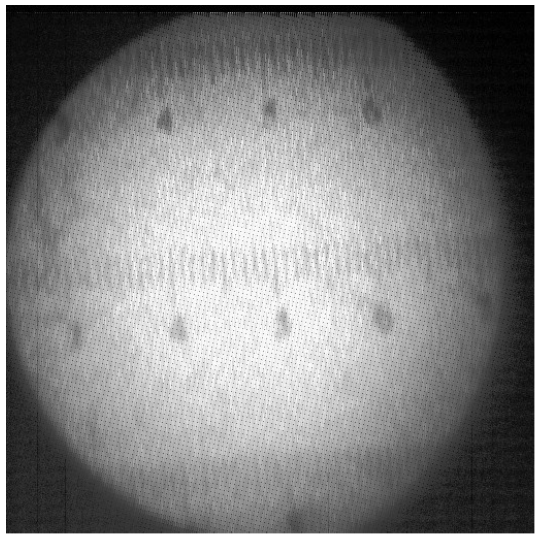
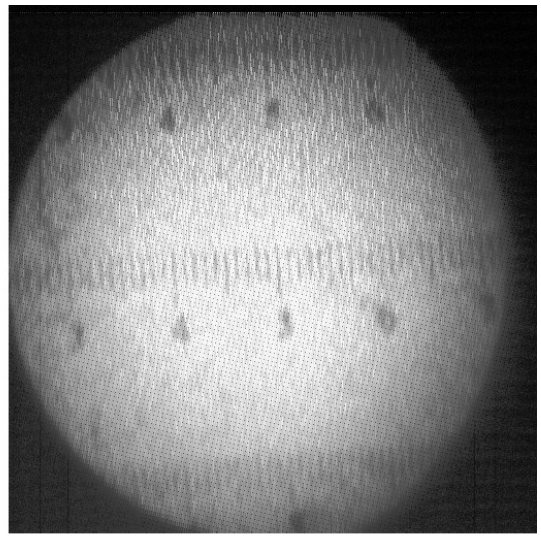
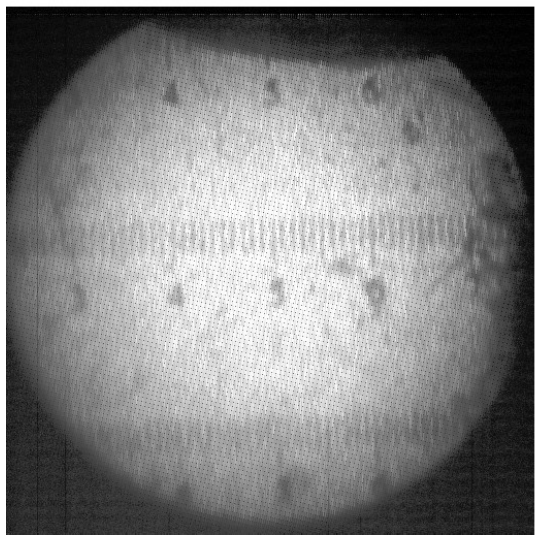
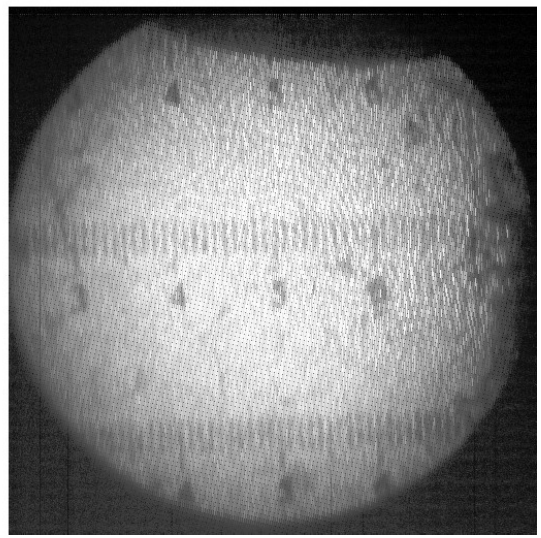
	0.1 ms NIR pulse	0.01 ms NIR pulse
Sumitomo IGN-08/30		
Fujikura FIGH-30-850N		

Water Jet Test,

November 16 @ Princeton Univ.

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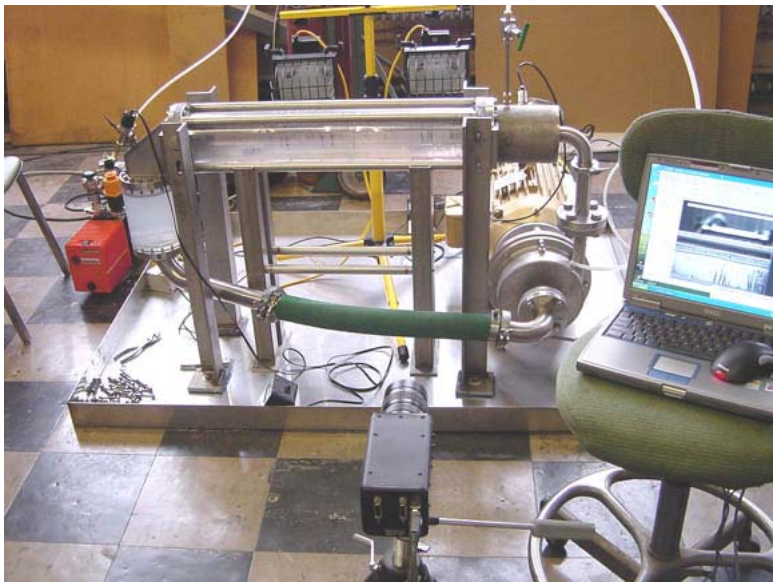
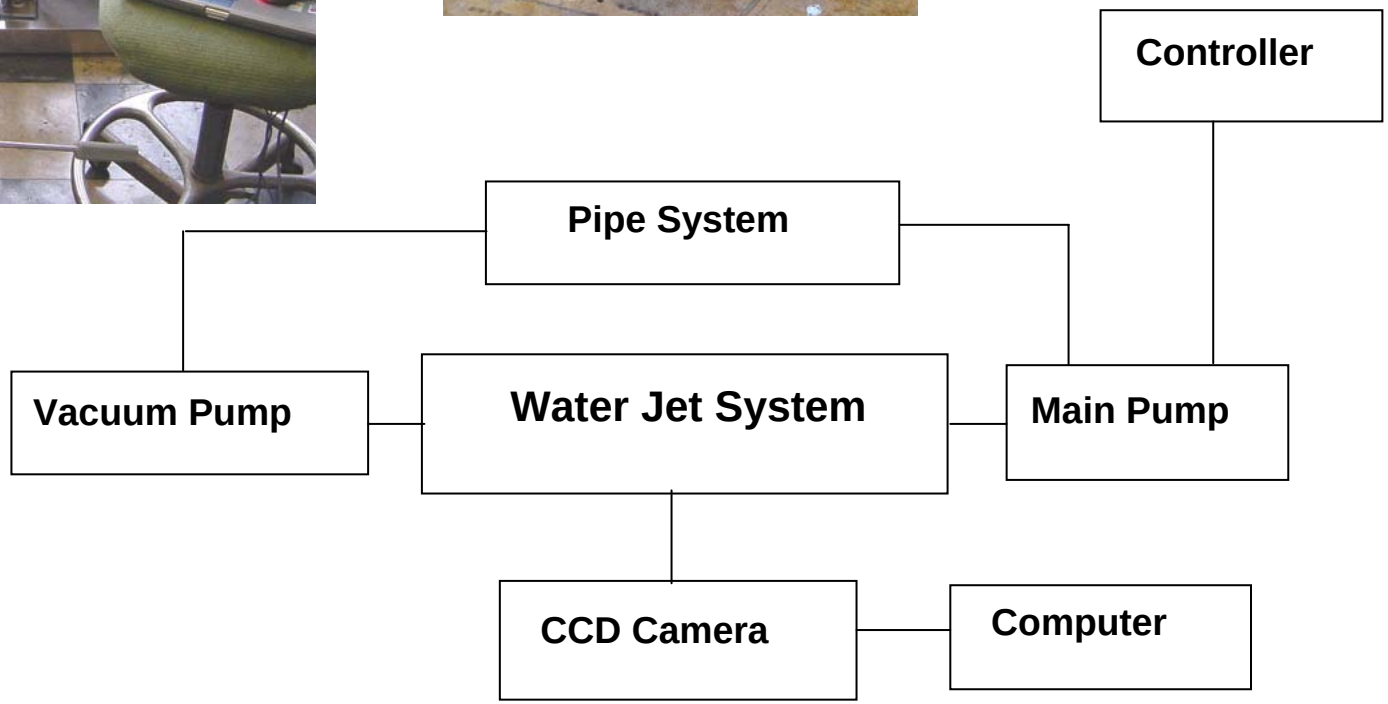
Front view



Nozzle



Fast Camera Capture of Water Jet, November 16 @ Princeton

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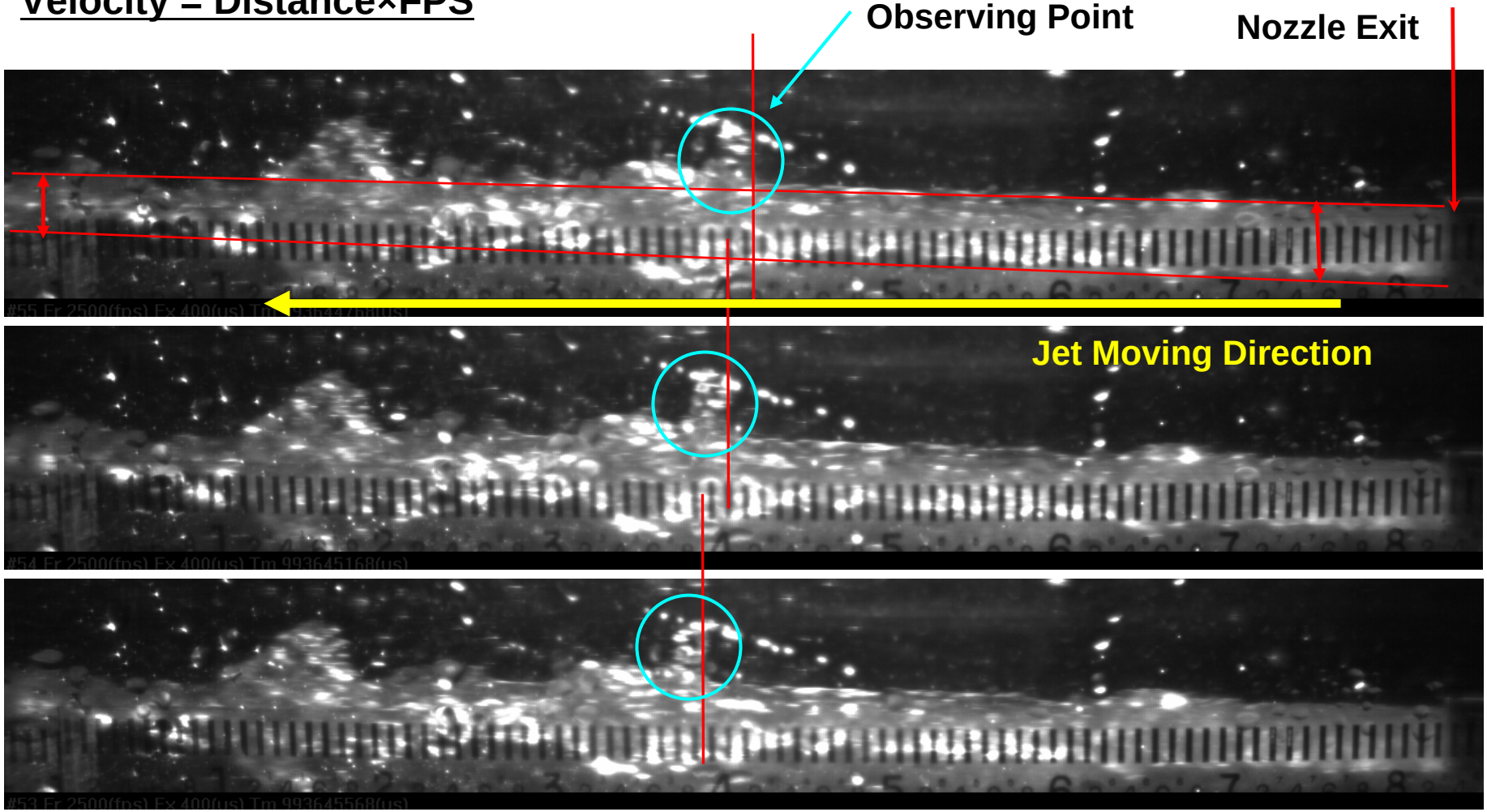
Example : Tapered Nozzle with Straight (atm. condition)

Frame Rate(fps)	2500
Exposure Time(μs)	200
Resolution	1280×200

Velocity = Distance×FPS



Experimental Parameters Investigation For Water Jet

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$$\mathrm{Re} = \frac{\rho_0 V_0 D}{\mu_0} \qquad Ec = \frac{V_0^2}{c_{p_0}(T_w - T_0)}$$

$$\mathrm{Pr} = \frac{\mu_0 c_{p_0}}{k_0} \qquad C = \frac{P_a - P_0}{\rho_0 V_0^2}$$

$$Fr = \frac{V_0^2}{gD} \qquad We = \frac{\rho_0 V_0^2 D}{\Gamma}$$

ρ : density
V : velocity
D : diameter
μ : viscocity
Cp : specific heat
P : pressure
Γ : surface tension
k : thermal conductivity

Nondimensionalized Basic Equations

$$\frac{\partial \rho^*}{\partial t^*} + \nabla^* \cdot \rho^* V^* = 0$$

$$\frac{DV^*}{Dt^*} = -\nabla^* P^* - \frac{Gr}{\mathrm{Re}^2}\beta^* T^* g^* + \frac{1}{\mathrm{Re}}\nabla^* \cdot \tau_{ij}^*$$

$$\rho^* c_p^* \frac{DT^*}{Dt^*} = Ec\frac{Dp^*}{Dt^*} + \frac{1}{\mathrm{Re}\,\mathrm{Pr}}\nabla^* \cdot (k^* \nabla^* T^*) + \frac{Ec}{\mathrm{Re}}\Phi^*$$

$$\Phi = \tau_{ij}^{'} \frac{\partial u_i}{\partial x_j}$$

$$\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_p$$

Boundary Condition (Free Surface)

$$w^* = \frac{D\eta^*}{Dt^*}$$

$$P^* = C + \frac{1}{Fr}\eta^* - \frac{1}{We}(R_x^{*-1} + R_y^{*-1})$$

Later, Magnetic field effect should be considered for MHD experiment and the deformation of jet is going be investigated experimentally based on the parameters.

Other Issues

1. Laser power increase to ~40 W/pulse (instead of 10 Watt/pulse)
2. Viewports: sapphire window
3. Number of viewports: 4
4. Location of the viewports: 6-inches aparts
5. How many fast CCD camera ? 1 fast (1 µs) camera, ~3 slower (250 µs) camera ?
6. Potential to illuminate all viewports with one laser system
7. Make mockup with 1 viewports based on all-in-one optical layout fitting inside 6'' diameter secondary containment and optical feasibility test in terms of image quality