Wavelength tunable, 264 J Laser Diode Array for 10 Hz/1ms Yb:YAG pumping

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Abstract. The Lucia [1,2] Laser program, under development at the LULI laboratory, aims at delivering a 1030 nm, 100J, 10 Hz, 10 ns pulse train. The two laser heads used in the amplification stage relies on water-cooled mm-thick Yb:YAG disks, each of them pumped by a 34x13 cm² Laser Diode Array (LDA). For each LDA, the 88 QCW diodes stacks manufactured by DILAS GmbH will be tiled in an 8x11 arrangement. Fine wavelength tuning is performed through bias current adjustment, water temperature control and conductivity adjustment. Wavelength homogeneity experimental verification has been validated.

1. Overview of the Lucia project

Lucia is a Diode Pumped Solid State Laser (DPSSL) being built at the LULI laboratory, the national civil facility for intense laser matter interaction in France. It relies on the Yb³⁺ lasing ion hosted in YAG and is designed to deliver a 100 Joules, 10 ns, 10 Hz pulse train at 1030 nm.

Figure 1. Extraction layout and emission observation for 9 stacks simultaneously operated.
Extraction architecture is displayed on figure 1 (left). A sub-Joule pulse train generated by the front-end oscillator will be amplified in 3 passes through a pair of amplifiers pumped by LDA of 4400 diode laser bars. Deformable mirrors and amplifiers will be image-relayed.

When frequency converted, the output 1030 nm, 100 Joules, 10 ns, 10 Hz pulse train will be an efficient pump source for high repetition rate petaWatt class solid state laser like OPCPA [3] or Titanium-sapphire laser chains. Such sources could have indirect applications in protontherapy for instance. In the field of laser-matter interaction physics, Lucia will motivate the development of high repetition rate targets and diagnostic capabilities.

2. Laser Diode Arrays

The diodes panels or LDA (figure 1-right) are manufactured by DILAS, GmbH; one panel is required per amplifier head. Each of them is paved by 88 stacks distributed over 8 columns of 11 stacks. Each stack is made of 25 diode bars, leading to a total number of 2200 bars able to deliver a maximum of 264 kW peak power (or 264 J). This energy will be concentrated onto a ~10 cm² gain medium with a ~20 kW/cm² brightness.

The vertical gap (slow axis) between two adjacent stacks is equal to 2 mm whereas the horizontal gap (fast axis) is equal to 4.3 mm. Comparing the 39.2x10 mm² individual stack emissive area with the global 343.7x130 mm² LDA emissive area, one reaches a 77% fill factor value.

The 88 stacks are fixed onto a water-cooled copper plate and are driven with a 10 Hz, 1 ms, ~130 A square electrical signals with a DC offset varying between 0 and 1 A (see section 2.2). The wavelength target is 941 nm and figure 2 shows the peak wavelength and associated spectral bandwidth distributions for 35 stacks.

2.1. Wavelength control with water temperature

Stack individual emission wavelength can be adjusted through the coolant temperature (see figure 2-right). In our case we have individual water temperature adjustability only for our 4 stacks front end. But such flexibility was not kept for the LDA backplane in order to simplify the LDA design as well as the cooling unit (a single water channel instead of 88). Taking into account room temperature and due point value, a 25°C temperature was chosen for the circulating water.

2.2. Wavelength control with bias current local heating

Diode light emission efficiency is usually characterized by the optical power (Watts) versus driver current (Amperes) P(I) curve displayed on figure 3 (left). Typical slope for the stacks under consideration here is 27W/A. Stacks start emitting when a 15A current threshold is reach. Below that
I_{Th} value, most of the energy is converted into heat. We are here taking advantage of such threshold behavior to give ourselves an alternative way to control the emission wavelength. Indeed, our stacks are operated in the 1 ms/10Hz QCW regime (purple curve reaching 130 A on the right graph of figure 4). A DC offset (bias current) is added on top of the pulsed electrical driving signal. The value of this I_{BIAS} current is carefully kept much below I_{Th}. By precisely (5 mA accuracy) tuning I_{BIAS}, it is then possible to finely adjust the quantity of heat added to the diode junction. Since the diodes emission wavelength is increasing with junction temperature, this offset current offers us an accurate way for emission wavelength tuning.

![Figure 4](image)

**Figure 4.** P(I) curve of a typical stack where the ~15 A threshold can easily be located. Schematic diagram (right) showing driving AC current (oscillating purple curve) and DC bias current (bottom green horizontal line).

Typical bias current required for our stacks is around 200 mA (figure 5) taking into account the 0.012 nm/mA spectral shift/I_{bias}. Our electronic drivers are design to operate with a maximum bias current of 500mA.

![Figure 5](image)

**Figure 5.** Bias current required to reach the 941 nm target wavelength while operating the LDA at 25°C and ~130 A. The dash line show the 500 mA hardware limit of our drivers. The three stacks for which more than this limit would be required will need conductivity adjustment as described in section 2.3.

2.3. Wavelength control through conductivity adjustment

Figure 5 shows that 3 stacks would request an excessive bias current in order to emit at 941 nm while being cooled with a 25°C water. A third possibility is available in order to overcome such issues. We can indeed adjust the thickness (~200 μm) of the thermally conductive graphite foil located below the stack heatsink.
3. Spectral homogeneity experimental assessment

A series of experimental tests was performed in order to verify if we could get all 88 stacks operating at the same peak wavelength. Figure 7 shows the spectrum of a stack located on column D in position 10 for different environments. We observed that the central wavelength shift is mainly caused by two mechanisms:

- heating of the coolant flowing behind the stack mount (in the order of 0.1 K per emitting stack).
- heating by the neighboring stacks in its column (in the order of 0.3K/stack).

Taking into account:

- the typical thermal chirp observed on our stacks ($\Delta \lambda_T = 0.37$ nm/K),
- their 0.012 nm/mA spectral shift/$I_{\text{BIAS}}$ typical value,
- the 5 mA accuracy available with our drivers,

we do not forecast any difficulties in achieving the requested spectral homogeneity of 941 nm +/- 0.5 nm for our LDA.

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References

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