OSRAM PL530 OPSL Laser Project

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Nightlase Technologies – www.nightlase.com.au

Abstract – This document details the project undertaken to construct a stable, Single Longitudinal Mode (SLM) laser source for exposing holographic film plates such as the LitiHolo C-RT20 instant films. The Osram PL530 is an Optically Pumped Semiconductor Laser (OPSL) device that was originally developed for Pico laser projectors and mounted into an RGB "Light Engine". The PL530 can be "coaxed" into SLM operation through very careful control of temperatures.

Introduction

The PL530 is an incredibly small and very impressive device measuring only 14.15mm x 6.75mm x 4.3mm, and capable of stable 50mW-120mW SLM 530nm (Green) output.

To achieve stable output, the laser must be carefully controlled. The operating requirements are 1.8V at 450mA for the pump diode. The PPLN (Periodically Poled Lithium Niobate) crystal temperature is controlled using an internal heater element which has a resistance around 25Ω (range may be between 27Ω - 32Ω or higher). The PPLN is the most crucial element that needs to be fine-tuned and kept stable. The PPLN Heater (PTC) current must not exceed 80mA.

Finally, the device needs to be mounted onto a thermal-electric cooler (TEC), and feedback provided by a thermistor (NTC) to maintain contact temperature.

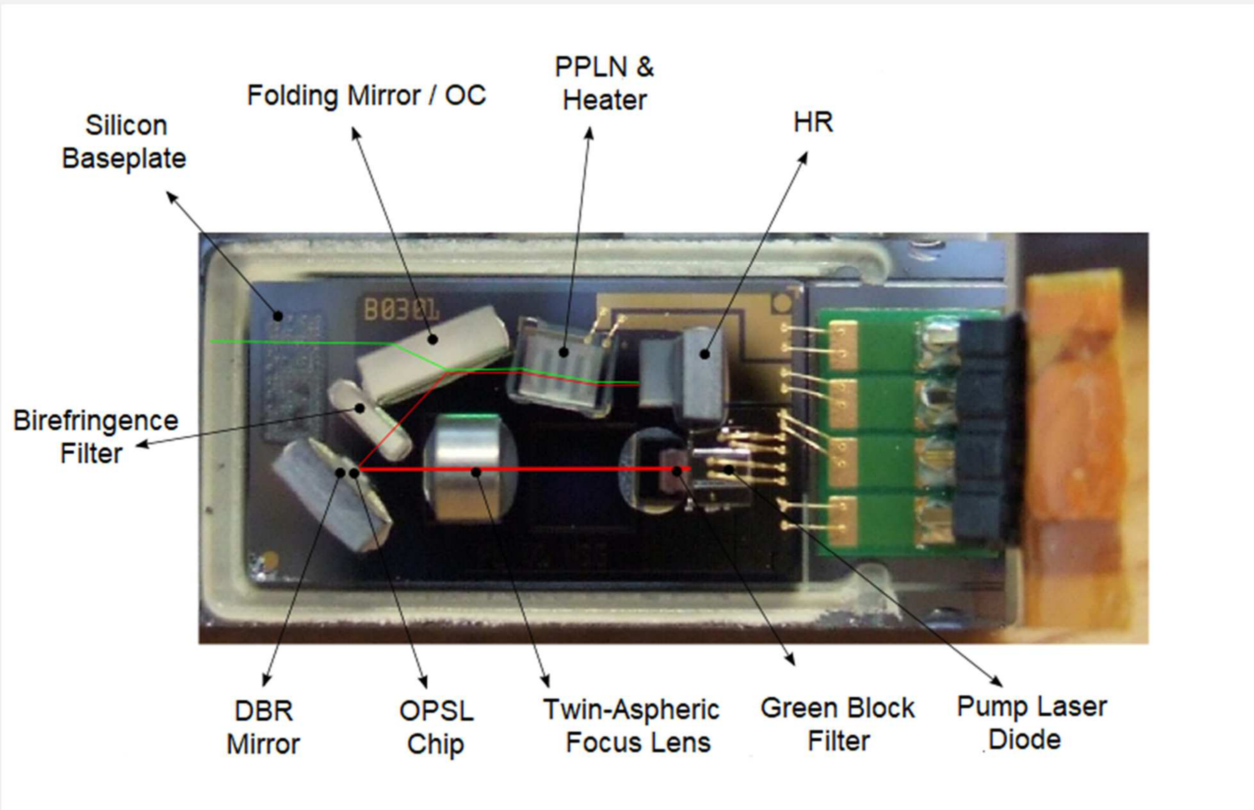
In total, 3 drivers are required to operate the laser.

PL530 Laser & Peltier (TEC), 24 August 2022

I ordered two PL530 Devices on 9th February 2022.

PL530 Internal layout and identified components

Below – Two images; author unknown. Ref: *Experimental Engineering*

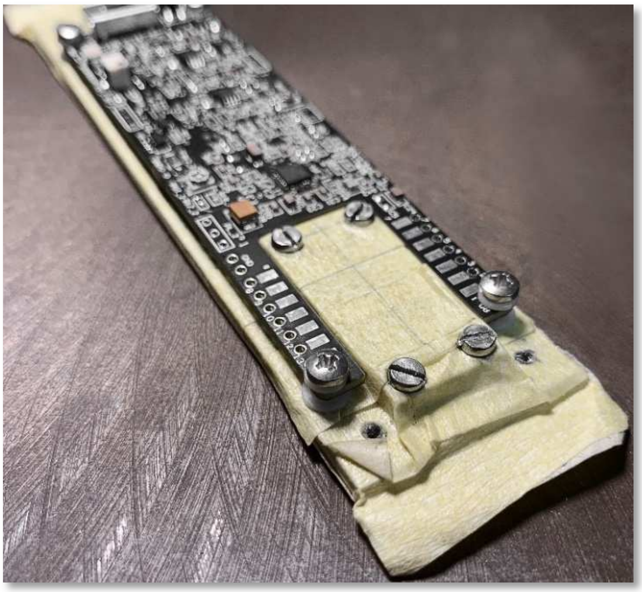


Laser Driver & Construction

To operate these lasers in SLM regime, the temperature and operating conditions must be carefully controlled, something that requires dedicated driving circuits to manage both current and thermal conditions. This alone required some study and research.

In early August, while searching on Ebay, I came across a driver board that was designed to operate these lasers. Investigating further, I narrowed down the manufacture, *Power Drive Controls*, where after some discussions with the owner, Dasheng, placed an order for a driver board as well as a TEC and thermistors, The order was received within two weeks of dispatch.

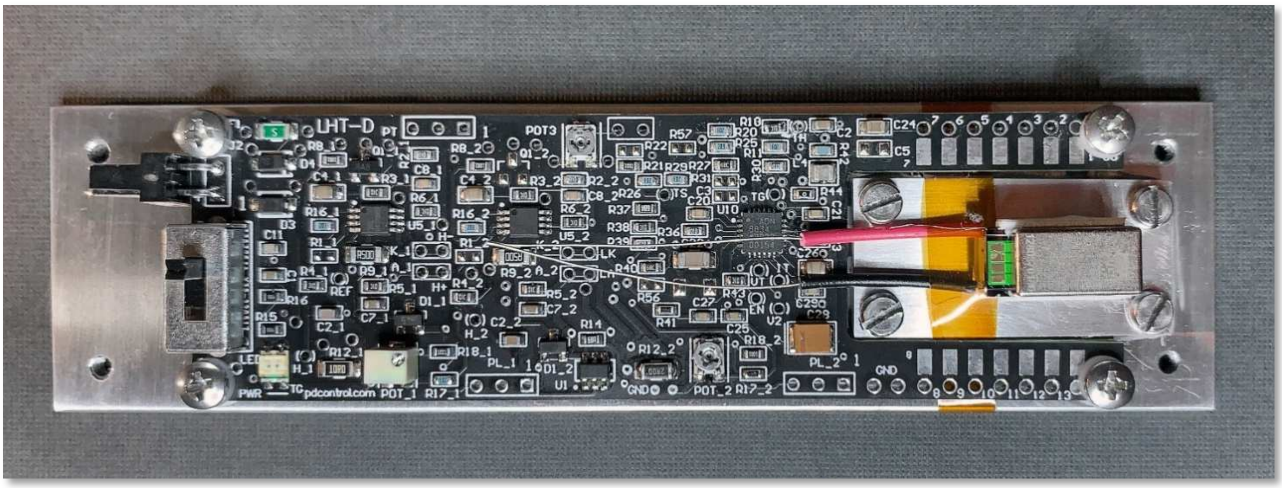
I have to say, that dealing with Dasheng at Power Drive Controls has been one of the best customer service experiences that I have ever encountered from a US company, and the immense support and guidance has been invaluable.



The driver board that was selected is the LHD-94. This features 3 PID drivers (closed loop) to control the Laser Diode current, PPLN Heater and external TEC. The board measures 94mm x 29mm.

I began setting out on the project development on 24th August 2022 researching how to mount the very tiny thermistor as well as the overall mounting of the laser module, TEC and driver board. The Design and construction of the base of the module commenced on 22nd September 2022. Two aluminium sections; a 32mm x 120mm for the main base, and 15mm x 32mm for the small plinth. M2.5 threads for screws.

Above - Engineering of Baseplate & Mount – 26 September 2022.

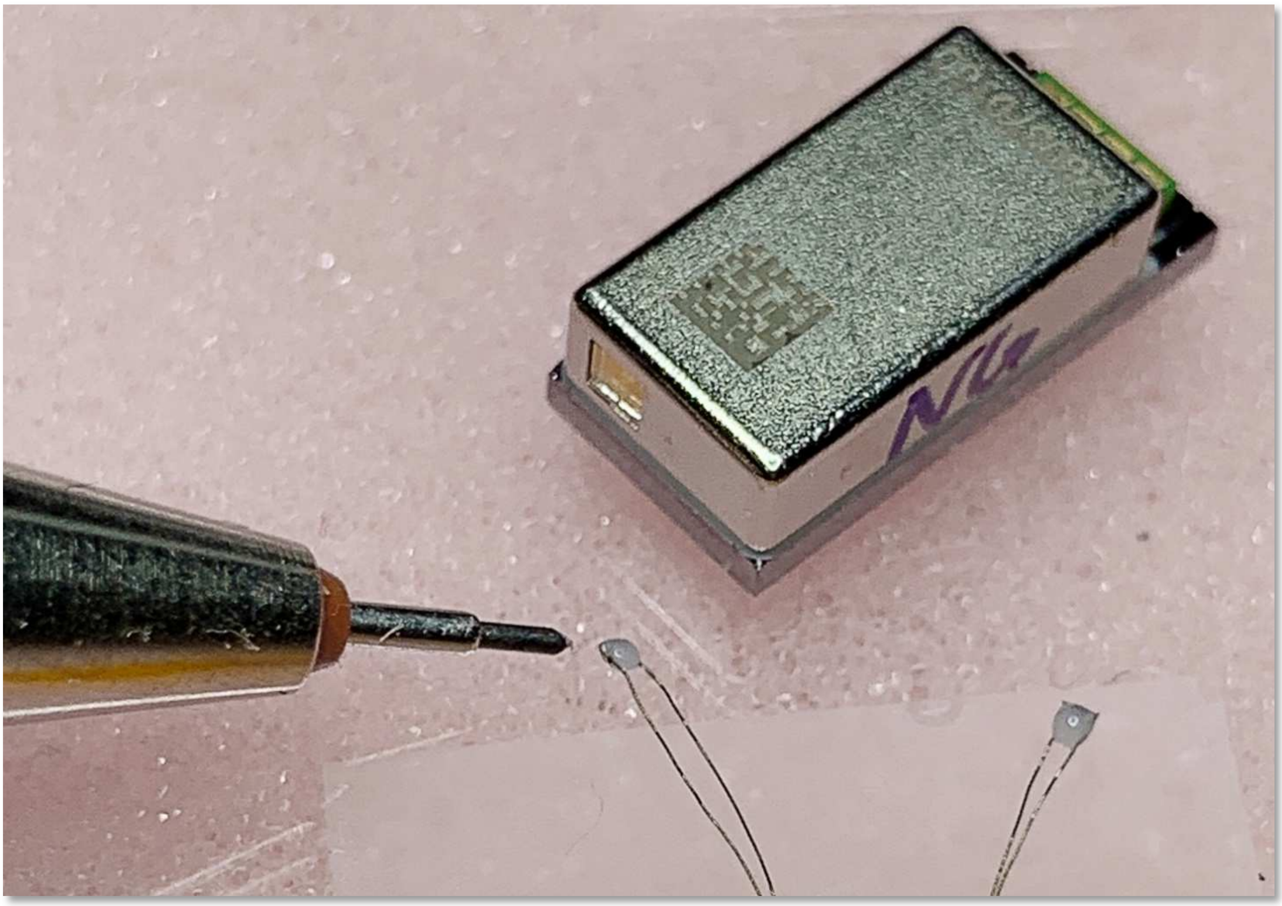


LHD-94 Driver board - 26 September 2022.

Some considerable time was spent researching thermal interface materials (TIM) required for mounting the Laser, TEC and Thermistor (NTC) to a base and then a heatsink. One of the critical specifications is the Thermal Conductivity in W/m.K, the efficiency of the material to conduct heat.

When received the thermistors, the first reaction is the incredibly small size of the device, less than 1mm diameter, with wires several times smaller.

Attaching the NTC would become a challenging part of the project as well as the fine soldering required.



Glass Bead Thermistor, with 0.7mm lead for scale - 12 September 2022.

Researching various interface materials including epoxy / adhesives, and thermally conductive tapes, it was found that the best thermal conductive materials are heat transfer pasts followed by tapes.

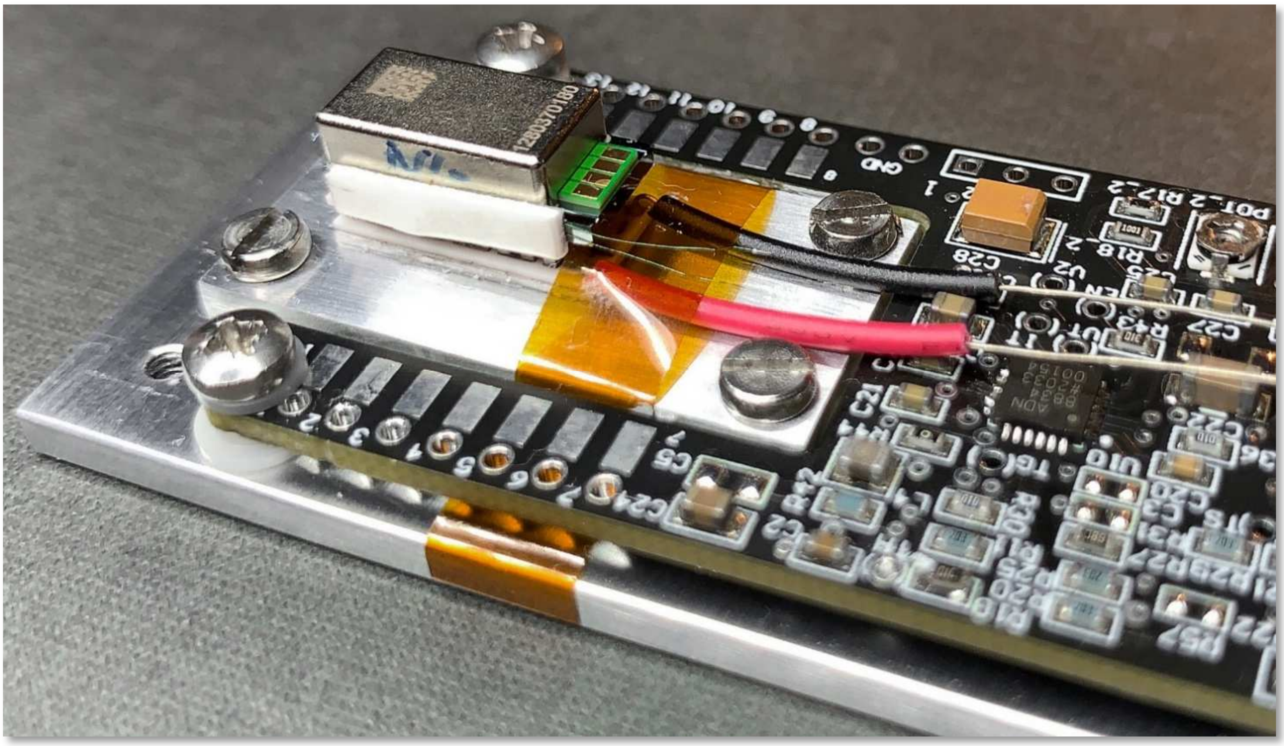
Most thermal adhesives I found, their thermal conductivity typically around 0.6W/m-k to at best 4W/m-k, and are very expensive, even more difficult when only a very tiny amount is required.

For attaching the PL530 to the TEC and TEC to Aluminium base, I found that our local supplier, Jaycar Electronics stocks a 100mm x 100mm x 0.5mm sheet of L37-5 Silicon thermally conductive pad with very good thermal conductivity of 1.6W/m.K, and easily available. The part number: NM2790.

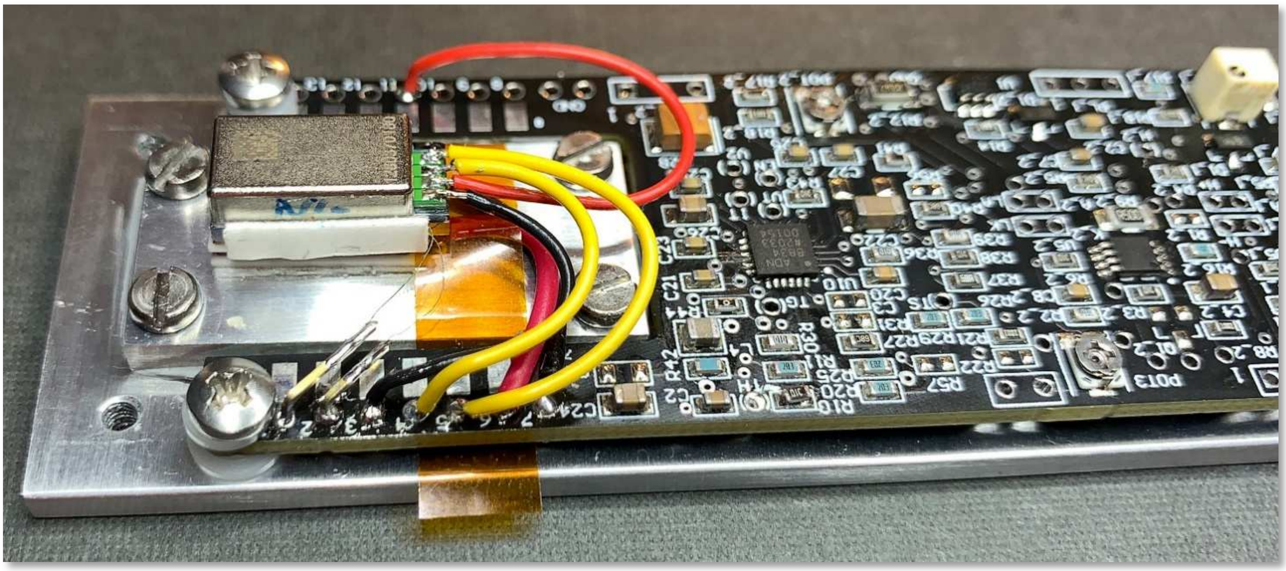
NTC Mounting & Connection

Perhaps one of the most daunting tasks was dealing with the shear small scales of the connections required both on the PL530 laser but more so the NTC thermistor with its wires of less than 0.1mm.

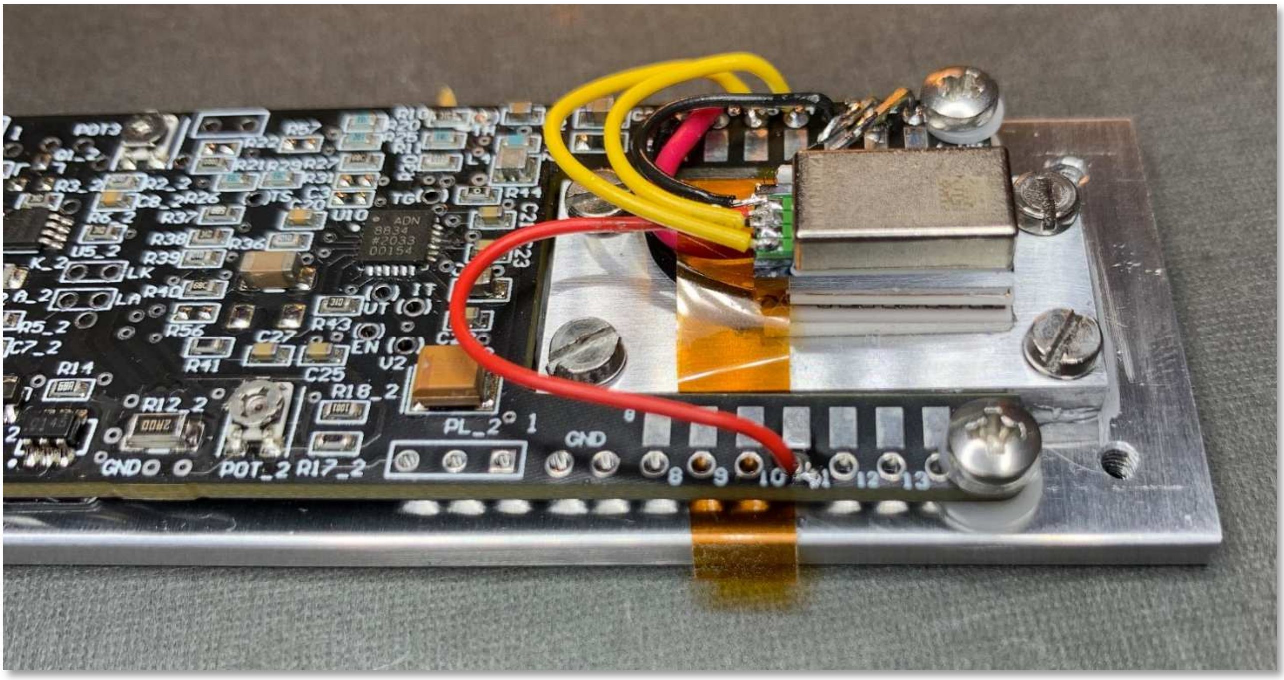
Initially, the NTC was mounted in contact with the PL530 silicon baseplate and thermal tape attached, however, later would prove problematic.



Above - Mounted NTC, Attempt 1 - 26 September 2022.



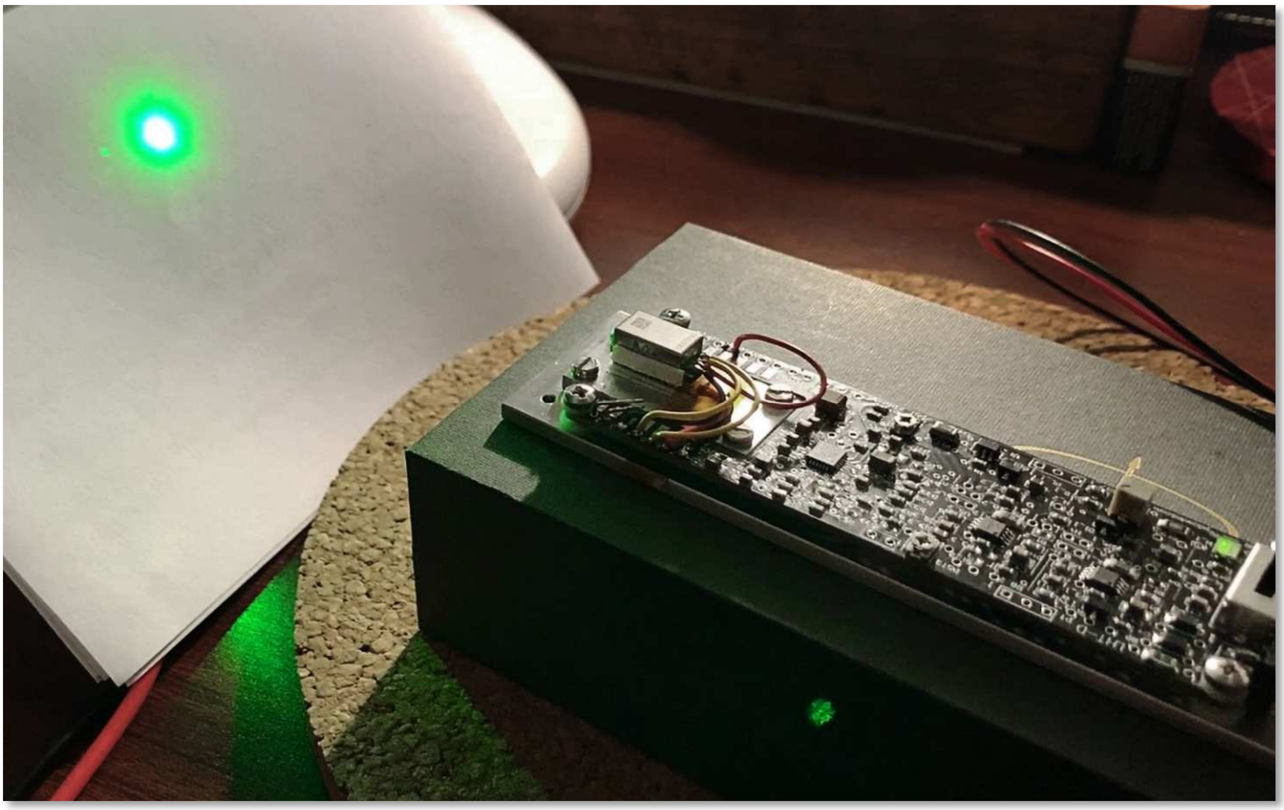
Wiring Complete, Ready for Testing - 27 September 2022.



Wiring Complete, Ready for Testing - 27 September 2022.

With the components wired, it was time to apply power and begin testing of the laser.

First Light – 27 September 2022

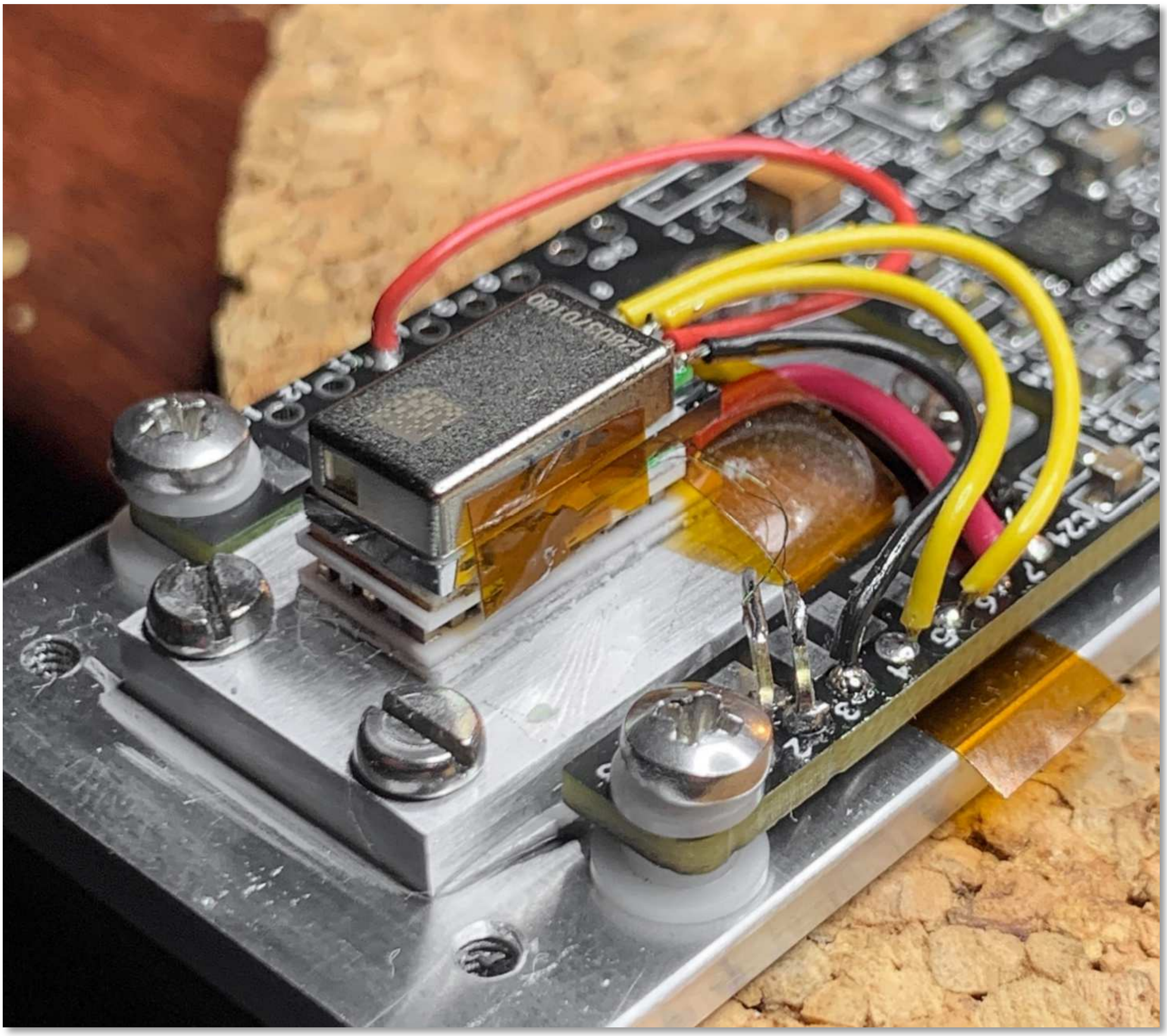


With power applied, and after considerable work, I was greeted with the 530nm green output, however the challenges soon became reality as the laser was not stable and power cycling took over.

Over the course of the next week, I spent troubleshooting and diagnosing issues together with a wealth of information and support from the manufacture of the board, Dasheng from Power Drive Controls.

One of the first suggestions was to remove the thermal tape as would cause reading errors and to increase input voltage to 4.5V at 2A.

I replaced the thermal tape with Kapton tape.



Thermistor Rework – Kapton Tape - 29 September 2022.

In the tests that followed, the thermal cycling issues had not been resolved. Further email discussions with Dasheng provided other suggestions included adding an additional 100µF or 200µF capacitor across C22, (some clients using upto 800µF). Increasing to 400µF did not settle cycling. Reading further on the laser, I concluded that perhaps the location of the thermistor was causing further errors.

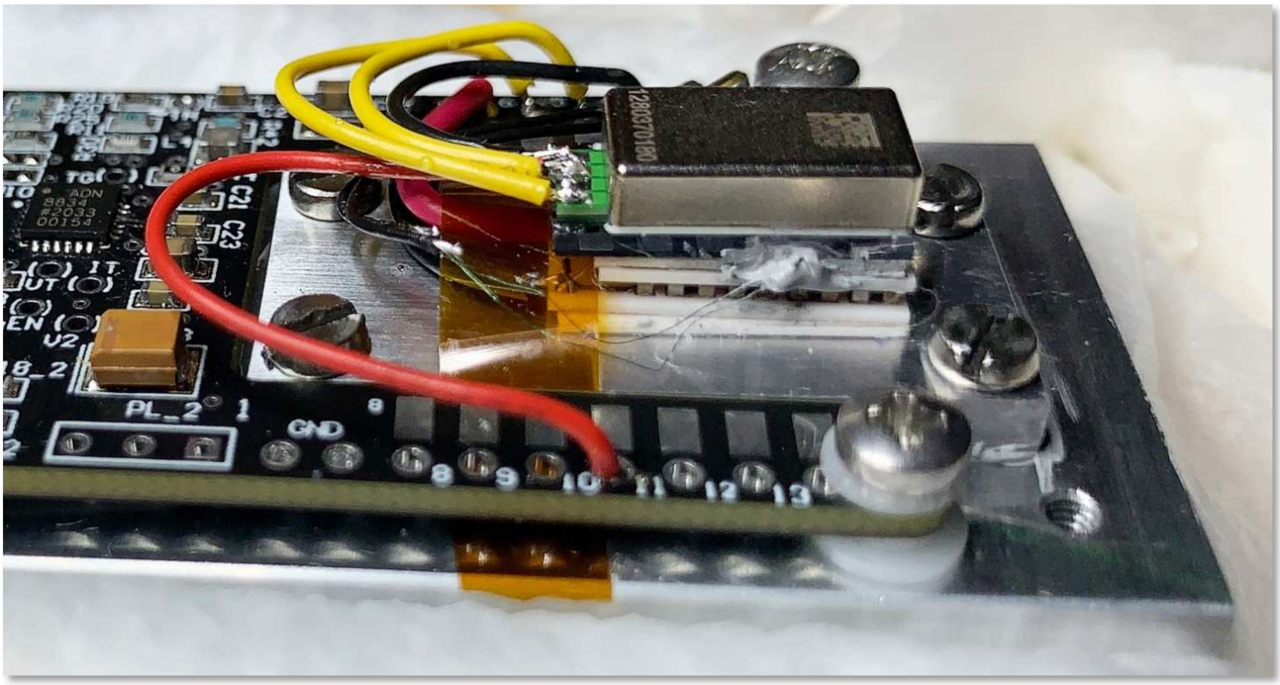
As part of reworking the thermistor, I looked further into thermal pasts, and decided to obtain some "*Arctic Silver 5*" which has a thermal conductivity of 8.9W/m.K.

Over the next few days, I played around with the positioning of the thermistor, however still not achieving any stability.

As I began to take note of current draw, and thermistor positioning, I found some glimpse of stability and concluded that defiantly was a case of a thermal runaway.

Going over thermistor positioning, it was determined that the thermistor must only contact the ceramic part of the TEC and NOT the baseplate of the laser.

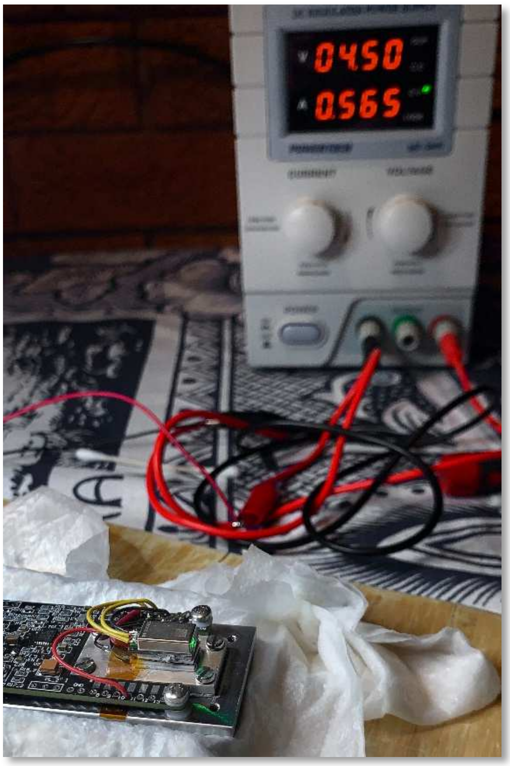
I carefully reworked the thermistor and then decided to place the entire laser assembly on cold block (made with ice wrapped in foil and paper towel in between).



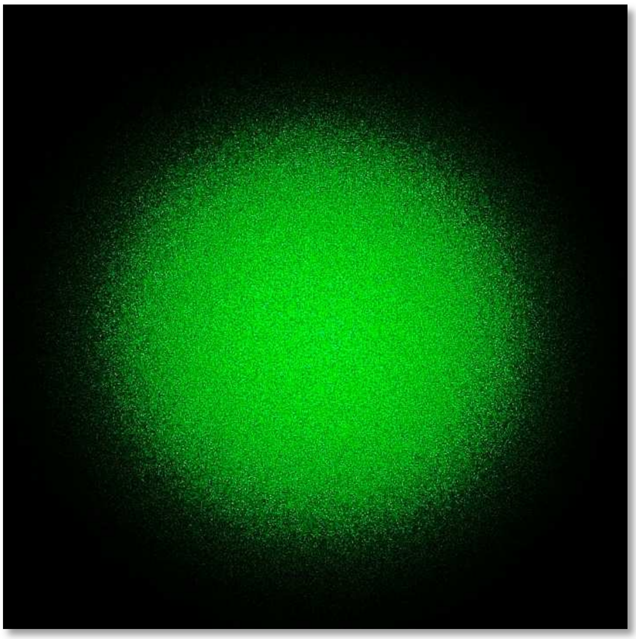
Remounted Thermistor & Wiring – 4 October 2022

Stable Output – 4 October 2022

Above & Lower Left – Laser Operating on Cold block – 4 October 2022



Following considerable work, and significant learning curve, stable output was achieved with the laser module sitting on a cold block.



Right - Beautiful output spot at 7 meters from the laser – 4 October 2022

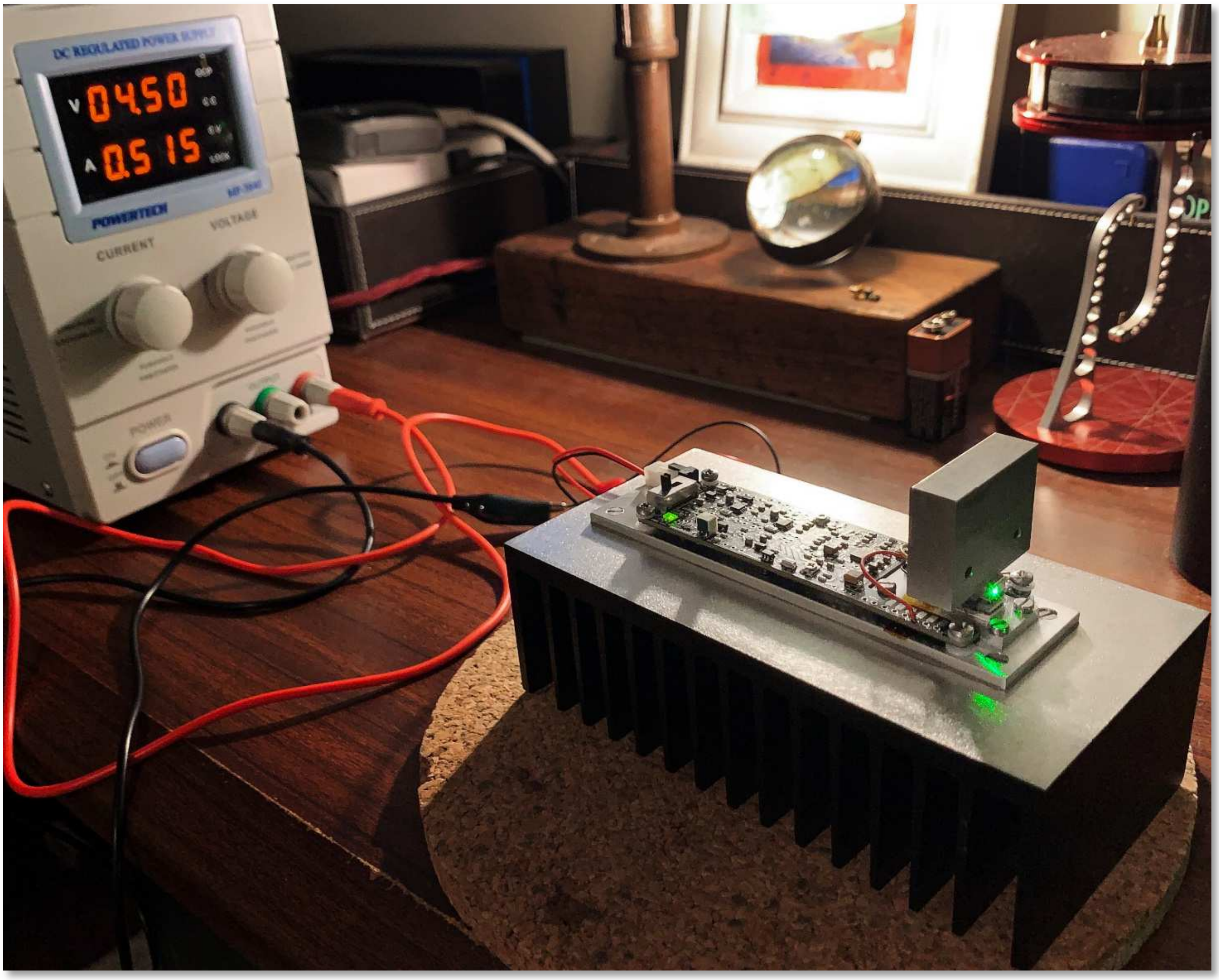
Thermal Stability – 5 October 2022

With the laser now showing stable operation, the next step was to mount the module onto a large finned heatsink. On power up, there was observed changes in output behaviour to a stable point, then slowly would begin reducing. Current draw from the power supply began to climb where after a couple minutes, the laser would then cut out (thermal runaway?).

I then touched the top of the laser, and noticed the laser would begin picking up, the current draw from the supply also began to reduce, curious to the behaviour I then experimented with placing a small block of Aluminium on top of the laser case, and found that over the course of several minutes the laser stabilises solid with a very bright beam, and the power supply current draw locks in tight at 520mA in the first minute, dropping to 515mA, then dropping by 5mA each subsequent minute.

At 5 minutes, we see current solid at 496mA. At 6 minutes observe current flutter between 496mA to 503ma. At 10 minutes, power supply current stable at 515ma to 520mA any deviation due to air current over the laser, the circuit corrects back.

Using a laser power meter, the laser output was measured at 85mW.



Laser Operating with Additional Heatsinking – 5 October 2022

So, the question is, why does placing the block on top of the laser completely stabilise the system?

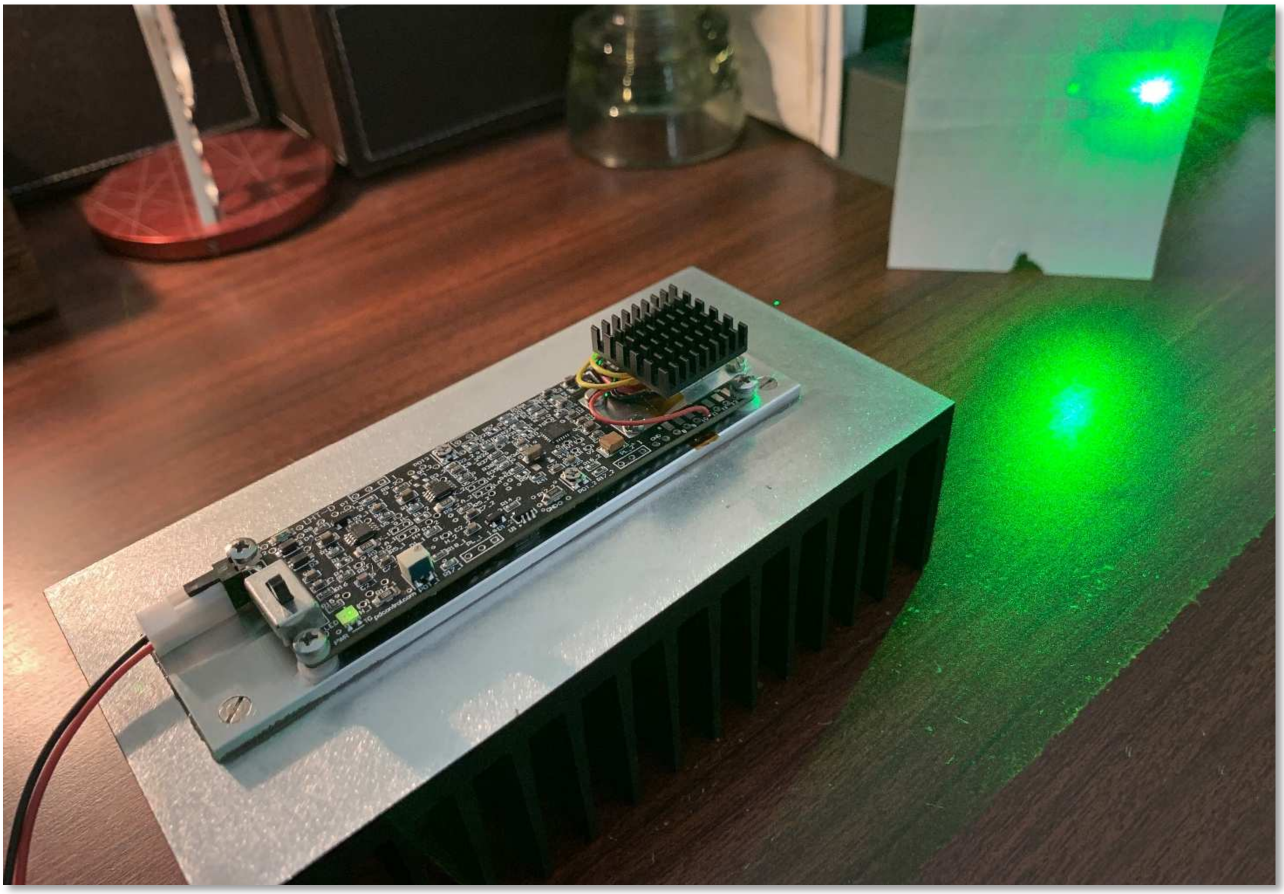
Analysing the behaviour of the laser, it's clear that very careful thermal control is paramount to stable operation.

One also needs to account for the thermal input from the pump laser that will cause a temperature rise in the laser case, together with the PPLN heater. The temperature of the PPLN must be carefully set (tuned) and very stable to optimise its optical performance (and the output characteristics of the laser) A balance needs to be struck, where the thermal input of the pump is nulled out, (but cooled to ensure correct operation) and the correct operating temperature of the PPLN crystal.

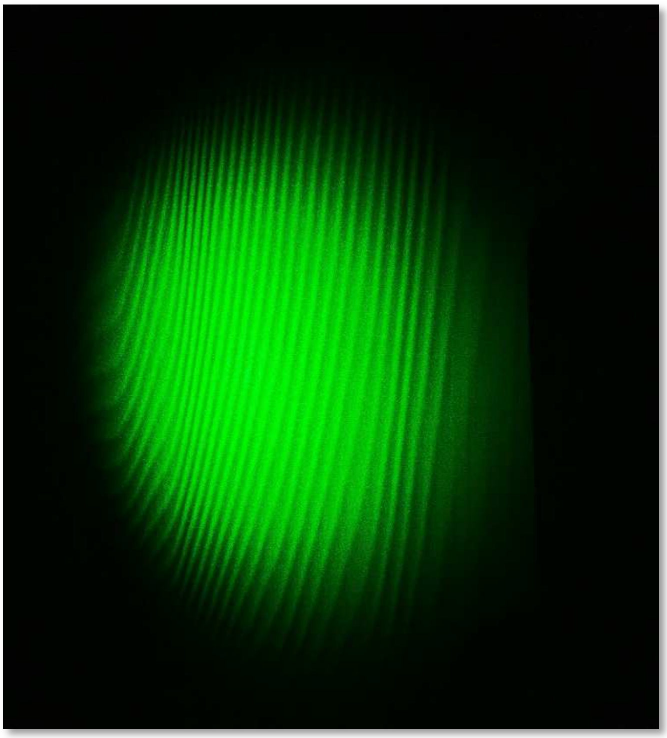
With knowledge some additional heatsinking of the laser would completely bring the system into stable operation, I decided to experiment with a small finned heatsink.

On 7 October 2022, I added a proper finned heatsink to the laser, where full stable output was observed, when measured the output of the laser, I was very impressed to see an output at 105mW, a phenomenal output from such a device, the chosen heatsink providing better efficiency again.

Power input: 4.5V @ 534mA - 538mA, the laser now ready for further detailed characterisation.



Finned Heatsink on Laser – 7 October 2022



Laser Measurements, 105mW (Left), Beam reflected off a mirror (Right) – 7 October 2022

One interesting observation is the resultant strong contract fringes produced as the laser bounces off a (rear surface) mirror on one side of the room and back onto the wall, a travel of 7.5 meters. The Interference pattern produced is a result of interference of light from front and rear surface of the mirror (also known as the Modulation Transfer Function in optics).

With the laser now showing very stable output and operation, it was time to begin characterising the laser and fine tune any parameters.

Laser Characterisation: -

Observed behaviour of Laser power sweet spots

Measured Points		
TS:	1.25V	Default (POT3 Disabled)
TH:	0.625V	Standby - (SW Position 2)
	0.621V	Laser Active - (SW Position 3)
Heater Resistance:		30.5Ω (Measured)

TS = TEC temperature set. @ 1.25V TEC Temperature set at 25°C. R22 must be shorted first to enable adjustment using POT3.

TH = Thermistor voltage. @ 0.625V, Temperature of TEC is 25°C.

Measured heater resistance is the PPLN heater, (pins 3, 4).

Power supply voltage input vs optical power.
Heater Current Measured at K_1 mV x 2

The following are determined "Sweet spots" by measured optical output.

Voltage (V)	Current (mA)	Optical Power (mW)	Laser Current (mA)	Heater Current (mA)
3.8	490	53.5	351	65
4.1	400	121.4	400	69.2*
4.2	400	112.2	400	71

* This power level reached by starting the laser at 4.2V and allow 2-5 min warm up to reach above 100mW, then reduce to 4.1V, this increases laser output and tighter stability observed.

The following measurements taken at 1 min intervals over a 20 min period on 8 October 2022

Input (V):	4.2V	Input (V): 4.1V	Input (V):	4.2V
LD Current (K_2):	400mA	Test Stopped @ T=5	Reduce to 4.1V @ T=5	
TEC, (TH):	0.621V		Power Increase ~ 120mW	
Heater Current (K_1):	71mA		> T=20, Po ~ 121.4mW	

	Measurement 1		Measurement 2		Measurement 3	
Time (Min)	Current (mA)	Laser Power (mW)	Current (mA)	Laser Power (mW)	Current (mA)	Laser Power (mW)
1	503	94.0	528	82.5	515	90.0
2	520	119.0	553	91.0	540	115.0
3	528	115.0	565	92.3	552	112.0
4	534	112.9	571	93.0	559	110.5
5	539	111.9	572	93.0	564	110.0
6	540	111.3			559	121.2
7	540	111.4			559	121.2
8	546	111.2			564	121.2
9	546	111.4			565	121.1
10	546	111.4			565	121.0
11	546	112.2			565	121.1
12	552	112.0			565	121.0
13	553	111.7			571	120.9
14	553	111.8			571	120.9
15	553	112.2			571	120.9
16	558	112.2			566	120.9
17	559	112.3			571	120.9
18	559	112.3			571	120.9
19	562	112.5			571	120.9
20	564	112.4			571	120.9

Observation 1

Input voltage set to 4.2V and TEC turned on and left to settle ≥ 1 minute

Immediately following turn-on of Laser and heater, brief start-up current to heater ~ 33mV (66mA) then within a second or two settles to approximately 35.8mV (71.6mA), Laser output measured at 90mW. Within first 2 min, heater current flutters back/forward slightly between 35.83mV and 35.88mV. (71.66mA and 71.76mA) – A difference of 0.10mA

At approximately 2-minute mark, Laser power increases to approximately 114-116mW. Heater current drops slightly to 35.7 and flutters at the lower end of 35.71mV to 35.74mV (71.42mA and 71.48mA)

At around 5-minute mark, the observed Laser output will settle in at 108-109mW, overall current 565mA, and heater current 35.60mV to 35.65mV (71.2mA to 71.3mA).

Observation 2

At 10-minute mark, set input voltage to 4.1V, observed heater current drop to 34.84mV then flutters ± 0.04mV (69.68mA ± 0.08mA) and the measured laser output increases to 122mW and overall current 558mA.

Observation 3

If commence experiment with input set to 4.1V, then allow 10 minutes to reach thermal stability, the laser will lock in at exactly 90.4mW, the heater current is 34.7mV (69.4mA) an overall current 558mA.

Observation 4

After 10 minutes, increase to 4.2V to allow laser power to climb above 100mW, then switch back to 4.1V, power will increase to 121.9mW remaining locked, heater current 34.8mV (69.6mA) and overall current 559mA.

Final Notes

The experiments are repeatable with values returning to these points after power ups.

Most stable of all values observed with an input of 4.1V and subsequently at a lower value 3.8V producing a very stable output at 53mW.

Following Table shows calculated heater voltage Vs Laser Output

Heater Voltage				
Input V	**K_1**	**Current**	**Heater V**	**Laser mW**
4.2	35.88	71.76	2.18868	90
4.2	35.74	71.48	2.18014	114
4.2	35.65	71.3	2.17465	109
4.1	34.84	69.68	2.12524	122
4.1	34.7	69.4	2.1167	90.4
4.1	34.8	69.6	2.1228	121.9

LASER ENCLOSURE

Following successful tests on the laser, the time arrived to build the enclosure of the laser.

An off the shelf instrument enclosure available from Jaycar Electronics, HB6034, measuring 150mm x 80mm x 30mm has been employed to enclose the laser module.

The bottom section of the enclosure has a cut-out to side over the laser module and is attached to the main heatsink via M2.5 screw.

As continued to undertake testing, found that the laser power had increased to 125.8mW.

Above – Laser Enclosure – 11 October 2022

Right – Laser, Cover Removed – 11 October 22

The next day, work continued, to install the plugs as well as a cut-out for access to the switch.

A breakout port also provisioned to access GND, K_1 (Heater Monitor) and K_2 (Laser Diode Current) for external measurements as required.

In future, some fine adjustment to the heater current may be required to compensate for any drift, however so far, the laser has been operating with very consistent and predictable results.

Laser Shutter

The next task was to install the shutter; however it was found after provisioning a 3.5mm TRS socket and then testing the shutter, that its operation works by pulsing it with 3V + (to open), then reverse the polarity to close (it is not under spring return)., therefore to enable correct operation, would need to provision 4 connections (two for power, and two for switched side.

With this information, I had to order two TRRS 3.5mm (4 contact) panel sockets,

The sockets had to be ordered from Digikey, P/N: 839-54-00173-ND.

The order was placed on 12 October 2022 and arrived on 17 October 2022.

With the TRRS plug installed, the shutter now operable via a momentary switch with centre-off position.

Finally, all wiring secured, and an extension piece added to the switch to enable it to be operated once the cover is on.

On 20 October 2022, the remote switch for the shutter was completed. This using a smaller version of the same enclosure measuring 90mm x 50mm x 24mm available from Jaycar Electronics, PN: HB6031.

Above – Laser Power 128.7mW – 12 October 2022

Below – Completed Laser – 10 November 2022

Completed Remote – 10 November 2022

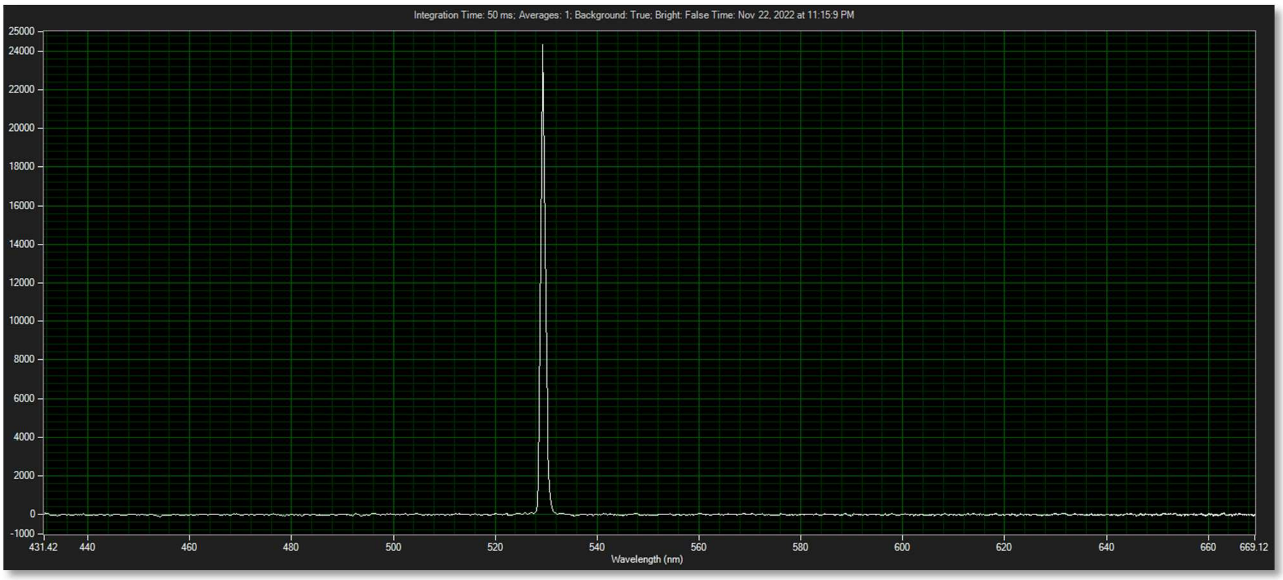
The final components to add are two double concave beam expansion lenses to allow the beam to be used to fill a holographic plate.

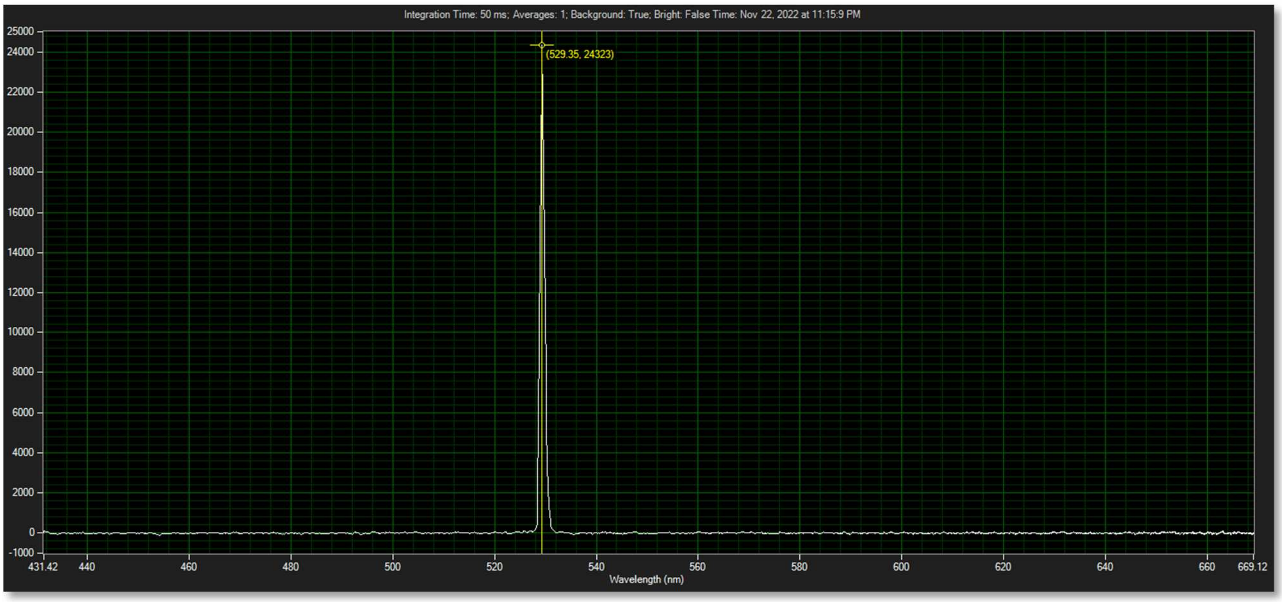
Completed Laser & Remote

Notes

Spectrum Measurements

The laser spectrum was measured using a B&WTek BTC11-S Spectrometer. The wavelength measured at 529.35nm, (the device specifications 528nm to 535nm) as can be observed, the width is very narrow, with a precise wavelength, a characteristic of Single Longitudinal Mode quality.





Spectrometer Curves – PL530 OPSL – 22 November 2022

Technical Notes

TEC Driver

TEC driver chip uses a PID control loop to make the temp stable, the main components associated with the TEC PID:

1. P: R36 = 100K, gain
2. I: C22 = 100 µF, integral parameter
2. D: None, not used

11 October 2022

Addition of case to laser.

Supply input set at 4.1V. Complete stability achieved at T=10.

At T=10, Current = 534mA, Laser Power = 94mW.
At T=13, Current = 540mA, Laser Power = 94mW.
Heater current measured at T=15, 69.64mA.

At T=22, Increase supply input to 4.2V (momentarily) then reduce back to 4.1V.
Laser Power measured at 124.7mW, Current = 544mA.

At T=25, Current = 546mA, Laser Power = 124.6mW, Heater = 69.66mA.

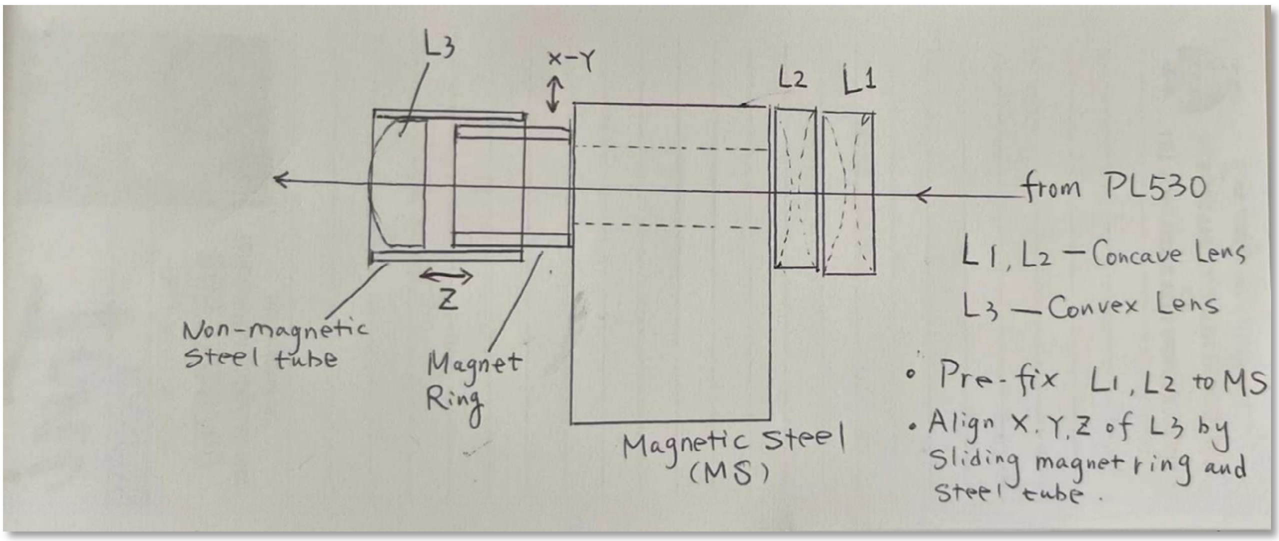
At T=33, Cover off, Supply = 4.1V at 528mA, Laser Power = 125.9mW, Heater = 69.8mA.

12 October 2022

Laser fully enclosed. Laser run time, > 30 min

Supply input: 4.1V at 528mA, Laser Power = 128.5mW, Heater = 69.94mA

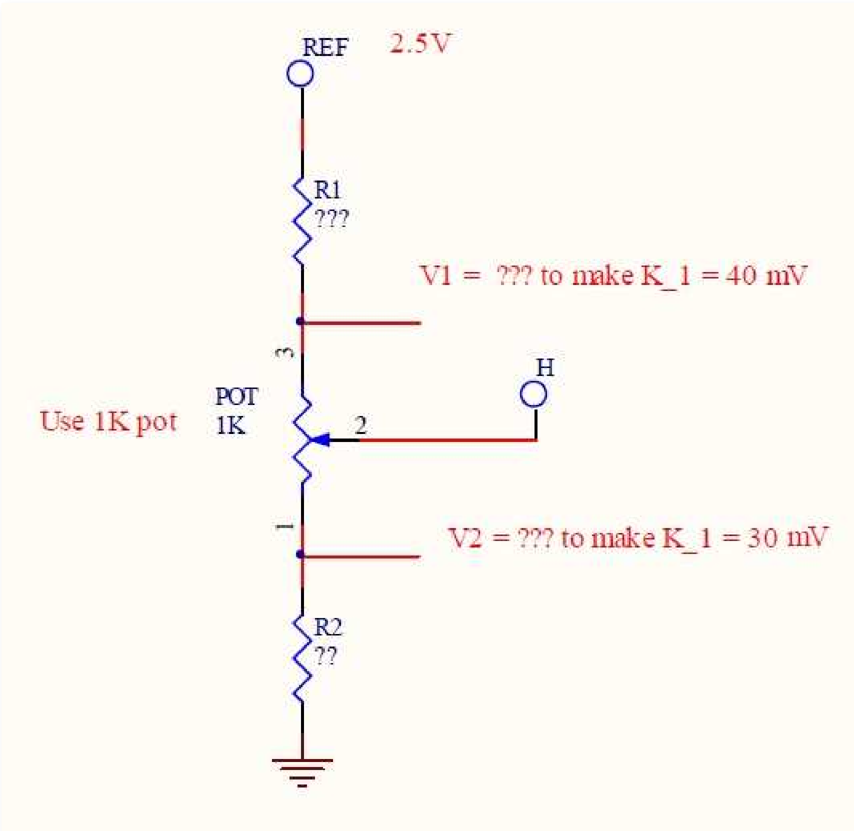
Collimation Optics



Technical Notes

Heater Current Control – For Fine Adjustment

Voltage divider circuit to allow for finer adjustment of heater current (use with caution). Max heater current must not exceed 80mA.



TEC Temperature Setting

To enable using POT3 to adjust TEC temp, short R22 or 2 holes above R22. Default is R22 and the 2 holes are open, the temp is set to 25°C that is TS = 1.25V and TH = 0.625V

Adjust POT3 to set TS = 0.4 VDC will set the temp to 20°C. How to know? – With reference to "TS vs Power Test Data" excel sheet, Column T, U and W.

T and U data are obtained from the thermistor data, e. g. the temp vs. the resistance, and column W is the calculated voltage TH across the thermistor.

Example for setting a TEC temperature of 20°C:

Looking at the blue coloured row for 20°C, the resistance is 12.142 KΩ, the calculated voltage across the thermistor TH should be = 2.5*U5/(U5+30) = 0.72030.

In another words, if the voltage across the thermistor at TH = 0.72030, the temperature must be = 20°C.

Technical Notes

TEC Temperature Setting - Continued

Referring to columns A, B, C, D and E, find the row 6 in red;

4, 20, 0.4, 0.712 66

If TS set to 0.4 V, can get TH = 0.712 V, checking column W to find the calculated TH = 0.720303 which is the closest value that will result a set temperature of 20°C.

Recommended TECs and Thermistors

To achieve a stable and optimized PL530 laser power output, it is necessary to use Thermoelectric Coolers (TEC) to keep the laser diode at a constant temperature while setting the proper laser and heater currents of PL530.

The recommended TECs and Thermistors are:

TEC: from DigiKey

PN: 926-1457-ND (expensive)
PN: 926-1461-ND (expensive)
PN: 1487-387006839-ND

Thermistors (NTC)

Any thermistors that have a nominal Resistance 10K ohm @ 25 C, NTC and with the following B values would be suitable:

B Value @ 25°C /85°C = 3478k ± 1%

B Value @ 25°C /100°C = 3492k ± 1%

https://www.analogtechnologies.com/

PN: ATH10KR8B0
Note: Analog Technologies are expensive for shipping, and not financially economical.

DigiKey:
PN: 495-4599-ND
PN: 495-5054-ND

Mouser:
PN: NXFT15XH103FEAB045

Technical Notes

Technical Discussion – Thermal Stability

The input voltage is constant with the following observations:

Reviewing how PIDs work, they track to correct for over/undershooting of the signal (the error), at first this deviation is large, but then as the PID stabilises the error the deviation reduces to be almost zero.

As we are dealing with thermal parameters, you introduce latency, how quickly can the error in temperature be corrected, once the system reaches thermal equilibrium, the PID would not need to correct for extremely small errors.

With larger thermal mass, this also allows for more thermal stability. The heatsinks provide this thermal mass.

For example, the smaller heatsink on the laser, this allows for an increase of the thermal mass for the laser case, therefore dampening thermal fluctuations (like how a capacitor stores energy).

With the above, we can now understand a little more what is going on with the laser and findings:

An Input of 4.2V will get the laser settled in three steps.

1. At 90mW, however the heater takes ~ 2 min to settle into semi-equilibrium dropping from 71.76mA to 71.48mA, where

2. The laser power increases to 114mA and then,

3. Over the next 5-10 min, settles at 109 as the heater continues to be more tightly controlled by the PID.

As the heater current is always above 70mA, a lower power efficiency is observed (which is above a very tight sweet spot where 120mW is observed).

If the Laser is powered from 4.1V, the heater will not go above 69.4mA, (below the sweet spot range) the laser is output stable at 90.4mW, however it appears that the PID servo is much more precise - perhaps due to the construction of the laser.

Now, how to reach 120mW?

By allowing the servo to settle at 109mW output (71.3mA heater) with an input at 4.2V, as you switch down to 4.1, this causes a fluctuation in the servo causing a very slight drop in the heater current, down to between 69.60 - 69.68, Where the sweet spot is observed, again the thermal balance of the laser assembly, allows precise control of the heater to remain in this very tight range (0.08mA), above or below this range, power reduces to 90mW.

The same observation can be repeated even by starting with 4.1V input and even after 10 min (where the laser produces exactly 90.4mW), momentary increase to 4.2V, within 30 sec the output will go to ~ 114mW, you can then switch back to 4.1V and the output increases to 121.9mW - and remains solid.

Therefore, in conclusion, the heater current needs to be controlled be at 69.60 - 69.68 to obtain the 120mW output.

We don't know the actual heater temperature - this would be an interesting to understand. It's the PPLN (Periodically Poled Lithium Niobate) crystal, when its precise temperature is hit, you maximise its efficiency.

Not all lasers will be the same, however would be interesting if this precise heater current (69.60 to 69.68) would be consistent on all diodes to maximise output.

It's obvious the PID driver can control within 0.08mA, however, also how the laser is mounted, the thermal interface materials etc that allow control of the temperatures.

Remember, we are controlling the temperature of the laser case, but we also need to control the temperature of the PPLN crystal, but we also have the Pump Laser Diode which also produces heat which throws its own error into the thermal mix.

What we have come to learn - A complex balance of several thermal requirements - yes critical as we know ;)

The fact the laser Specification (Datasheet) states ~50mW, getting 120mW is very impressive. I believe the average is between 80 and 90mW, and the driver board parameters (400mA laser, ~70mA heater) is conservative, therefore making my setup even more impressive indeed.

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Additional references to resources and information included in the Reference section.

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