Defense Systems
Information Analysis Center

DSIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

State-of-the-Art (SOA) Fiber Lasers to Support Ongoing Directed-Energy (DE) Efforts

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ABOUT DSIAC

The Defense Systems Information Analysis Center (DSIAC) is a U.S. Department of Defense information analysis center sponsored by the Defense Technical Information Center. DSIAC is operated by SURVICE Engineering Company under contract FA8075-14-D-0001.

DSIAC serves as the national clearinghouse for worldwide scientific and technical information for weapon systems; survivability and vulnerability; reliability, maintainability, quality, supportability, and interoperability; advanced materials; military sensing; autonomous systems; energetics; directed energy; and non-lethal weapons. We collect, analyze, synthesize, and disseminate related technical information and data for each of these focus areas.

A chief service of DSIAC is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry. For more information about DSIAC and our TI service, please visit www.DSIAC.org.

ABSTRACT

The Defense Systems Information Analysis Center (DSIAC) received an inquiry requesting information on original equipment manufacturers (OEMs) of high-power fiber lasers that met a list of desired attributes. DSIAC was assisted by subject matter experts from Georgia Tech Research Institute in compiling a list of potential OEMs and supplemental information about the products. The information gathered was detailed in a response report and sent to the inquirer.

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1.0 TI Request

1.1 INQUIRY

What state-of-the-art (SOA) fiber lasers are available to support directed energy (DE) efforts?

1.2 DESCRIPTION:

The inquirer requested information on original equipment manufacturers (OEMs) that sell SOA fiber lasers that meet the following requirements or can be combined to meet the following requirements:

- Emits in the 1.0–1.1 µm wavelength band.
- Includes the laser, laser-pumping components, power supply, cooling system, etc.
- Demonstrates high-power/energy laser pulses and high efficiency.
- Has relatively low system size, weight, and power usage (SWaP).

The inquirer asked for the vendor name, address, product name, power level, wall plug efficiency, watts per kilogram of total weight, and watts per liter total volume (including power supply with lase time considering cooling and power availability). The inquirer also requested final technical reports or research summaries that would indicate companies that fit their requirements.

2.0 TI Response

The Defense Systems Information Analysis Center (DSIAC) compiled a list of potential OEMs that produce high-power fiber lasers, and supplemental information about the products with the help of subject matter experts (SMEs) from Georgia Tech Research Institute (GTRI) Electro-Optical Systems Laboratory (EOSL) and Sensors and Electromagnetics Applications Laboratory (SEAL) as well as information gathered in support of a Core Analysis Task (CAT) conducted by DSIAC for the Special Operations Command (CAT 15-1195).

2.1 INTRODUCTION TO HIGH-POWER FIBER LASERS

High-power fiber lasers can be combined to create high-energy laser systems that can deliver hundreds of kilowatts of average power to a target through adverse conditions multiple kilometers away. This capability is obviously of interest to Department of Defense (DoD) and military operations as potential DE weapons and for power beaming to unmanned aerial vehicles (UAVs) and low-orbit satellites. There is significant interest from both the DoD and industry for application of current and future fiber-based laser research in these areas [1].

2.2 U.S. OEM INDUSTRY VENDORS

GTRI SMEs compiled information on OEMs of high-powered laser systems. In GTRI's response, they identified U.S. OEMs who sell SOA fiber laser systems emitting in the 1.0−1.1-µm wavelength band. The systems 1) include the laser, pumping components, power supply, cooling system, etc.; 2) generate high-power/energy laser pulses; 3) are highly efficient; 4) come in form factors that are relatively small and low weight; and 5) require relatively low power—or can be combined to provide the same. GTRI provided information on the following OEMs:

- IPG Photonics.
- Coherent, Inc.
- Nufern (a subsidiary of Coherent, Inc.).
- nLIGHT.
- Lumentum.
- Lasertel (a subsidiary of Leonardo).
- OFS Fitel (a subsidiary of Fujikura).

GTRI also noted that U.S. OEMs who sell fiber laser weapons or major assemblies include the following companies:

- Lockheed Martin.
- Northrop Grumman.
- Boeing.

2.2.1 IPG Photonics

Table 1: IPG Photonics Contact Information [2]

Company	IPG Photonics World Headquarters
Phone	Sales: 1(508)-373-1100 Laser Systems Support: 1(508)-506-2888
Email	Sales: SalesUS@ipgphotonics.com Laser Systems Support: SystemsProductSupport@ipgphotonics.com
Address	50 Old Webster Road Oxford, MA 01540 USA

IPG Photonics is a leading developer and manufacturer of high-performance fiber lasers and amplifiers for diverse applications in numerous markets. In October 2012, MBDA Systems' German subsidiary used its 40-kW system to shoot down airborne artillery from a distance of

2 km. The 40-kW system was built with four 10-kW sources provided by industrial fiber laser maker IPG Photonics [3].

IPG Photonics Vertical Integration

IPG Photonics is a pioneer in high-power laser development. IPG employs a "Vertical Integration Strategy" to ensure complete control over the quality, performance, and cost of critical components [4]. The following is an excerpt from "IPG Technology" [4]:

> **Vertically Integrated Development and Manufacturing**
>
> Dissatisfied with the performance and quality of available components, IPG embarked on a comprehensive strategy of vertical integration. We design and manufacture all key components, from our active and passive fibers, highest quality seed and pump diodes, active fiber blocks and modular resonators, pump couplers, combiners, acousto-optical modulators, fiber volume Bragg gratings, nonlinear and active crystals, various micro and bulk optics, power supplies and controllers responsible for the lasers' performance, to delivery cables, the processing delivery heads, beam switches and water chillers directly responsible for our customers' user experience. Through our complete control over the quality, performance and cost of critical components, IPG is able to deliver laser solutions consistently exceeding our customers' expectations.

Seamless Integration, Relentless Quality Control

Our vertical integration strategy allows IPG to closely couple laser and component developments resulting in fully optimized fiber lasers. This holistic approach to product design improves product performance and greatly reduces time-to-market. Every element of an IPG laser solution is designed for cost and manufactured in an environment of relentless quality control. Since components are developed within IPG's own manufacturing centers of excellence, our cutting-edge technologies emerge uniquely ready for industrial deployment.

The IPG Innovation and Supply Chain

IPG's growing manufacturing footprint includes sites in the US, Germany, Russia and Italy. Ownership of the entire innovation and supply chain truly sets IPG apart through our ability to fully control the performance, quality, capacity and cost of our products. IPG application labs distributed worldwide rapidly bring our new technologies to our customer base allowing collaborative innovation to continuously refuel the new product pipeline.

IPG's vertical integration turns gallium arsenide and glass into seamlessly engineered laser solutions.

Integration from the Wafer Fab to our Customers' Factory Floor

IPG's vertical integration begins with the transformation of raw materials into our diode and fiber components. IPG's state-of-the-art wafer fab fabricates the world's finest high power semiconductor lasers from bare gallium arsenide, while our fiber fabs draw spools of optical fiber from glass preforms grown in-house. Diode chips and optical fiber spools are integrated into IPG's proprietary component packages which are further integrated into laser modules, each capable of > 1 kW of fiber laser output.

The integration of multiple module building blocks into a final assembly provides our fiber lasers with IPG's trademark scalability and reliability. Each module operates independently, meaning no module failure can disable an entire laser. Every IPG laser can be scaled up in power and reliability by simply including more modules in the design. Following this approach, IPG delivered a 100,000 Watt laser which leverages the same basic design as our 1,000 Watt lasers.

IPG Photonics High-Power Fiber Laser Overview

Excerpt from the 2016 article "Photonics Products: High-Power Fiber Lasers: Kilowatt-Level Fiber Lasers Mature" by J. Wallace [5]:

> Alexei Markevitch, market development manager at IPG Photonics (Oxford, MA), outlined the range of wavelengths and powers available for kilowatt-class fiber lasers. "IPG manufactures standard kilowatt-class CW lasers at 1 µm (ytterbium-doped fiber) and 1.5 µm (erbium-doped fiber) and also manufactures custom kilowatt-class lasers at 2 µm (thulium doped fiber), along with lasers that have Raman-shifted wavelengths between 1.1 and 1.7 µm," he says. "The longer wavelengths enable nonmetal materials processing and other new applications and are considered to be eye-safe, as the eye-damage threshold is many orders of magnitude higher than for 1 µm lasers."
>
> Markevitch notes that the kilowatt-class fiber laser systems operate in CW or modulated modes up to 5 kHz, and have dynamic range from 10% to full power with no change in beam divergence or beam profile.
>
> At 1 µm, the company's single-mode YLS-SM ytterbium-doped fiber lasers span a power range from 1 to 10 kW, says Markevitch. These single-mode systems are used in advanced materials-processing applications requiring extremely high power and brightness, such as fine cutting and surface structuring, cutting high-reflectivity metals, microwelding, sintering, and engraving, as well as remote processing and directed-energy applications.
>
> "IPG's multimode YLS ytterbium-doped CW fiber lasers span a power range from 1 to 100 kW and can be manufactured up to several hundreds of kilowatts upon customer request," says Markevitch. "Their many uses include cutting, drilling, brazing, welding, annealing, heat treating, and cladding. With continuous improvement in their design, wall-plug efficiencies of standard industrial YLS system have now reached over 40%, and the industry record YLS-ECO series has a WPE exceeding 50%."

IPG High-Power Fiber Laser Datasheet and Other Relevant Information

No open-literature information is available regarding IPG fiber lasers used in DE weapons. An IPG industrial-grade fiber laser is described in the YLS-CL Datasheet [6]. Other relevant systems include the YLS-SM, 1-10 kW [7], and the YLS-10000-ECO [8].

2.2.2 Coherent, Inc.

Table 2: Coherent Inc. Contact Information [9]

Company	Coherent Corporate Headquarters
Phone	(408)-764-4000
Email	tech.sales@coherent.com
Address	5100 Patrick Henry Drive Santa Clara, CA 95054 USA

Subsidiaries of Coherent, Inc. include Coherent/Nufern (United States), Coherent/DILAS (Germany), and Coherent/Rofin (Germany).

The following information is an excerpt from the 2016 *Laser Focus World* article "Photonics Products: High-Power Fiber Lasers: Kilowatt-Level Fiber Lasers Mature" by J. Wallace [5]:

> As described by Frank Gaebler, marketing director for materials processing at Coherent (Santa Clara, CA), first-generation fiber lasers were based directly on telecom platforms massively scaled to higher power, using a large number of separate pump laser diodes, each independently fiber coupled and permanently spliced together.
>
> "This brute-force approach to higher power has several limitations," he says. "In particular, all the components are permanently spliced together. If one component fails or degrades, there is no way to replace it. For example, early models were found to be susceptible to back reflections from metal processing. If the fiber splices, pump diodes, delivery fiber, or any other laser component is damaged by such back reflections, the laser had to be factory-repaired or exchanged, negatively impacting uptime and net production.
>
> Coherent makes a second-generation kilowatt-scale fiber platform (the Highlight FL) based on a flexible modular architecture. Engineers at Coherent have used a substantially different design approach that eliminates the complexity of multiple pumps and splices, with a modular architecture that also enables simple replacement and/or upgrade of the various components, including the delivery fiber, notes Gaebler.
>
> We use fiber-coupled high-power laser-diode bars rather than multiple separate laser diodes," he says. "Their output is then coupled into the gain fiber using free-space coupling; this coupling module is also used to connect the gain fiber to the detachable delivery fiber." He adds that this

> approach is particularly attractive to OEM system builders, as they can buy complete lasers or separate modules depending on their level of expertise or requirements for deep integration, and they can quickly change or replace the delivery fiber to suit different applications.

Articles and documents containing information regarding Coherent, Inc.'s defense applications include the following:

- "Pump Laser Diodes Deliver High Power for Leading-Edge Applications" by J. Wallace [10].
- "DILAS: The Diode Laser Company" product brochure by Coherent/DILAS [11].
- "Diode Lasers Used in Defense Applications" by Coherent/DILAS [12].
- "Defense and Military Laser Technology" by Coherent [13].
- "Defense Technology" by Coherent/Nufern [14].

Additionally, relevant Coherent, Inc. datasheets include the following:

- "HighLight FL10000" [15].
- "1064nm, Water-Cooled, Frameless Vertical Stacks" by Coherent/DILAS [16].
- "940nm, Water-Cooled, Horizontal Diode Laser Stack" by Coherent/DILAS [17].

2.2.3 Nufern, Inc. (A Subsidiary of Coherent, Inc.)

Table 3: Nufern Inc. Contact Information [18]

Company	Nufern, Inc.
Phone	860-408-5000
Address	7 Airport Park Rd East Granby, CT 06026

The following information in an excerpt from "Defense Technology" by Coherent/Nufern [14]:

> Nufern provides the US defense industry with force multiplying optical fiber-based technologies from sensors to HEL. Founded in 2000 we are a US company experienced at servicing the US government, its agencies, foreign governments under license as well as myriad allied military and aerospace contractors from our volume manufacturing plant in Connecticut. Nufern is equally capable and experienced at executing rated (DX, DO) and commercial term transactions satisfying customer needs and FAR. Our products are working on Mars, the depths of our oceans and many places in between.

Nufern is a registered defense contractor with the US state department. Our state of the art, ITAR compliant headquarters and flex manufacturing facilities in E. Granby, CT have hosted the development of many sensitive products & technologies. We strive to make our customers successful on every project we do.

CW Kilowatt-Class Amplifiers

Excerpt from "Defense Technology" by Coherent/Nufern [14]:

> Nufern has leveraged its preeminent specialty fiber business to create a family of compact, high performance, kilowatt-class amplifiers with diffraction limited beam quality designed specifically for defense applications.
>
> These compact & rugged systems provide requisite high beam quality, high efficiency, and narrow linewidth making them optimal for spectral or coherent beam combination applications.
>
> Fast MRO support is available from our depot service integrated with our high production capacity facility and direct and open access to our engaged scientists & technical development team. Field service and application assistance is provided from that same motivated team of experts.
>
> Most clients building proof of concept and prototype demonstration systems choose to utilize our broad line of integration accessories. Each accessory is custom designed to compliment [sic] the highest performance Nufern amplifiers with state of the art ancilliary [sic] equipment.

CW Kilowatt-Class Amplifier Accessories

A range of compatible kilowatt-class accessories are available, including the following accessories identified in an excerpt from "Defense Technology" by Coherent/Nufern [14]:

> **1. Stand-alone Chassis**
> 19" Rack mounted amplifier housing containing: high power laser diode drivers, DC power supplies/turn-key safety circuitry & interlocks, Ethernet interface, input: 208VAC/30A.
> Windows Based GUI Control Software included.
>
> **2. Linewidth Broadening Units, 19" Rack Mounted**
> Stimulated Brillouin Scattering (SBS) is one of the major limiting factors in high power amplification with a narrow linewidth seed laser required for

beam combination. The linewidth broadening unit manipulates the seed to apparently increase the seed Laser linewidth in order to increase the SBS threshold which in turn enables higher power amplification.

3. Polarization Controllers, 19" Rack Mounted
The Polarization Controller unit, typically positioned between the seed laser and amplifier, enables a stable State of Polarization (SOP) to be achieved in a non-Polarization Maintaining (PM) amplifier. For instance, linearly polarized light with a stable high degree of polarization purity can be achieved (PER>17dB) using this device. An optical pick off from the output is used to generate an electrical feedback signal used in turn to control the optical servo loop.

4. Output Fiber Termination Connectors
Robust kilowatt-level "Output" connectors with a minimal impact to beam quality. (<0.1 BQ differential) designed for field serviceability as well as easier integration.
Standard units available as well as build-to-spec.

5. Packaged Seed Lasers
Low-SWAP narrow line width signal sources with integrated line width broadening unit. <50mW output. Designed to match and drive Nufern high power CW fiber amplifiers.

2.2.4 nLIGHT

Table 4: nLIGHT Contact Information [19]

Company	nLIGHT, Inc., Headquarters
Phone	1-360-566-4460
Email	sales@nlight.net
Address	5408 NE 88th Street Building E Vancouver, WA 98665 USA

nLIGHT is a vertically integrated supplier of high-performance lasers that enable innovation in materials processing, defense, and medical applications. nLIGHT develops and manufactures semiconductor and fiber lasers based on industry-leading semiconductor laser and optical fiber technology. nLIGHT is headquartered in Vancouver, Washington with additional sites in North America, Europe, and Asia [20]. According to nLIGHT, the "nLIGHT alta™ is the first in a line of next generation high power fiber lasers" [21].

In the 2016 *Laser Focus World* article "Photonics Products: High-Power Fiber Lasers: Kilowatt-Level Fiber Lasers Mature" by J. Wallace, Jake Bell, the general manager at nLIGHT, noted the following [5]:

> "Most multi-kilowatt fiber laser systems employ an architecture based on combining the outputs of multiple, lower-power fiber lasers, resulting in significant shortcomings in cost, performance, serviceability, upgradeability, and amenability to technological advances," he [Bell] adds. "We (nLIGHT) introduce a novel kilowatt fiber-laser architecture that solves these problems by housing the pump diodes and drivers in standalone pump modules and the gain fibers in a configurable gain module that can generate more than 4 kW of output power."

2.2.5 Lumentum Operations LLC

Table 5: Lumentum Contact Information [22]

Company	Lumentum Operations LLC
Phone	408-546-5483
Email	customer.service@lumentum.com
Address	400 North McCarthy Blvd Milpitas, California 95035 USA

Lumentum provides high-power fiber lasers operating at multi-kilowatt levels. The following is an excerpt from the 2016 *Laser Focus World* article "Photonics Products: High-Power Fiber Lasers: Kilowatt-Level Fiber Lasers Mature" by J. Wallace [5]:

> Erik Zucker, senior director of laser products and technology at Lumentum (Bloomfield, CT) describes both the modular nature and the inner workings of the company's Corelight kilowatt-class CW fiber-laser line. "Our basic building block is a double-clad fiber, single-oscillator module with over 2 kW output power," he says. "Several of these modules may be combined to provide significantly higher power from a single beam. Our fiber lasers are predominantly used for 2D sheet-metal cutting of materials ranging from mild and stainless steels to aluminum, copper, and brass. They can also be used for metal welding, brazing, and cladding applications."
>
> The 2 kW fiber-laser module is made up of a single fiber oscillator that is end-pumped by an array of Lumentum's ST Series high-brightness, fiber-

> coupled laser diodes, which are designed and manufactured in-house, notes Zucker.
>
> "Each pump produces 140 W of output power from a 106-µm-diameter fiber at over 50% wall-plug efficiency," he explains. "Multiple pump fibers are fusion-combined together into a single fiber, which in turn is spliced to one end of the oscillator. Fiber Bragg gratings define the cavity and output coupler. Because the 2 kW is produced from a single module, the beam-parameter product (BPP) is very low, typically 0.8 mm-mrad. This allows a small spot diameter with large depth of field to be focused on the workpiece in metal-cutting applications, which in turn creates a very high intensity and leads to extremely efficient cutting."

Lumentum's CORELIGHT Kilowatt-Class CW fiber lasers, based on advanced, compact ytterbium fiber laser modules, offer straightforward integration into assemblies that feature higher output power [23].

2.2.6 Lasertel (A Subsidiary of Leonardo)

Table 6: Lasertel Contact Information [24]

Company	Lasertel North America
Phone	520-744-5700
Email	info@lasertel.com
Address	7775 N. Casa Grande Hwy Tucson, AZ 85743 USA

Excerpt from "Defense" by Lasertel [25]:

> Lasertel is the #1 diode supplier for military laser systems worldwide and a proven partner in over 100 defense programs. Our military laser diodes benefit from engineer-to-engineer collaboration, design and troubleshooting offered for your program development.
>
> We develop products for Directed Energy, Illumination, Targeting and Pointing systems.

No open-literature datasheets are available for Lasertel Directed Energy Weapon modules.

Excerpt from "Directed Energy" by Lasertel [26]:

> Laser-based systems are ideal for countering modern-day threats, as they offer very low consumable costs while also offering greater speed and range compared to conventional ballistic weapons.

Excerpt from "High Energy Laser Systems for Directed Energy & Emerging Applications" by Lasertel [27]:

> Specifically, laser systems:
>
> - Provide virtually instant target engagement.
> - Have low cost per shot.
> - Achieve highly focused damage on specific areas of a target for precision targeting.
>
> The successful integration of the Laser Weapon System (LaWS) aboard the USS Ponce has proven that directed energy is a viable defensive technology. The depth of applications for laser-based directed energy systems is extensive and includes anti-UAV, small ship deterrent, and missile defense. Each application and platform represents unique challenges and a wide range of performance requirements. The optical output power demanded can range from 10's of kilowatts for counter-UAV applications to megawatts of power for intercontinental ballistic missile defense kill lasers.
>
> Several laser technologies are being studied for scalability and deployability in the multitude of platforms that might serve as a home for directed energy weapons. Fiber lasers, solid state and hybrid (DPAL) lasers, among others, are being researched and developed by defense and industry partners. All of these lasers have one commonality: they use semiconductor laser diodes as pump sources.
>
> Power scaling is not the only technical challenge in directed energy lasers. Weight and volume restrictions are of paramount importance for airborne applications such as the F-35 Joint Strike Fighter, AC-130 gunship, and lasers mounted on unmanned aerial vehicles. The US Department of Defense and DARPA are actively researching methods to drastically decrease the current weight/power ratio and volume of pump diodes for directed energy lasers.
>
> **Diode Pump Sources for Directed Energy Lasers**
>
> Due to the thousands of pump diodes required for directed energy laser systems, it is essential to develop and optimize the laser diode pump

sources. Pump sources are the single largest contributors to the size, weight and costs of these systems.

Laser Diode Bars

With wavelengths available from 760nm to 1700nm, the semiconductor laser diode bar (1cm) is the most basic element of the system. A variety of cavity lengths and fill factors can be chosen to optimize for performance. Typically, electrical-to-optical efficiencies >60% can be achieved. Both high average power and high peak power laser diode bars are available.

Laser Packaging

Lasertel's T6 package is a heat sink building block used to deliver very high power to the laser diode bars while also efficiently maintaining operation temperature. The T6 uses high performance heat sink materials that are expansion matched to minimize thermally induced mechanical stress. Up to 50 individual diode bars can be mounted on each T6. The small form factor and back-mounted mechanical and cooling fluid interfaces allow for multiple devices to be stacked in very close proximity, enabling megawatt-level scalability while maintain brightness. This package has been qualified for harsh MIL environments including airborne qualified systems.

Beam Shaping and Collimation

A high degree of beam collimation is needed to focus and shape the light into the desired form factor needed for pumping or direct diode illumination. To minimize the physical footprint and weight of the device, it is advantageous to perform this collimation at a micro optic level. The T6 package allows for the addition of fast and slow-axis lenses, as well as more advanced optics that correct for smile and pointing errors, all of which can be attached directly to the laser diode package. These optics are attached using a proprietary process that provides extreme physical ruggedness and maintains alignment over large temperature ranges. Additional beam shaping and focusing can be added to provide a well-conditioned, homogenized output beam. Designs have been developed for coupling the light into a delivery fiber, direct coupling into a solid state rod or slab or directly on target.

Scalability

Scaling power is essential for directed energy systems. Lasertel manufactures systems capable of megawatts of power with a common coolant and electrical manifold. These laser diode systems have provided brightness over 11kW/cm2 and total powers over 1 Megawatt per unit.

2.2.7 OFS Fitel (A Subsidiary of Furukawa, a Japanese Company)

Table 7: OFS Fitel Contact Information [28]

Company	OFS Fitel, LLC.
Phone	1(888)-342-3743
Address	6305 Crescent Drive NW Norcross, GA 30071 USA

All branches of the military have an interest in high-power fiber lasers for defense applications due to their advantages such as high efficiency, excellent beam quality, and the smaller size and lighter weight of packaged units. One of the key challenges in designing these components is the power scaling of fiber lasers to the kilowatt range, while maintaining single polarization and narrow signal bandwidth.

The documents “High Power CoolMode™ Pump Combiners High Power CoolMode Pump Signal Combiners for Directed Energy” [29] and “Optical Gain Fiber for Fiber Lasers and Amplifiers” [30] contain information relevant to the inquiry. The following is an excerpt from “High Power CoolMode™ Pump Combiners High Power CoolMode Pump Signal Combiners for Directed Energy” by OFS [29]:

> Fiber laser technology for defense applications is advancing rapidly due to advantages over solid state lasers and funding by the US Department of Defense. Fiber lasers offer features that are critical to the Directed Energy platform. Key components of a highly integrated fiber laser and amplifier system are high-power all-fiber pump and pump signal combiners. OFS fiber combiners can be implemented in almost any fiber laser or amplifier architecture.
>
> OFS combiners can be used in a high brightness, (42+1) x 1 cascaded combiner system which consists of one (6+1) x 1 pump-signal combiner pumped with six 7x1 multimode pump combiners. The cascaded combiner system has a pump efficiency of ≥96%. The higher brightness of

the combiner system is driven by optimized high efficiency multimode pump combiners that have 99% pump throughput.

OFS has an extensive fiber laser and amplifier research program and seeks partners for collaboration in defense related opportunities.

Extensive OFS capabilities in specialty fiber design and manufacture come together with advanced fiber processing technologies in OFS high-performance, all-fiber combiners; gain modules; and cavities for high-power lasers and amplifiers. OFS high-power products offer polarization-maintaining (PM) and non-PM devices based on ytterbium fiber for 1-µm applications, and erbium-ytterbium gain fiber for 1.5-µm applications. Pump combiners in 7:1 and 19:1 configurations using Single-mode, Multimode, or PM optical fiber are available [30].

For customized solutions, OFS offers collaboration with OFS Laboratories, where an extensive laser and amplifier research program is ongoing in fiber laser development [31].

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