New advancements in 793 nm fiber-coupled modules for Tm fiber laser pumping, including packages optimized for low SWaP applications

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ABSTRACT

Targeted at the 793nm absorption band, DILAS Diode Laser, Inc. offers a range of products specifically designed for Thulium fiber laser pumping, spanning from 12 W to >300W of pump power and coupled into fiber sizes starting at 105um and upwards. A variety of different diode architectures are utilized, ranging from single-emitters, conduction-cooled bars, and DILAS's T-bar structure extended to the 793nm range, resulting in a wide variety of power levels and packaging options to support different applications. As IRCM for airborne platforms is a major application for Tm fiber lasers, packages optimized for low SWaP will be presented, which utilize a combination of the T-bar structure and macrochannel coolers specifically designed for compact, lightweight applications. Examples and results of Tm fiber lasers pumped using DILAS diodes will also be presented and discussed.

KEYWORDS: Tm fiber lasers, 793nm fiber laser pump source, fiber coupling, lightweight

1 INTRODUCTION

Emitting in the 1.9-2.1 µm range, Thulium (Tm) fiber lasers are becoming increasingly popular for a variety of applications. New medical and material processing applications are being explored as both average and peak power increase. In addition, due to the emitted radiation being in the eyesafe region of the spectrum, Tm fiber lasers are also attracting interest for ranging and imaging systems. IRCM for airborne platforms is another major application for Tm fiber lasers, and adds further requirements as the overall SWaP of the system needs to be optimized. Tm fiber lasers are often pumped at 793nm, with the result being two photons emitted at the lasing wavelength for every pump photon absorbed\(^1\), and optical efficiencies of >60% can be achieved\(^3\).

DILAS offers a variety of suitable 793nm pump modules specifically designed for Tm fiber laser pumping. Standard features include fiber pigtails (for splicing), and integral filters to protect against any 1900-2100 nm radiation from the Tm fiber laser. Furthermore, DILAS' portfolio of 793nm pump modules now includes three different diode architectures – single emitters, standard bars, and Tailored-bars – to address a variety of power levels and fiber sizes, and also allowing some flexibility in the electrical characteristics of the system.

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For low-powered fiber lasers in the 10-20W average power range, one ideal pump source is the PM3 module. Based on a single-emitter architecture, the PM3 offers 9W of 793nm power out of a 105 µm fiber, operating currents in the ~4A range, in a conductively cooled package.

Multiple pumps can be spliced to standard pump combiners to achieve the desired amount of pump power for CW or pulsed fiber lasers. Figure 2 illustrates an example where four PM3 modules are utilized in a fiber amplifier to amplify the pulse from the master oscillator, resulting in an average power of 15W, with peak powers > 4kW at 30 kHz.

Still utilizing a 105 µm fiber pigtail, next DILAS offers a 32W module. This module is based on a standard diode bar with 19 emitters, and also utilizes conductive cooling. Once again, these can combined using off-the-shelf
combiners to achieve the desired amount of power. Using a 19:1 combiner with these units, over 600W of pump power can be launched, resulting in over 300W of 1.9 µm output power.

![Fiber Combiner Diagram](image)

**Fig. 3:** Schematic drawing showing 19 x 793 nm pump diodes (courtesy of BAE).

![Power vs. Output](image)

**Fig. 4:** Pump Power vs. 1908 nm Output Power (courtesy of BAE).

Wavelength stabilization is also available in these modules, allowing the system to operate over a wide temperature range while still overlapping the Tm absorption peak.

Increasing the fiber core size to 200 µm, DILAS offers pumps ranging from 60W to 300W. Once again, these are based on standard diode bars with 19 emitters. As power levels increase, water cooling becomes increasingly necessary to efficiently transport away all of the waste heat generated. As these modules do not utilize microchannel coolers, conditioned water that is controlled for particle size and biological growth can be used, and it is not necessary to control the water resistivity. Together these modules meet the needs of various architectures, whether continuing to use fiber combiners, or for direct end-pumping. One particularly common module is a 200W pump into a 200 µm fiber. Six diode bars are arranged in a compact water-cooled package measuring ~175 mm x 110 mm x 65 mm.
Fig. 5: Front and back of DILAS FC7 module, with output powers of 200W into a 200 µm fiber.
Since >50% optical-optical conversion efficiency can be achieved with 793 nm pumping, output powers of >100W at 1900-2100 nm can be achieved with a single pump module.

In order to expand the range of 793 nm pump modules even more, it was decided to more closely align the diode structure with that being used for 976 nm fiber-coupled pump modules. First, Tailored bars (T-bars) were fabricated at 793 nm. Each T-bar is 5mm wide, and has 5 x 100 µm emitters patterned. Operating currents are in the 20-25 A range, with 18-20W of raw optical power per T-bar. A single SAC and FAC lens is used on each T-bar to collimate the light. With a beam parameter product (BPP) of about 22 mm*mrad, the slow axis beam quality of one diode with appropriate micro optics fits within a 200 µm/ 0.22 NA fiber, whereas the fast axis has enough clearance in BPP for spatial combining of up to 16 bars. A key advantage of the T-bar architecture is that the emitters are thermally isolated with minimal cross-talk between neighbors. This lowers the overall junction temperature in the active region, which is critical for long life.

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Fig. 6: Current vs. Power and Wavelength Data for FC7 module at 793 nm.
Existing optical designs are then used to couple the T-bars into a 200 µm fiber. One example, used to verify the 793 nm T-bar performance, was to use an existing module design which couples the light from 7 T-bars into a 200 µm fiber, achieving a 100W output. The design of this module is specifically optimized for close packing, and is ideal for use in an industrial setting to generate large quantities of pump power for high-power lasers.

\[ \text{Fig. 7: 7 T-bar package with 100W of 793 nm output into 200 µm fiber} \]

Especially for IRCM applications, low SWaP pump diodes are a key to optimizing the entire laser system for airborne use. DILAS has several years of experience in producing lightweight pump modules at 976 nm, and is now leveraging this expertise for 793 nm pump modules. Utilizing the IS53 platform, DILAS can couple the output from 16 T-bars into a 225 µm fiber. Macrochannel cooler heatsinks are used, so once again resistivity control of the water is not required. These modules can also be densely packed if power scaling is required.
Fig. 8: IS53 Lightweight package housing which couples the output power from 16 T-bars into a 225 μm fiber, while weighing less than 400 grams.

To date, 16 T-bars at 793nm have been bonded onto the macrochannel coolers and assembled into an IS53 module. Measured power output of the module is >200 W at a maximum current of 20 A.
As mentioned earlier, with these power levels it is possibly to directly end-pump active Tm fiber and achieve >100W (with 200W of pump power). These power levels become particularly attractive for IRCM applications, where oftentimes non-linear conversion is used to shift the Tm fiber laser output to yet longer wavelengths. As with any non-linear process, high intensity levels are required for efficient conversion.

**SUMMARY AND CONCLUSION**

In conclusion, DILAS offers a wide portfolio of 793nm fiber-coupled pump modules that are suitable for Tm fiber laser pumping. These modules span power levels from 9W to 200W, with the output power coupled out of 105 µm or 200 µm fibers. Three different types of laser diode technologies are utilized – single emitters, standard laser diode bars, and T-Bars – depending on the power level and package type required. Furthermore, results of a lightweight module with >200W output power from a package weighing <400 gr are demonstrated. This module is uniquely suited for airborne application, where a compact and lightweight package is needed for Tm fiber laser pumping.

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