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Investigation on the performance of high power long pulse laser diode arrays for hair removal and illumination

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ABSTRACT

By designing a lightweight and compact stacked bar package, we can achieve high-power, high-brightness, and high-stability pulse laser output. The laser diode package consists of eight 1cm high power laser bars, which are bonded between two copper-tungsten heat sinks with AuSn hard solder like a sandwich. These sandwiches are bonded in a second soldering step on a backplane macro-channel cooler. The package structure is very compact and lightweight. We can achieve different frequency, pulse width, duty cycle combinations, which easily allows to adapt to different applications.

In this paper, the performance of 808nm and 940nm laser bars is verified under different conditions: The pulse width is varied from 5 to 300ms, and the frequency range is between 1Hz to 10Hz. Resulting duty cycles range from 10% to 40%.

In addition this structure can combine two or more wavelengths (808nm and 940nm, 760 and 1060 optional). We achieve 1788W under the condition of 5ms, 10%DC, 200A. This compact and powerful 2D diode laser array with mixed wavelengths is very suitable for laser hair removal. It can not only fully act on the melanin of the hair follicle, but also coagulate the micro vessels around the hair follicle to cut off the blood supply of the hair follicle. With the right combination of wavelength, the penetration depth and absorbtion characteristics can be tailored to the different skin types from white to dark skin, avoiding skin irritation and pain.

For pulsed pumping applications or far field illumination, FAC lenses can be applied to allow for best beam brightness. The package can be designed from single bar to 12 bars, depending of the power demand for the individual applications. Dense packaging of more than one stack in one laser unit allows high application power of multiple kW in a compact handpiece design for hair removal.

Keywords: QCW laser diode arrays, High pulse, High power, Reliability, hair removal, epilation, laser illumination, diode laser stack, pump stack

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1.INTRODUCTION

Quasi-continuous wave (QCW) laser diode arrays (LDAs) have found a wide range of scientific research, industrial, medical, military and space applications including solid-state laser pumping, printing, lighting and so on. In recent years, the application of laser diode arrays has developed rapidly in the medical cosmetic market and has become the core light source of mainstream hair removal instruments, because of its wide wavelength range and high conversion efficiency[1]. The specific use conditions depend on the needs of application scenarios: frequency, duty-cycle and pulse duration.

The mechanism of laser hair removal is based on selective photo thermolysis theory. The semiconductor laser hair removal mainly thermally destroys the hair follicles in the growing stage by absorbtion of the laser light in the follicle's melanin to achieve clinical hair removal effect. It has good tolerance to people of different skin colors, and has adjustable pulse width, energy and irradiation time.

Multiwavelength array can not only fully act on the melanin of the hair follicle, but also coagulate the micro vessels around the hair follicle to cut off the blood supply of the hair follicle, and so further improve the effect of hair removal.

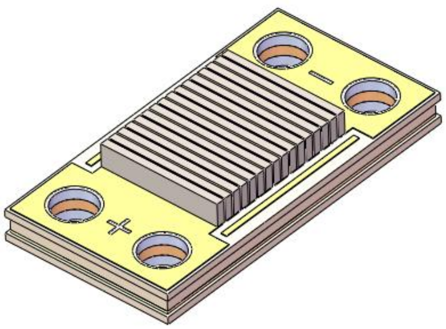
To adapt the stack as a pump source for a solid state laser crystal and for achieving a well and evenly distributed pump irradiation, the sandwich structure can be customized according to the tungsten-copper thickness, such as 0.9mm,1.1mm,1.7mm. A smaller pitch compared to classic microchannel stacks can be achieved and the pump power intensity can be increased.

Under the condition of high power pump operation, the distortion of the optical beam path of the signal beam in the crystal caused by the temperature gradient distribution in the gain medium plays a dominant role. The distortion caused by the thermal lens effect will lead to the instability of the output power and the coupling between various modes. At the same time, the improvement of the power of the laser is limited, and the performance of the solid-state laser is seriously affected. Quasi-continuous-wave operation of a laser diode means that its pump source is switched on only for certain time intervals being short enough to reduce thermal effects significantly, but still long enough that the laser process is close to its steady state [2]. Therefore, working in QCW mode can effectively reduce thermal lensing effect damage due to overheating[3].

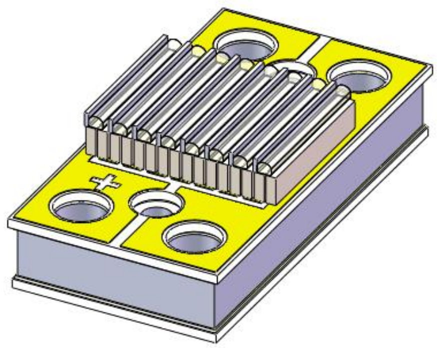
2. Experiment and design

LDAs introduced in this paper are composed of different number of SBS bar structures (A unit consists of a maximum of 12 bars). The SBS structure uses a bar which is bonded between two copper-tungsten heat sinks with AuSn hard solder like a sandwich, the thermal expansion coefficient of tungsten-copper is close to that of the GaAs laser bar, and the thermal conductivity is high. A certain amount of SBS is bonded on the macro channel heat sink with SnAgCu solder. The structure is designed to dissipate heat by cooling the backplane of the laser stack[4].

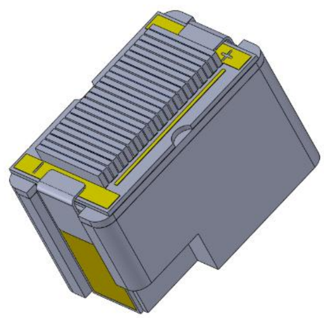
The custom size and shape of the macro channel heat sink allows for an easy adaption to different usage requirement. In this paper, three kinds of macro channel heat sinks are used to test the relative performance. The three structures are shown in Figure 1. It can also integrate multiple stacks to form higher power products, which is shown in Figure 2. Three small units are grouped together and mounted on a water base.



(a) 8bar structure-a



(b) 8bar structure-b



(c) 12bar structure

Fig 1. three kinds of structure

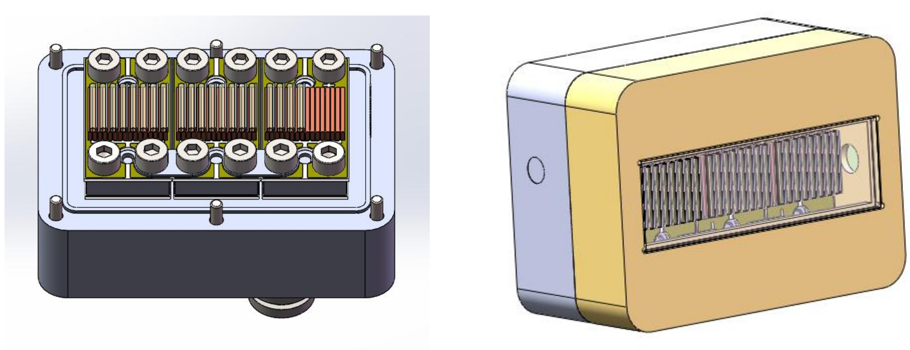


Fig 2. higher power products with three units

Based on the above structure design, 808nm and 940nm laser bars were packaged and tested. The performance of LDAs were tested under different frequency pulse width conditions: The pulse width is varied from 5 to 300ms, and the frequency range is between 1Hz to 10Hz. Resulting duty cycles range from 10% to 40%. And the test results are analyzed and processed.

3. Results and discussion

At first eight 808nm laser bars with 1.5mm cavity length were packaged using the 8bar structure - as shown in Figure 1, bar-to-bar pitch is 1.7 mm. Test conditions are shown in Table 1.

Table 1. 8bar 808nm LDAs test condition

frequency(Hz)	pulse width(ms)	duty cycle(%)
1	400	40
1	300	30
1	200	20
2	200	40
1	100	10
2	100	20
3	100	30
4	100	40
2	50	10
4	50	20
6	50	30
8	50	40
5	20	10
9	20	18
10	10	10
10	5	5

The peak power of the 8bar, 808nm LDA under different duty cycle is shown in Figure 3. Due to the limitation of the power supply at long pulse length, the maximum current is tested to 150A. The test shows best linearity under the condition of 5ms-10Hz, and the power of 1430W can reach at 150A. Under the condition of 20ms and 5Hz, the test can be run up to 200A and the power can reach 1620W. This condition is widely used in hair removal at present, the PI curve is shown in Figure 4. The peak power at 90A current under different conditions is also compared. As shown in Figure 5, the smaller the frequency, pulse width and duty cycle, the higher the power.

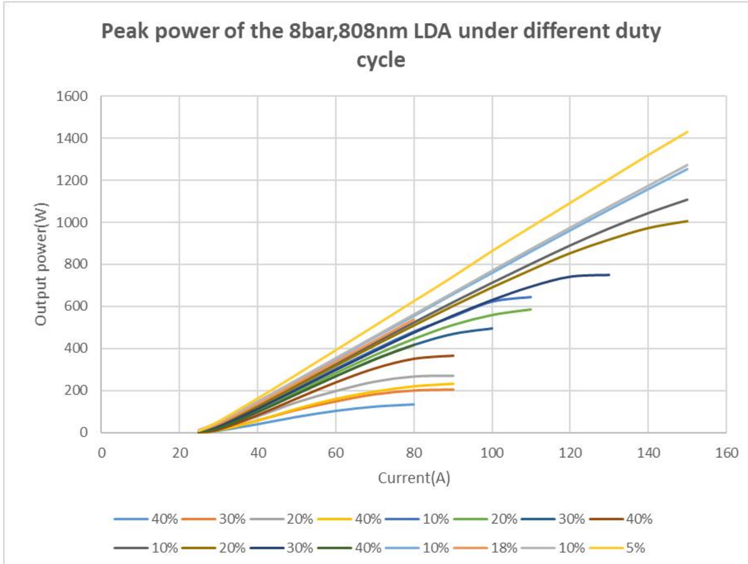


Fig 3. peak power of the 8bar, 808nm LDA under different duty cycle

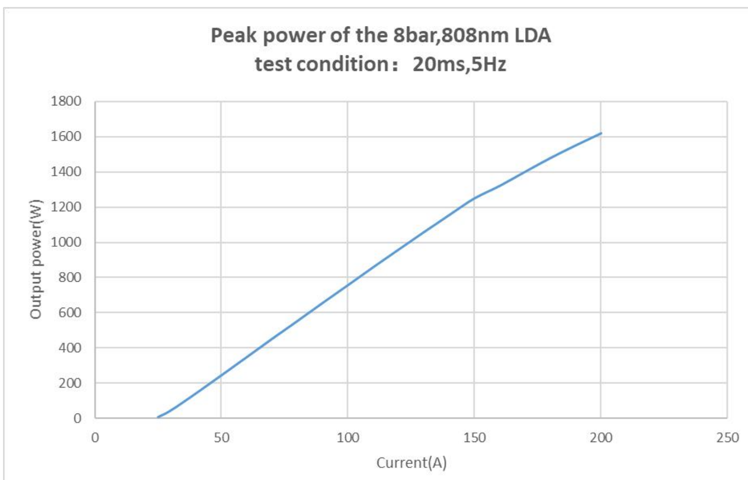


Fig 4. Peak power of the 8bar,808nm LDA under 20ms,5Hz

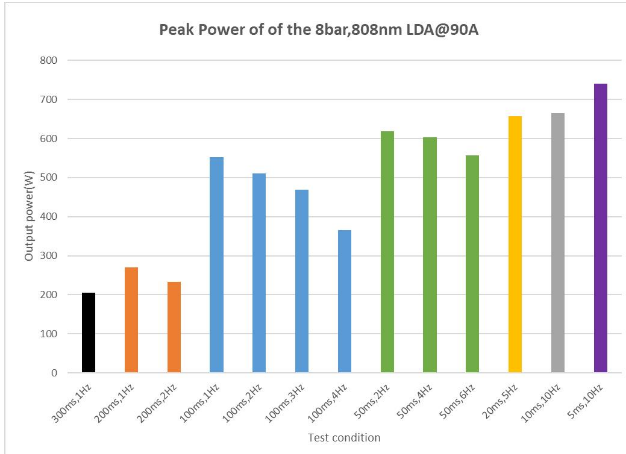


Fig 5. Peak Power of the 8bar,808nm LDA @90A

FAC lenses were applied to allow for best beam brightness. The pointing tolerance is less than 0.5mrad, the fast axis divergence angle is less than 6mrad. The light spots at different positions are shown in Figure 6

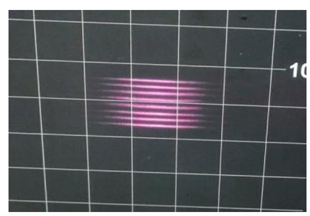
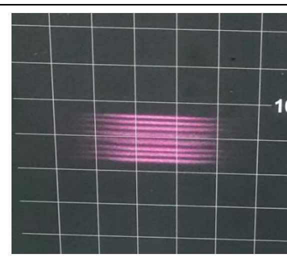
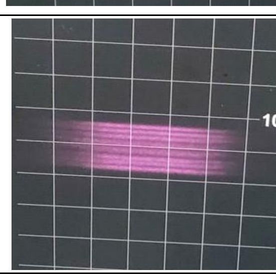
directivity	< 0.5mrad
SA divergence angle	6mrad
100mm	
200mm	
300mm	

Fig 6. Light spot of the 8bar,808nm LDA

With the same structure, eight 940nm bars with 1.5mm cavity length were packaged and tested shown in Figure 7 and Figure 8, performance is different due to the difference in electro optical efficiency and it's thermal impact for 808 and 940nm bars. For the 940nm LDA, the power difference of the same pulse width and different duty ratio doesn't change significantly within 100ms, the smaller the pulse width, the lower the power. When tested at 10ms,10Hz,10%DC and 150A, the peak power reaches 1260W.

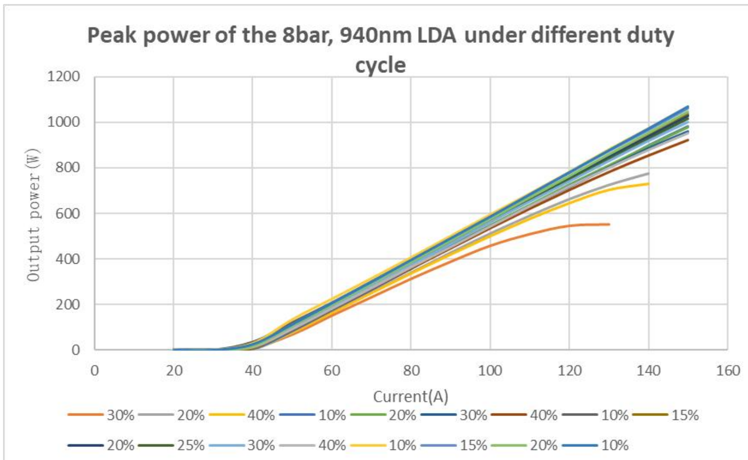


Fig 7. Peak power of the 8bar, 940nm LDA under different duty cycle

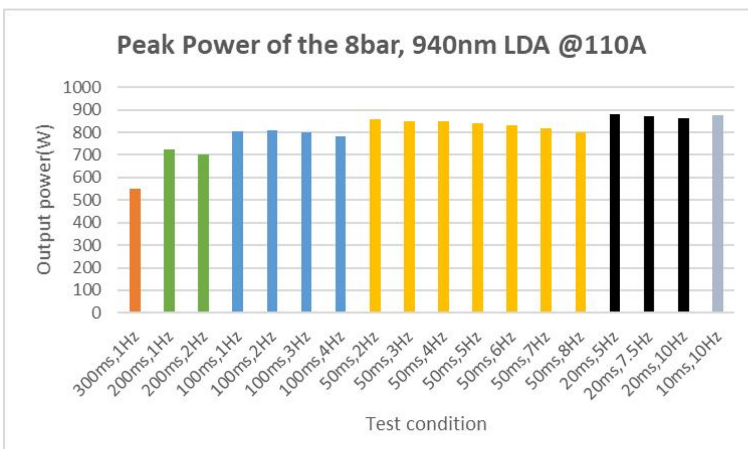


Fig 8. Peak Power of the 8bar,940nm LDA @110A

Based on the above 808nm and 940nm laser bars, a laser array of mixed wavelength was made with seven 808nm and one 940nm laser bars. This high-power semiconductor laser of mixed wavelength is representative for a laser hair removal stack, which can combine the effects laser absorbtion in the melanin of the hair follicle at 808nm, and also coagulation of the microvessels around the hair follicle at 940nm, to further enhance the effect of the epilation. We achieve 1788W under the condition of 5ms, 10%DC, 200A shown in Figure 9.

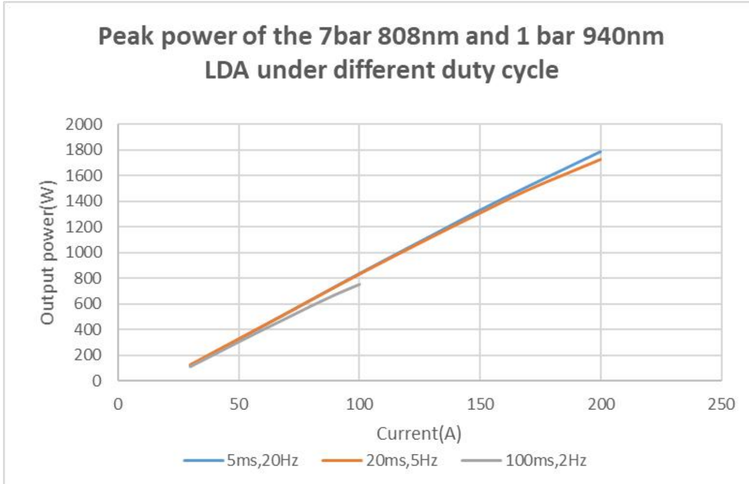


Fig 9. Peak power of the 7bar 808nm and 1 bar 940nm LDA under different duty cycle

Finally, three compact stack units of 8 bars of structure-b were installed on a common water cooling base to make a 20 bar LDA (2x8 bars at 808nm and 4bars at 940nm), the peak power under 20ms 5Hz was shown in Figure 10. The peak power at 150A is 3101.55W. And the collimated beam pointing is less than 0.5mrad, the fast axis divergence angle is less than 6mrad. The light spots at different positions are shown in Figure 11.

Fig 10. Peak power of the 14bar 808nm and 6bar 940nm LDA under 20ms,5Hz

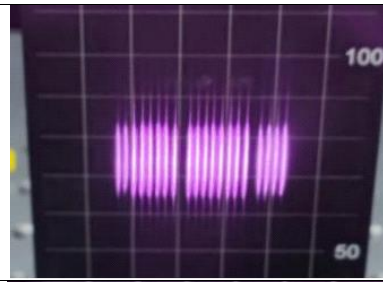
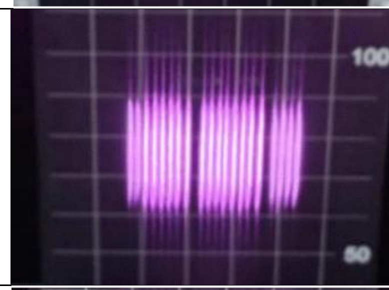
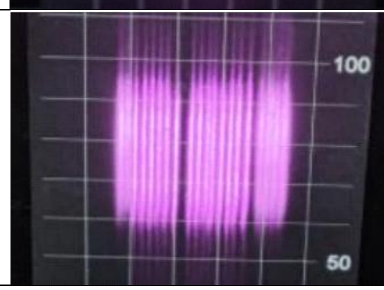
directivity	< 0.5mrad
SA divergence angle	6mrad
100mm	
200mm	
300mm	

Fig 11. Light spot of the 20bar, 808nm and 940nm LDA

4. Conclusion

In the medical application of laser, pulse width refers to the duration of the laser radiation or photon action on the skin surface, like a dose rate. Short high intensive pulses absorbed by the skin for rejuvenation applications. Long pulse widths are designed to penetrate the surface of the skin to the hair follicle layer and thermally destroy them, to avoid further hair growth. These products have been tested for long and short pulse widths and are compatible with a wide range of applications.

For 808nm LDA the smaller the frequency, pulse width and duty cycle, the higher the power. we achieve:

1620W under the condition of 20ms,5Hz,10%DC, 200A;
1430W under the condition of 5ms,10Hz,5%DC, 150A;
1108W under the condition of 50ms,2Hz,10%DC, 150A;
1006.5W under the condition of 50ms,4Hz,20%DC, 150A;
750.7W under the condition of 50ms,6Hz,30%DC, 130A.

For 940nm LDA, the power difference of the same pulse width and different duty ratio is not significant within 100ms. we achieve 1260W under the condition of 10ms, 10Hz, 10%DC, 150A.

For 7bars at 808nm and 1bar at 940nm LDA, we achieve 1788W under the condition of 50ms,2Hz,10%DC, 200A.

Product for 3units combination:14bars at 808nm and 6bars at 940nm LDA, we achieve 3101W under the condition of 20ms,5Hz,10%DC, 150A.

The above laser operation bands reflect the use of laser hair removal and medical cosmetics applications, to meet the needs of different conditions. We can also adjust the design of aluminum nitride ceramics, thermal conductivity and macro-channel structure design, as well as different bar types and test conditions to adapt to different application scenarios, to meet the requirements of total power, intensity distribution, wavelength effects and beam shaping.

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