Scalability of Fiber Laser Technology
And the Challenge to Safe Installations
Active Fiber:
Multi-Clad, Circular Cladding,
Low Diameter, ~2-10m Total Length
High Yb$^{3+}$ Concentration

Pump Diodes:
Multimode
90μm stripe
30W to 100W Output Power
Fiber Laser Construction

Broad-Area Multimode Pump Diodes

HR (R>20dB)

Multimode Coupler

Cladding-Pumped Active Fiber

Multimode Coupler

Broad-Area Multimode Pump Diodes

collimated laser output

QC (1dB)

Laser Beam

Fiber Bragg Gratings

single-mode signal

cladding

multi-mode pump light
is absorbed by ytterbium atoms in the single-mode core

amplified single-mode signal

Multi-mode pump light

Rare earth doped single-mode core
Double clad design, pump energy delivered through large core fiber, laser produced in 9um inner core, single mode output

Scalable to Higher power, high reliability, broad stripe diodes

No limitation on insertion of pump photons-can distribute gain

No residual pump light in output

Advantages:
Scalability, Reliability and Performance
High Power SM Fiber Laser Modules

• $P = 700 \& 1000 \text{ W}$

• $\lambda = 1070 \text{ nm}$

• $\text{BPP} = 0.34 \text{ mm x mrad} \quad (M^2 < 1.05)$

• $W\times H\times D = 42\times33\times4.7\text{ cm}$

• DC wall-plug efficiency $\geq 32\%$
IPG Single Stripe Diode

**Conventional Cooling**
- Low Current (5 amps)
- Low Heat Dissipation
- Easy to pigtail into fiber

**Est. Lifetime > 100,000 hrs**

**Efficiency > 70%**
Common Modules
Fiber Combiner

Single Mode Fibers From Modules

Multimode Fiber Output
10kW Fiber Laser – by Combining Modules
Modular Fiber Laser Structure

Multiple SM lasers are combined using all-fiber combiners.

Combiner output spliced to a MM output fiber.
Ytterbium Laser System 20,000 Watt
100 μm Delivery Fiber

- Output power: > 20 kW
- Beam quality
  - 100 μm core Fiber: BPP ≈ 4.0 mm*mrad
  - 50 μm core Fiber: BPP ≈ 2.0 mm*mrad
- Delivery fiber length:
  - 100 μm core Fiber: 10 m
  - 50 μm core Fiber: 5 m
- Modulation: up to 5 kHz
- Consumption for 100 μm < 67 kW
- Consumption for 50 μm < 80 kW
- Wall-plug efficiency 100 μm: > 30 %
- Wall-plug efficiency 50 μm: > 25 %
- Dimensions: 1475 x 806 x 1402 mm
- Weight: 1200 kg
30kW Multimode

- Output beam quality BPP~10 M^2~30
- DC EOE ~ 33%
- Output fiber core diameter 200um
- Output NA ~ 0.085
- Output fiber length 15m
- Linewidth (FWHM) ~4nm
Ytterbium Laser System 50,000 Watt
200 μm Delivery Fiber

- Output power: > 50 kW
- Beam quality
- 200 μm-core Fiber: BPP<12 mm*mrad
- 100 μm-core Fiber: BPP<4.5 mm*mrad
- Delivery fiber
  - 200 μm-core Fiber: up to 25 m
  - 100 μm-core Fiber: up to 10 m
- Modulation: up to 5 kHz
- Consumption
  - 200 μm-core Fiber: < 170 kW
  - 100 μm-core Fiber: < 200 kW
- Wall-plug efficiency
  - 200 μm-core Fiber: > 30 %
  - 100 μm-core Fiber: > 25 %
- Dimensions: 1800 x 2730 x 810 mm
- Weight: 3000 kg
100,000 Watts
# 1.0 Optical Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td><strong>Mode of Operation</strong></td>
<td>CW/ Modulated</td>
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<tr>
<td>Nominal Output Power, W</td>
<td>100 000</td>
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<tr>
<td>Emission Wavelength, μm</td>
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<tr>
<td>Emission Linewidth, nm</td>
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<tr>
<td>Switching On/Off Time, μs</td>
<td>20-100</td>
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<tr>
<td>Output Power Modulation Rate, kHz</td>
<td>up to 5</td>
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<tr>
<td>Feeding Fiber (HLC-24 Connector)</td>
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<tr>
<td>Core Diameter, μm</td>
<td>300</td>
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<tr>
<td>Optional: Fiber-to-fiber Coupler (FFC) Length, m</td>
<td>Integrated, Water-cooled, 3” Optics</td>
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<tr>
<td>Process Fiber Length, m</td>
<td>≥50</td>
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<tr>
<td>Beam Parameter Product, 86% Level, mm<em>mm</em>rad</td>
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<tr>
<td>Feeding Fiber Core Diameter, 300 μm</td>
<td>13.0</td>
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<tr>
<td>Process Fiber Core Diameter, 500 μm</td>
<td>23.0</td>
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<tr>
<td>Laser Interfaces:</td>
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<tr>
<td>Standard</td>
<td>Analogue Control</td>
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<tr>
<td>Optional</td>
<td>Hardwiring</td>
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<tr>
<td>Safety Interface, Chiller Interface</td>
<td>Industrial Ethernet</td>
</tr>
<tr>
<td>Fieldbus Interface</td>
<td></td>
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</tbody>
</table>

*IPG Photonics Confidential Information*
Fiber Laser Safety

...so what are we supposed to do to adequately safeguard 100 kW?

To demonstrate
Fiber Laser Safety

... Same as before, just more of it?

21 CFR 1040.10 FLPPS

IEC 60825-1 Safety & Classification

ANSI Z 136.1 Safe Use of Lasers

ANSI Z 136.9 Manufacturing Guidance

Guidance Z 136.7 & 60825-4
Fiber Laser Safety

.... 21 CFR 1040.10 FLPPS

IEC 60825-1 Safety & Classification

21 CFR Protective Housing function for its purpose and environment throughout the life product

International adds reasonably foreseeable single fault level, and requirement for automation to survive 30,000 seconds w/o human intervention

4 kW, 3 focal lengths past focus 10 seconds 9 mm. galv steel
Fiber Laser Safety

.... Prime methodology

Heat dissipation (cooling) as a safety provider

The radius of the robot arm plus the end effector plus the distance beyond the focal point at which damage to the inner wall could occur.

Aluminum dramatically outperforms steel for many powers up to crossover.
Fiber Laser Safety

... *Prime methodology*

In other words, insure the beam CANNOT point at the wall (or other surface) in a manner in which it could harm or breach the surface

No fly zone mechanisms
Fiber Laser Safety

And then

Deal with the remaining energy as primarily either a long distance divergent beam (several focal lengths on the other side of the box) or diffuse reflected.

Double walled steel panels buildings with calculated thicknesses and distances.
Fiber Laser Safety

... And then

While discouraging viewing windows or making them double/triple thick to ensure adequate attenuation to Class I AEL (many times addition of detection was also need in the event a beam began to damage a window)

Double thick with fusible filament
Fiber Laser Safety

.... But do all these tactics work, as we cross over the $10^\star$ kW mark (*or some other arbitrary number*)

Or will we need literal fortresses to contain them
Fiber Laser Safety

.... Well, some and maybe yes

we have anecdote and some empirical indication that even at current power there is reflected energy in significant energy concentration to cause harm, especially with longer focal lengths (which increase the reflected or directed irradiance)
Fiber Laser Safety

... So, although we will still ....

- do some exercise in controlling the direction (robot & optics head)
- maintain angles and distances
- Calculate melting points, and use material which will dissipate energy without vaporizing
- Discourage viewports
Fiber Laser Safety

We’re gonna need a bigger boat . . . . . . .
Fiber Laser Safety

We will likely need to add one or more functions we don’t consider necessary now, or implement them to a greater extent

- Add absorbing or dissipating thickness…even sacrificial static elements
- Eliminate all windows (except very fast, single use destructible)
- Employ active guard technology throughout
Fiber Laser Safety

- 5 inch thick walls, heavy gauge sheetmetal inside and out
- 5 surfaces with detection (active shut down)
- Fusible (one time) window

Example shown is a custom version of Lasermet Laser Castle but many brands are available.
Fiber Laser Safety

- So, life after the 10-12 kW threshold is possible
- Greater care in selecting enclosure design and material
- No windows
- As power increases, we will need greater reliance on active guard technology (absolute requirement in 50-100 kW automation applications)