High uniformity and high peak power 808nm QCW laser diode arrays

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ABSTRACT

808nm Quasi-continuous wave (QCW) laser diode arrays (LDAs) have found a wide range of applications in medical, scientific research, defense, surveillance and solid-state laser pumping, printing and others. As a result, the design varieties and upgrades of such products have emerged as prominent topics in the current discourse.

Through a compact structural design and optional independent bar beam shaping, we achieve high-power, high emission density, narrow spectral width, excellent uniformity, and consistent pulsed laser output. The entire product series, namely G-stack and C-stack, allowing for customization of pitch, number and type of bars, output power, wavelength range, overall dimensions, and beam profile according to customer requirements. This product features a highly reliable gold-tin bonding packaging, which ensures the stability and durability of the laser system over a long service life. These products demonstrate reliable operation up to 20% duty cycle.

This article primarily focuses on a sandwich structure as the basic building block for further packaging. Here, eight sandwiches with a pitch of 1.7mm form one subunit, and three units are vertically arranged in a 3×8, 24-bar array configuration. Under a 3% duty cycle test, by bar selection, the output wavelength could be achieved within a range of 808nm±1nm, with a FWHM of less than 3.5nm and peak power exceeding 11 kW pulsed. Additionally, this design showcases exceptional reliability, accumulating over 7000 hours of reliability test data under various conditions. Optically, precise collimation is achieved by employing not only best collimation alignment to the specified divergence using from simple fibers to aspheric cylinder lenses, but also specific pointing angles for each bar's fast axis, resulting in outstanding beam uniformity of 95%.

These high-power and high-uniformity array products find significant applications in scientific research fields, where the uniform laser output yields substantial benefits in crystal absorption and pumping efficiency. This design holds also great potential and benefits in the field of hair removal, serving to the increasing demand and widespread acceptance of laser-based epilation.

Keywords: QCW laser diode arrays, stack, epilation, hair removal, pump stack, high power diode laser stack, reliability, high uniformity, homogeneity, diode bar beam shaping, low pitch stack.

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1. Introduction

High power semiconductor lasers find various applications in industrial, medical aesthetics, aerospace, laser displays, and scientific research. These applications encompass scenarios such as solid-state laser pumping, laser hair removal, skin rejuvenation, laser annealing, surveillance and printing.

In recent years, laser diode arrays have swiftly gained traction in the medical aesthetics market, emerging as the fundamental light source for mainstream hair removal devices due to their broad wavelength range and high conversion efficiency [1]. Notably, visible light and lasers above 1um, though limited by the low power of single-point chip devices, have secured a prominent position in the medical market through stacked bars configurations. Moreover, their utilization in scientific research and defense applications is on the rise, driven by attributes like high peak power, compact dimensions, lightweight, controllable emission uniformity, and customizable spot size, gradually superseding fiber-output laser sources in domains such as scientific research and military security.

These diverse applications often necessitate small and lightweight semiconductor lasers. The most effective technical approaches to reduce overall laser system energy consumption, volume and weight, involve enhancing the electro-optical conversion efficiency, improving packaging structures and optimizing heat dissipation [2]. This article focuses on presenting a pulse semiconductor laser stack product characterized by high uniformity, power, reliability, and a compact footprint, meeting a spectrum of product requirements.

2. Experiment and Design

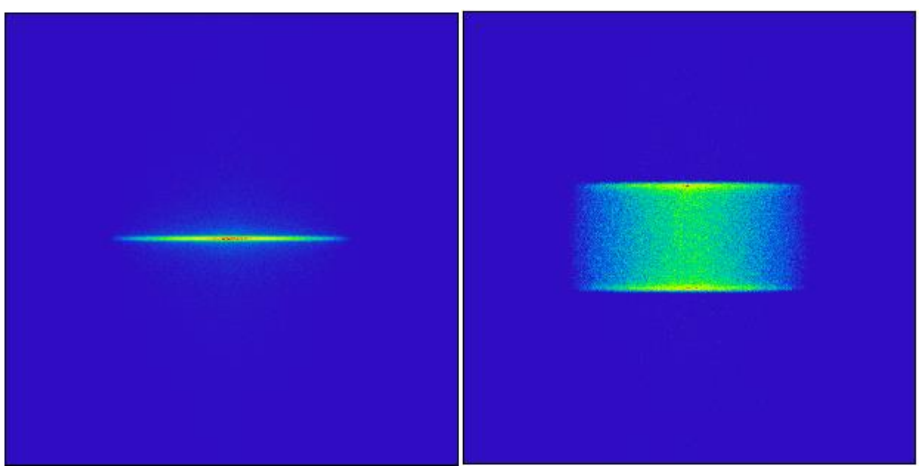
This section introduces a high-power, high-uniformity laser bar stack product comprising of 24 bars, organized into units of 8 bars each. These bars are encapsulated in a Sandwich Bonded Structure (SBS). The SBS design employs a bar bonded between two copper-tungsten heat sinks using AuSn hard solder, providing a sandwich-like configuration. Notably, the thermal expansion coefficient of tungsten-copper closely matches that of the GaAs laser bar, and the thermal conductivity is substantial. The 8 SBS units are affixed to an aluminum nitride ceramic heat sink using a soft solder alloy. With a bar pitch of 1.7mm forming a standard structure, three small units are evenly spaced to create a vertical stack mounted on a macro-channel water-cooled base, facilitating heat dissipation through the backplane of the laser stack [3].

Focused testing of the individual 8-bar units revealed wavelength consistency within ±1nm and exceptional power uniformity, attesting to the robust assurance of packaging uniformity. Post-packaging, coated fibers were deployed as fast-axis collimation mirrors for shaping the fast-axis beams of each bar. The achieved central energy uniformity is 95% and an output power surpassing 11000W.

The macro-channel products discussed herein allow customization of the pitch from 0.4mm to 1.7mm, addressing diverse requirements for product miniaturization, compact spot size, and high output power. The broad potential for future applications is complemented by our company's possession of various laser types to fulfill distinct demands.

3. Results and Discussion

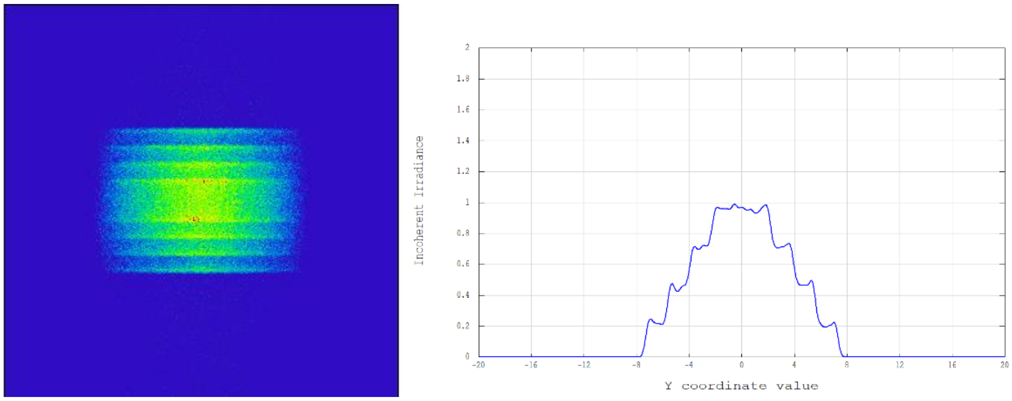
Aligned with the imperatives of compactness and cost-effectiveness, coated fiber optics were validated for use in fast-axis collimation as collimating lenses. To satisfy uniformity requirements for spot distribution at a designated distance, a defocused approach was employed. However, simulation results depicted in Figure 1 illustrate the collimation effects of coated fiber optics at the focus and after defocusing, revealing stronger energy distribution in the upper and lower spots compared to the central spot.



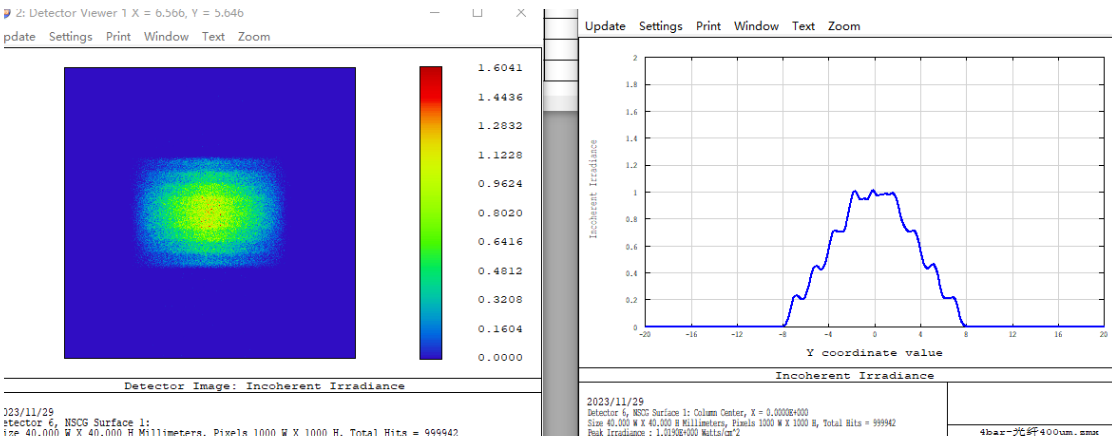
(a) After Fiber Collimation (b) After Defocusing

Figure 1: Simulation Results of Coated Fiber Optics for Fast-Axis Collimation

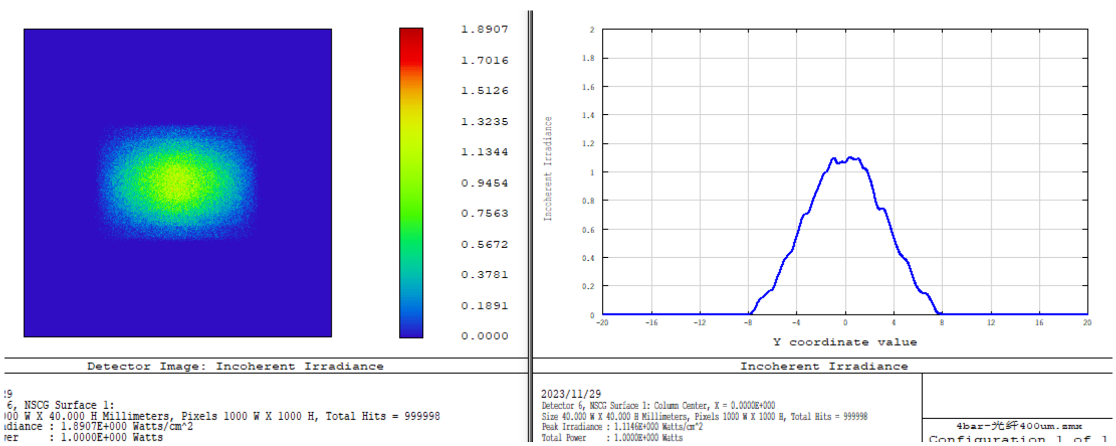
To achieve spot uniformity, simulations were conducted for different fast-axis angles of the bars, as showcased in Figure 2. A 20° fast-axis half-angle yielded spot uniformity closer to the desired specification, confirming the selection of the bar type.



(a) Fast-Axis Half-Angle 30°



(b) Fast-Axis Half-Angle 25°



(c) Fast-Axis Half-Angle 20°

Figure 2: Simulation Results for Different Fast-Axis Half-Angles

The selection converged on bars with a 1.5mm cavity length, a fast-axis half-angle of 20°, and a 75% fill factor. Subsequently, eight 808nm laser bars with a 1.5mm cavity length were packaged using the 8-bar structure, as illustrated in Figure 1, with a bar-to-bar pitch of 1.7mm. To validate welding quality and consistency, multiple 8-bar stack units （in Figure 3）underwent testing and aging under 400A, 3% duty cycle, and 20℃ conditions. The test data, presented in Figure 4, exhibits a normal distribution of overall wavelength data. At a current of 400A, the 8-bar unit achieves an output power exceeding 3800W, as portrayed in Figure 5.

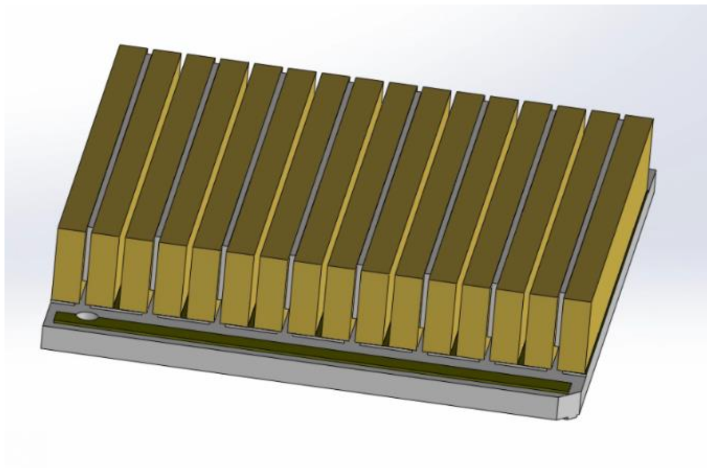


Figure 3: 8-bar stack units

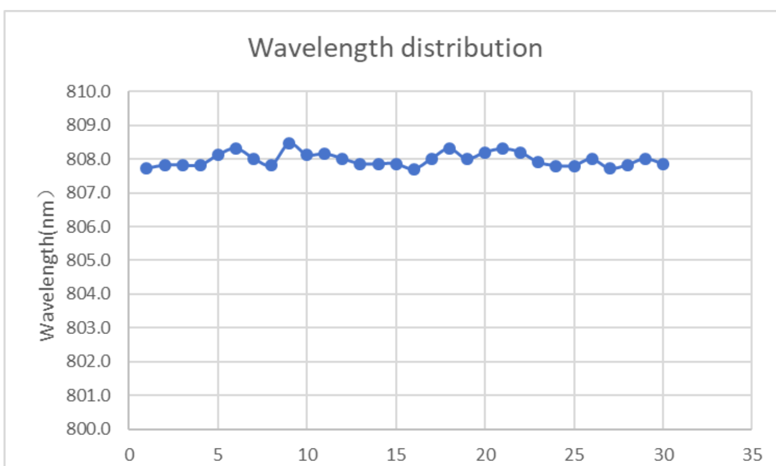


Figure 4: Test data

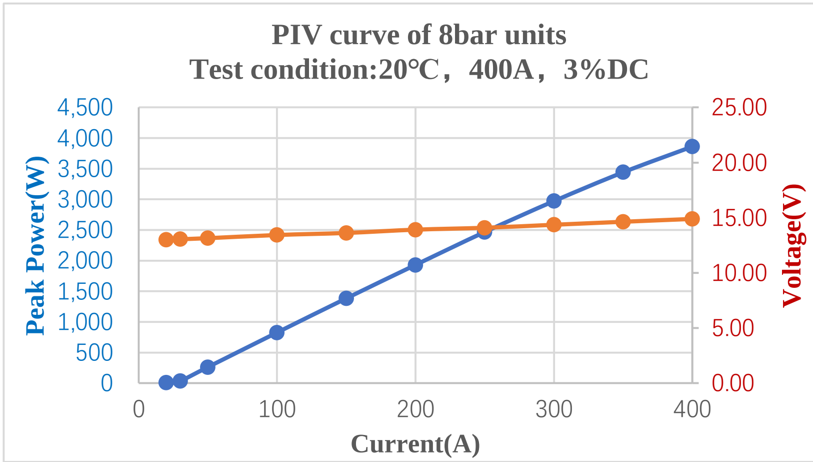


Figure 5: 8-bar unit LIV Curve

Furthermore, the 8-bar units underwent 60°C accelerated aging for 100 hours without any abnormalities, as indicated in Figure 6.

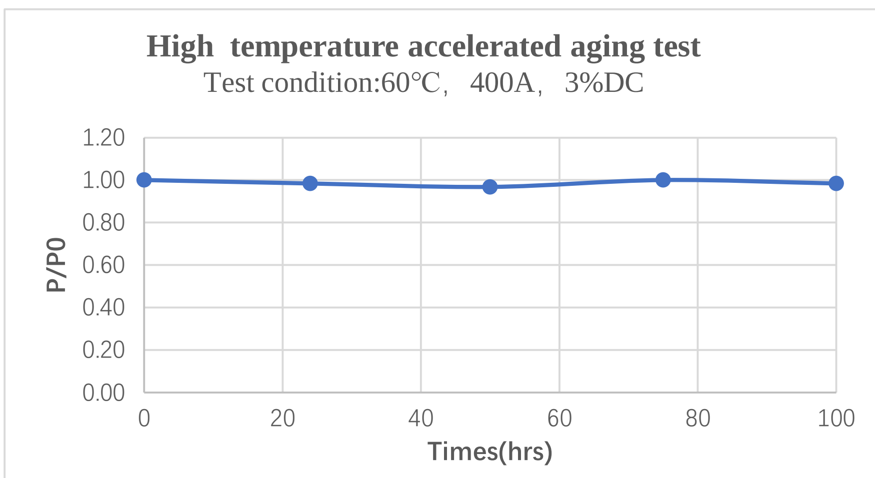


Figure 6: 8-bar units accelerated aging test

Building on the above data, three 8-bar units were encapsulated on a macro-channel water base for overall testing, yielding an output power of 11592W. The PIV curve is shown in Figure 7.

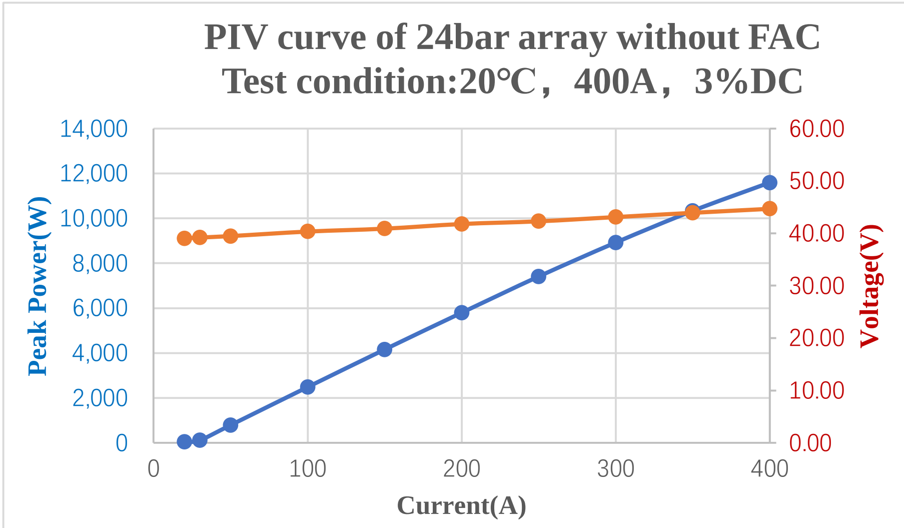


Figure 7: PIV curve of 24bar array

Leveraging coated fibers for fast-axis defocused collimation of each bar (as depicted in the product image in Figure 8), the overall loss was under 2%, with an output power exceeding 11360W, as indicated in Figure 9. Spot uniformity is 95%, and the spot is showcased in Figure 10.

$$\gamma = \left(1 - \frac{\sum|E_i - \bar{E}|}{n * \bar{E}}\right) * 100\% \ \ \text{(90\% energy)}$$

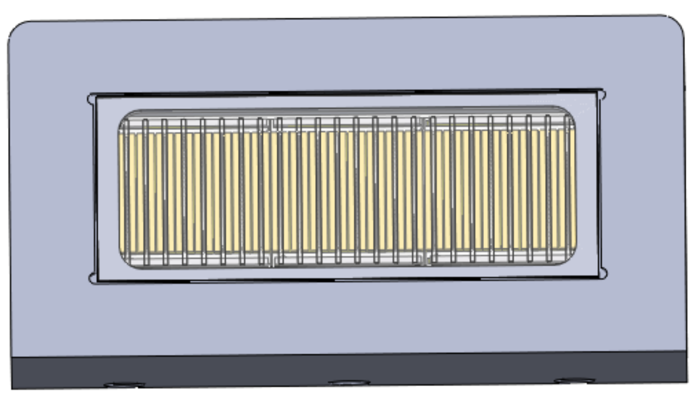


Figure 8: Overall Product Image

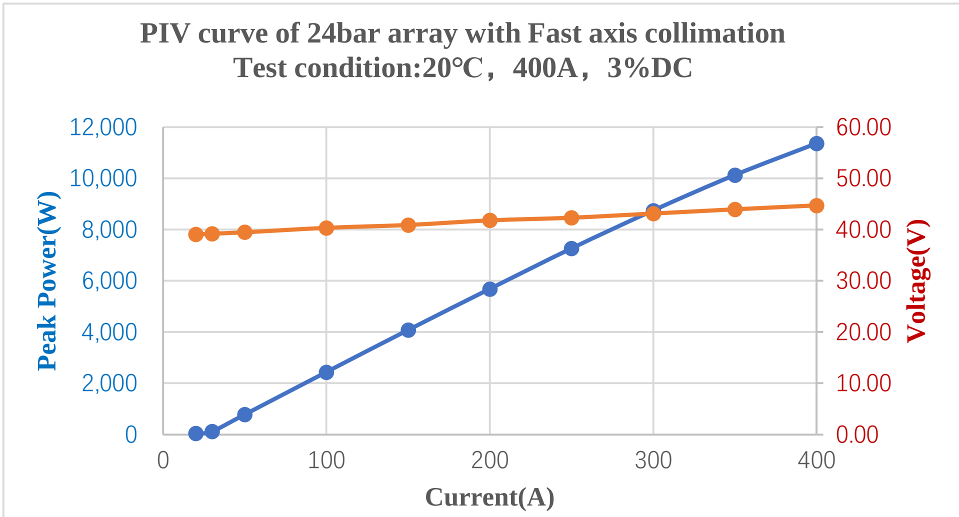


Figure 9: PIV curve of 24bar array with Fast axis collimation

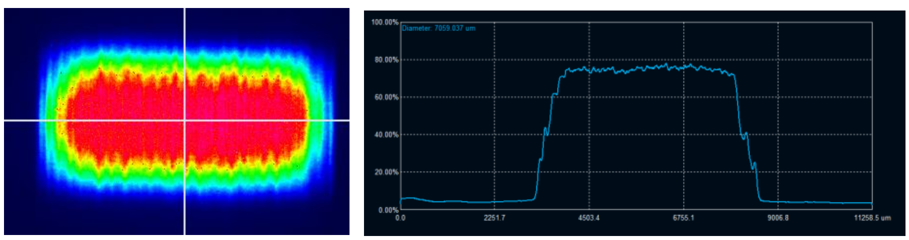


Figure 10: The spot of 24 bar array

The aforementioned diode laser stacks underwent extended-term aging, accumulating reliability data exceeding 7000 hours, as depicted in Figure 11.

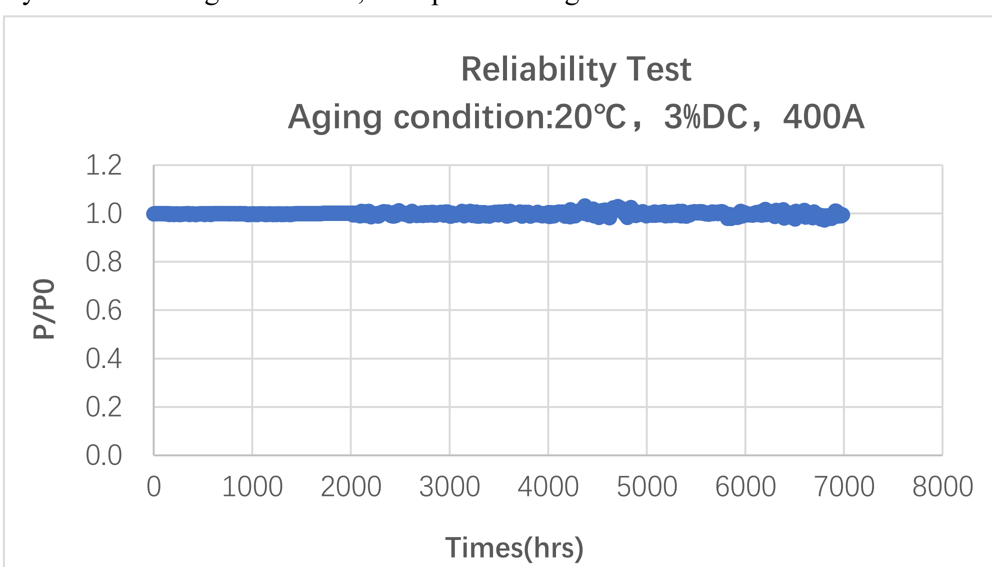


Figure 11: Reliability Test Result

4. Conclusion

In tandem with the continuous advancement of science, medical proficiency, and industrial processing, the demand for high-power laser bar arrays is escalating and diversifying. Varied applications, including hair removal, annealing, and solid-state side pumping, present diverse requirements that can be met through customized parameters such as power, spot uniformity, wavelength, and spectral width.

The product highlighted in this article, featuring an output power exceeding 11KW, wavelength accuracy controlled within ±0.5nm, uniformity is 95%, and a continuous life test surpassing 7000 hours under high-temperature conditions, holds promise for diverse application scenarios. Additionally, it can achieve higher peak power through combinations, catering to various types of application scenarios.

References:

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2、High-power, high-efficiency 808 nm semiconductor laser array∗
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