LASERLAB-EUROPE

The Integrated Initiative of European Laser Research Infrastructures III

Grant Agreement number: 284464

WP33

European Research Objectives on Lasers for Industry, Technology and Energy (EURO-LITE)

Deliverable number 20

Report on performance assessment of amplifier system components

Lead Beneficiary:

SCIENCE AND TECHNOLOGY FACILITIES COUNCIL – STFC

Due date: 31/10/2013

Date of delivery: 17/10/2013

Project webpage: www.laserlab-europe.eu

Deliverable Nature	
R = Report, P = Prototype, D = Demonstrator, O = Other	R
Dissemination Level	
PU = Public PP = Restricted to other programme participants (incl. the Commission Services) RE = Restricted to a group specified by the consortium (incl. the Commission Services) CO = Confidential, only for members of the consortium (incl. the Commission Services)	PU

A. Abstract / Executive Summary

The objective of this deliverable is to build two prototype test bed amplifiers operating at 10 J at 10 Hz with a diode pumped solid state laser amplifier that can be scaled to 1kJ systems. There are two concepts being developed to achieve this goal. The first prototype is being built with a multi disk concept based on transmission of the seed beam. This also incorporates active cooling of the amplifier medium by Helium flow over the large surface of the slabs. The second concept is based on the active mirror concept where the cooling is achieved by cooling the back surface of the disk while pumping and extraction occur through the front surface in reflection mode. These are being developed respectively within the DiPOLE and LUCIA programs of STFC CLF and CNRS-LULI partners. The main differences are the gas pressure, the number of gain medium elements, as well as the cooled surfaces: One ceramics cooled on a single face with 0.1 Atm in LUCIA, and up to 5 slabs cooled on both faces with high pressure (>1 Atm) in DiPOLE.

B. DiPOLE Deliverable Report

1 Introduction

This section describes the key elements of the 10 J DiPOLE amplifiers which are the cryo-cooling system, pump diodes and the co-sintered ceramic disks. This is written by Jonathan Phillips from Central Laser Facility STFC.

2 Objectives

The objectives were to take delivery and to validate the performance of the key components.

3 Work performed / results / description

3.1 Cryo system

The cryo-cooling system has been installed and is shown in **Erreur ! Source du renvoi introuvable.**.

Figure B 3-1 Image of the cryo-cooling system assembled in the 10 J Laboratory

3.1.1 Cryo-system baseline performance specification

The inlet pressure to the amplifier is 10 barA at a nominal mass flow rate of 30g/s. The pressure relieve valves are set to open at 22 barA. The temperature ranges from ambient to <90K, with the control system able to maintain a stability of ±0.5K. The accuracy should be within ±1K at the chosen set-point.

The rate of temperature change in the system is controllable to prevent too rapid cooling.

3.1.2 Amplifier Head

The pressure drop across the amplifier head has been calculated to be of the order of 3000 Pa. This has been reduced as much as possible by careful design of the flow paths and use of computational fluid dynamics to optimise the system.

As the cooled helium gas passes through the circuit, it will gain heat from various sources, the main contribution of course being from the laser amplification process itself. The heat load to be removed from the amplifier is approximately 300W. In addition to this, there is heating via radiation through the transfer lines and amplifier vessel of up to 300W, though this can be reduced by the use of MLI (multi-layer insulation) in the vacuum jacketed lines. In addition the cryo-fan introduces heat by compressing the gas, this figure was calculated to be 125W with a further 25W contribution from heat conducted down the fan motor shaft. This gives a total heat load of around 750W.

The total volume of the vacuum space in the head and transfer lines is 24 litres. This needs to be pumped down to a working vacuum pressure of 1×10^{-5} bar for efficient insulation. On cooling, the system is observed to cryopump to a lower vacuum pressure.

The helium circuit volume of the system is approximately 20 litres.

3.1.3 Diagnostics

To allow the control and monitoring of the system, certain diagnostic devices are installed.

- Temperature sensors are positioned at both inlet and outlet of the amplifier.
- Flow meter at the top of the head
- Pressure sensors also at the top of the head

3.2 Pump Diodes

The pump sources for DiPOLE were purchased as a turnkey system from a consortium led by Ingeneric, with parts of the system sub-contracted to Amtron (power supplies, chillers and control system) and Jenoptik (diode laser stacks assembled into sub modules of 3 stacks each.)

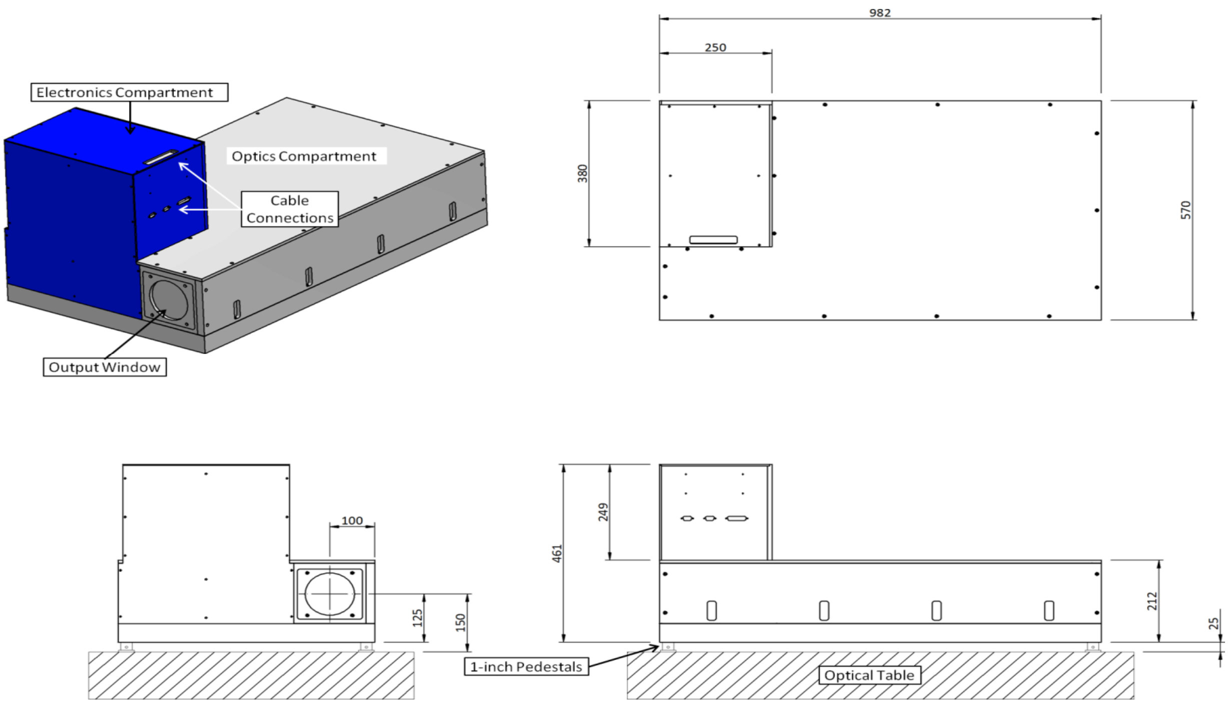

Figure B 3-2: Dimensions of diode laser head.

A drawing showing the outer dimensions of one laser head is shown in Figure B 3-2. The two diode laser heads are handed versions of each other so that they can be placed at a slight angle to each other, with the beams being emitted along an angle. Laser A, which is shown in Figure B 3-2 has the output window on the right-hand side and the electronics compartment on the left-hand side. The inverse is the case for Laser B. The weight of one laser head is approximately 160 kg.

3.2.1 Output power

The output power was characterised using a water-cooled thermopile detector which measures average power (Gentec UP55). The detector was placed after the first of the two dichroic turning mirrors that reflect the pump beams into the main amplifier head.

The operating parameters and the measured output powers are summarised in Table 1 and 2. The specified peak power of 20 kW at the nominal operating conditions of 10 Hz and 1 ms pulse duration was reached, and the system offers room to further increase the diode drive current and, with it, the peak power.

It has been found to be more convenient to reduce the pulse duration rather than the drive current in order to reduce the output pulse energy. This way it is easier to reach the desired pump wavelength at lower energies, where less internal heating of the diodes occurs and the wavelength therefore shifts to the blue.

Table 1**: Measured output power for Laser A. All measurements were done at a drive current of 300 A.**

Pulse duration / ms	Repetition Rate / Hz	Average power / W	Pulse energy /J
1.2	10	241	24.1
1.0	10	201	20.1
0.8	10	159	15.9
0.6	10	118	11.8
0.4	10	77	7.7
0.2	10	37	3.7
1.0	1	19.5	19.5
1.0	2	39.1	19.5
1.0	5	99	19.8

Table 2: **Measured output power for Laser B. All measurements were done at a drive current of 310 A.**

Pulse duration / ms	Repetition Rate / Hz	Average power / W	Pulse energy /J
1.2	10	242	24.2
1.0	10	201	20.1
0.8	10	160	16.0
0.6	10	119	11.9
0.4	10	77	7.7
0.2	10	37	3.7
1.0	1	19.7	19.7
1.0	2	39.6	19.8
1.0	5	99	19.8

3.2.2 Spatial characteristics, brightness and divergence

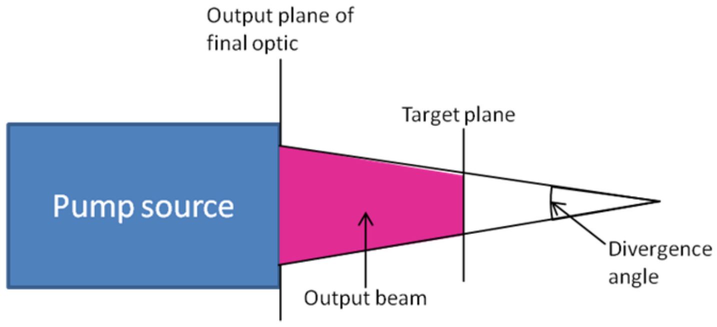

Figure B 3-3: Illustration of beam geometry.

During the design phase of the pump laser system it was decided to increase the working distance to 600 mm (distance between output plane of final optic and target plane in figure B 3-3).

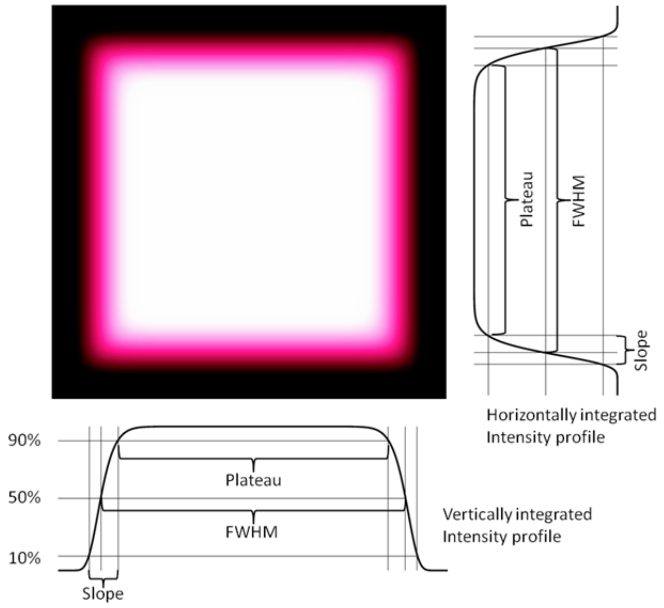

Figure B 3-4: Illustration of beam profile parameters

3.2.3 Spectral characteristics

The beam profiles that were actually achieved during the final on-site acceptance tests for both Lasers A and B are shown in Figure B 3-5. They show very good uniformity and the steepness of the edges is much higher than initially specified. Instead of 10 % of the FWHM, the slopes only take up a maximum of 3.5 %. The plateau region on the other hand extends over more than 98 % of the FWHM instead of the required minimum of 90 %.

During final acceptance tests it was found that 30 % of the energy was contained within a ±0.8 nm spectral band and 76 % within a –2.8 nm, +2.1 nm band. This asymmetric distribution is caused by the internal heating of the diodes during the pulse and matches well with the absorption spectrum of Yb:YAG, which shows a steep drop-off towards longer wavelengths.

It was also found that the optimum wavelength, yielding the maximum pump light absorption in the Yb:YAG gain media, lies more towards 940 nm, depending on how the centre wavelength is defined (peak, centroid, or 50 % point on cumulative spectral distribution).

As the emission wavelength of the laser diodes varies from stack to stack and is also highly dependent on the junction temperature, and therefore on current, repetition rate, pulse duration, and cooling water temperature, tuning mechanisms are required to compensate for

a) the stack-to-stack variations and b) wavelength shifts induced by changes in operating conditions.

To compensate for the stack-to-stack variations induced by manufacturing tolerances, each of the four diode modules contained within each head can be wavelength tuned with an individually controllable DC bias current. It was found that in both heads, currents of order 0.8 A needed to be applied to all but one of the modules in order to shift the individual spectrum to the same wavelength.

Overall wavelength tuning and adaptation to different duty cycle regimes is done by varying the temperature of the cooling water in each source. By using additional bias current for extremely low duty cycles we were able to obtain maximum absorption in the amplifier for operating conditions ranging from 0.2 ms to 1.2 ms pulse duration at 10 Hz and from 1 Hz to 10 Hz at 1.0 ms and 1.2 ms pulse duration.

It was found that the best method for reducing the pulse energy while maintaining the optimum wavelength was to reduce the pulse duration at full operating current, rather than reducing the operating current at full pulse duration.

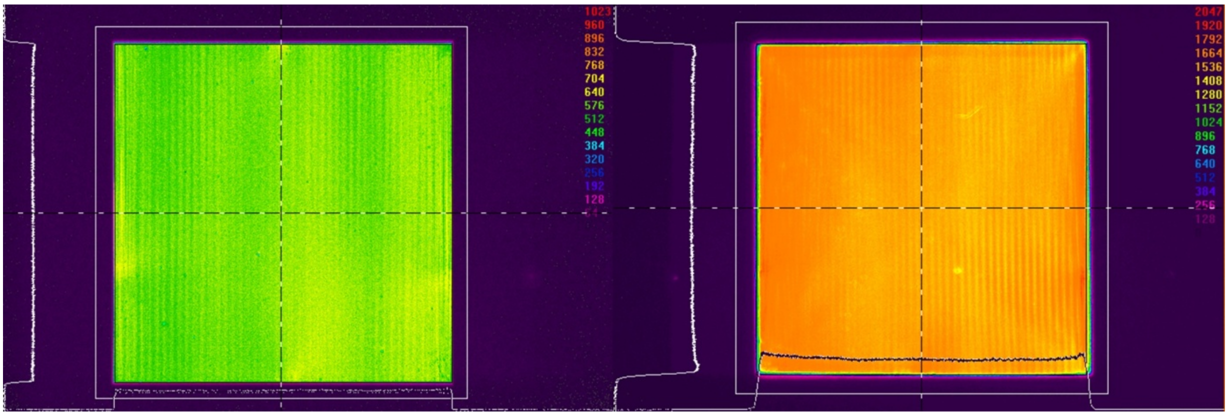

Figure B 3-5: Beam profile in target plane for Laser A (left) and Laser B (right).

The full angle beam divergence was measured to be 5 degrees in the horizontal direction and 6 degrees in the vertical direction, again significantly better than the minimum requirement.

3.3 Co-sintered Yb:Yag

We have chosen co-sintered (is CR^{4+}) Yb:Yag to minimise amplified spontaneous emission (ASE) in the transverse plane. We have taken delivery of the co-sintered Yb:Yag from Konoshmi (Japan). This is shown in Figure B 3-6 below.

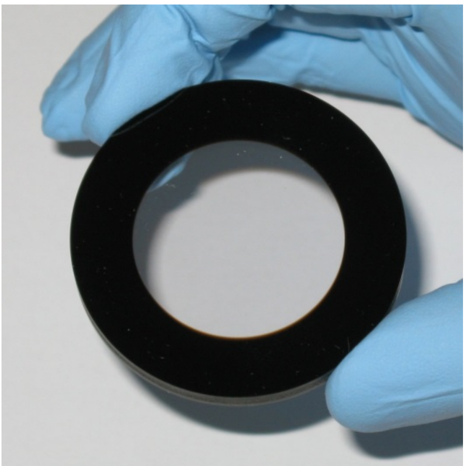

Figure B 3-6: Yb:YAG-CR^{4+}:YAG compound disk

The dimensions of the Yb:YAG are shown in Figure B 3-7.

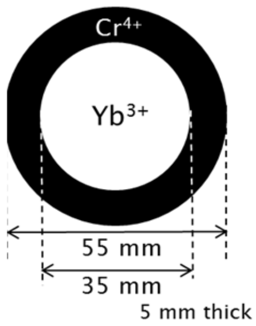

Figure B 3-7: Dimensions of the Yb:Yag disk used for DiPOLE.

We have carried out measurements at room temperature of the absorption of the doped Yb:YAG as well as the Cr^{4+}. The results are shown in Figure B 3-8. These measurements agreed with our expectations. We have also sent this for coating and there appear to be no issues.

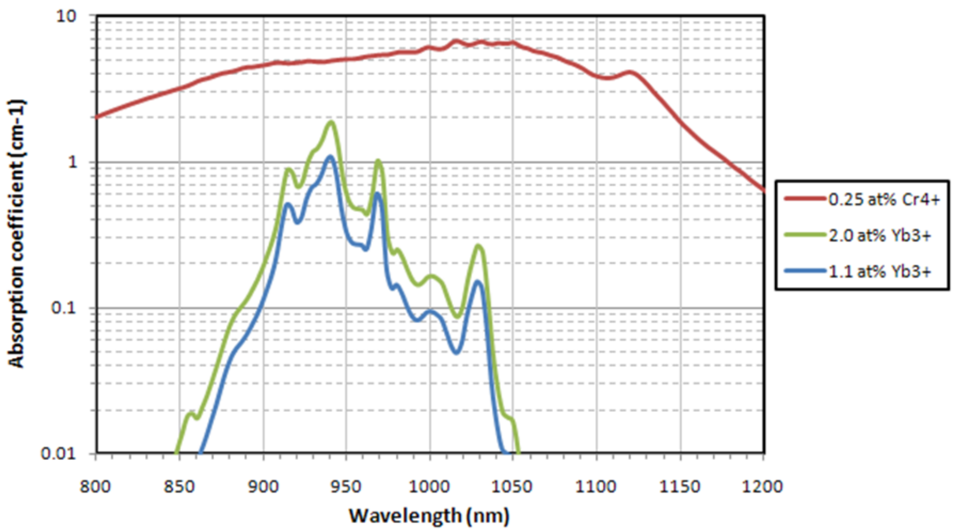

Figure B 3-8: Absorption of the co-sintered Yb:Yag disk with different doping levels and also the CR^{4+} absorption layer.

We have also sent the ceramic disks for coating at AR of 940 and 1030 nm with a 0-10 degree angle of incidence. The coating measurements are shown in Figure B 3-9.

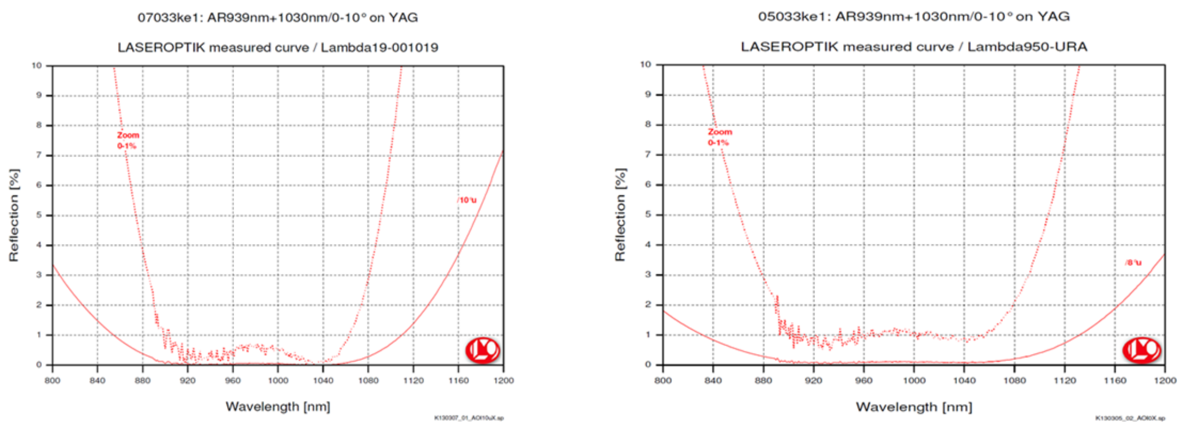

Figure B 3-9: Coating measured curve of the AR coating on the ceramic Yb:Yag displaying two curves with 10 and 8 degree angle of incidence.

4 Conclusions

The two 100 W pump diodes worked according to specifications and are now installed on the optical table in DiPOLE laboratory. The cryo-cooling system was delivered and is now installed in the DiPOLE laboratory as well as the optical head. We have taken delivery of the Ceramic Yb:YAG disks and have successful anti-reflected coated them.

5 References/Publications

K. Ertel et al, “Optimising the efficiency of pulsed diode pumped Yb:YAG laser amplifiers for ns pulse generation”, Optics Express, Vol. 19, Issue 27, pp. 26610-26626 (2011) http://dx.doi.org/10.1364/OE.19.026610

C. Lucia Deliverable Report

1 Introduction

This section describes the commissioning of key elements of Lucia new cryogenic amplifier head, namely, the co-sintered YAG ceramic, the cryostat hosting the laser head and the pumping source. It was written by Jean-Christophe Chanteloup, LULI Laboratory, France.

2 Objectives

The objectives were to validate the main specifications of all these elements with respect to what was actually ordered.

3 Work performed / results / description

3.1 Co-sintered ceramics

In order to circumvent deleterious effect associated with Amplified Spontaneous Emission (ASE), Lucia cryogenic amplifier will be filled up with co-sintered Cr^{4+}/Yb^{3+}:YAG ceramics. illustrates the relative distributions of the Chromium and Ytterbium doped parts of the 10 mm disks. The previously ordered ceramics have been proven to be too much absorbing in the Cr^{4+} peripheral part. In this case, we have then requested a very low doping level for this ion. A target value of 25% transmission over the 1 cm thickness was required. This corresponds to doping level almost 10 times lower than previously achieved by Konoshima, the Japanese manufacturer. After a year of tests and improvement, we finally decided to accept a first (over 3 ordered) ceramic with a higher than specified doping level. The transmission measurement revealed a 5.5% transmission in place of 25%. Further effort have since been engaged by the manufacturer to get as close as possible to our target.

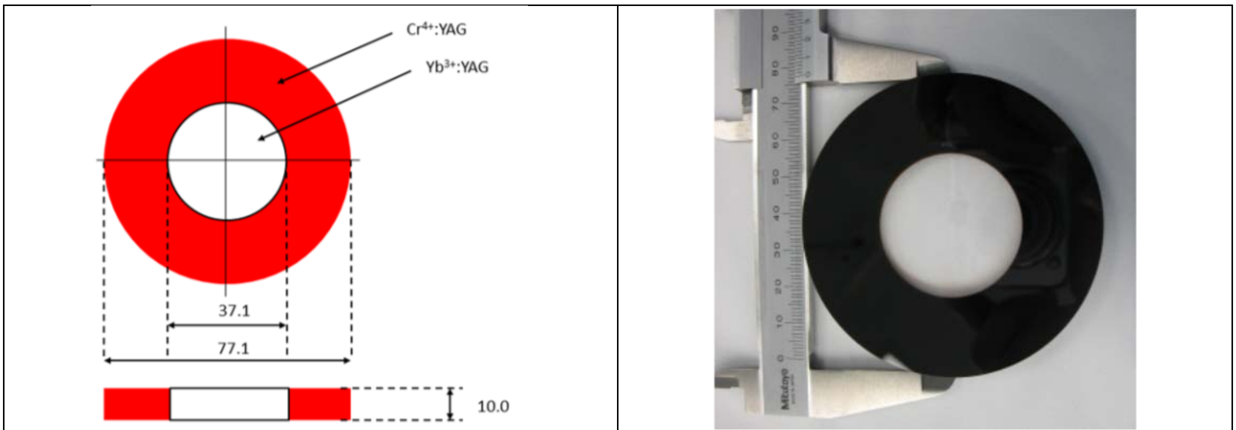

Figure C 3-1: Cr^{4+}/Yb^{3+}:YAG co-sintered ceramic manufactured by Konoshima for Lucia cryogenic amplifier

3.2 Cryostat

Lucia Cryogenic head is now in place in the laboratory as illustrated on Figure C 3-2.

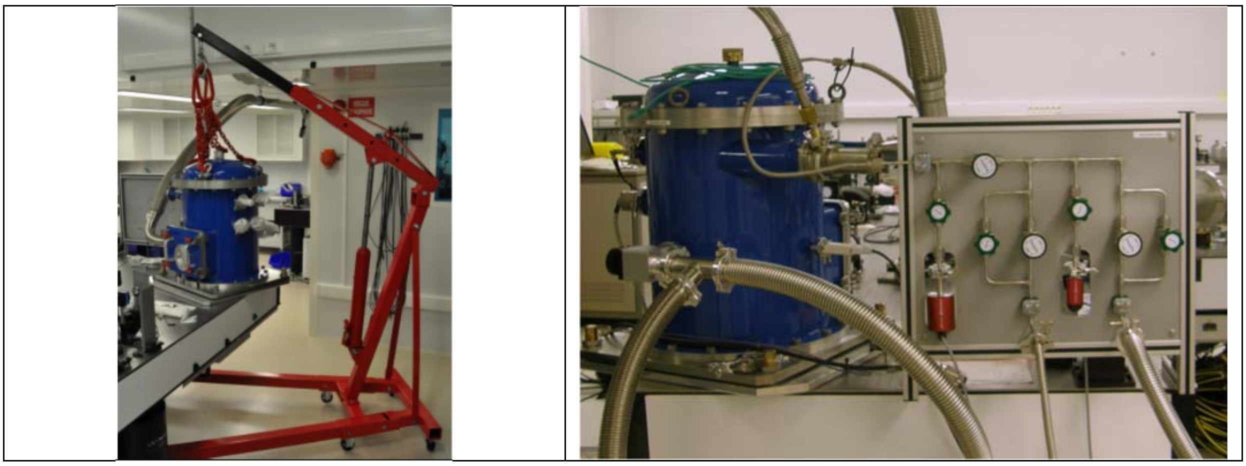

Figure C 3-2: Lucia Cryostat commissioning. Helium regulation tubing is illustrated on right.

It mode of operation relies on temperature adjustment through fine pressure tuning of a thin (<500µm) layer of helium located at the back side of the YAG active mirror. This approach is detailed in ref. [1].

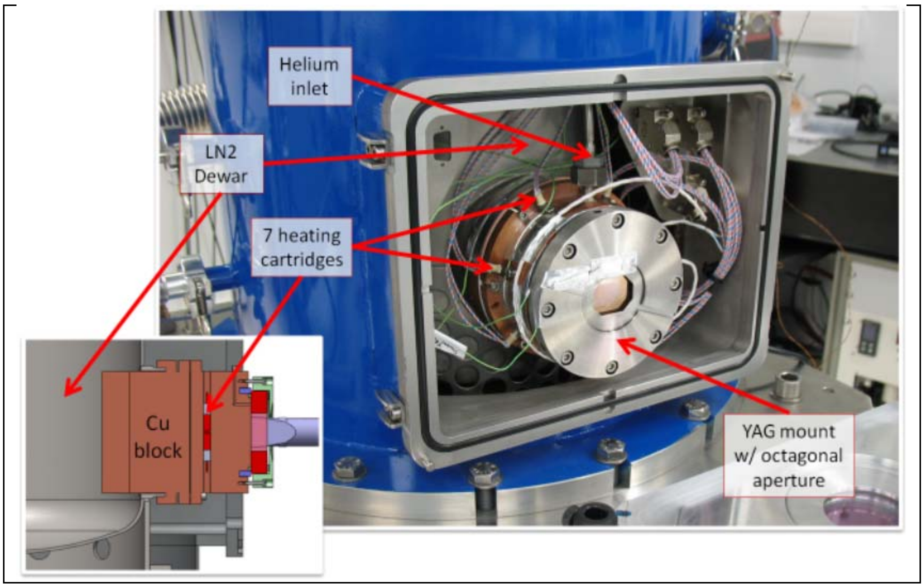

Figure C 3-3: Lucia cryogenic head made of a block of copper partially immerged in liquid nitrogen. Embedded eating cartridges allow a quick thermalization to be established.

Experimental ability to accurately select a defined temperature by modifying the pressure in the thin gas cell was crucial to test upon reception. To monitor the temperature of the gain medium, we inserted PT100 thermal probes into drilled holes into a Yb:YAG crystal we sacrificed for this purpose. A circular flat copper electrode was also used to have access to the surface temperature (see Figure C 3-4). Thermal measurements reveal a maximum axial gradient of 5K which is very satisfying.

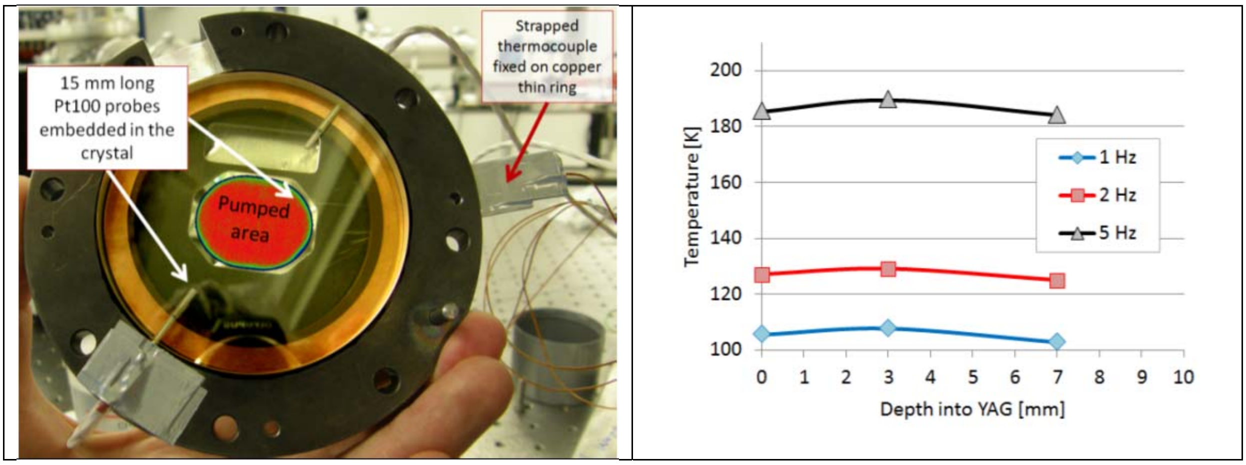

Figure C 3-4: Lucia 77 mm Yb:YAG disk with two platinum electrodes inserted and one thermocouple strapped onto a surface copper electrode. Measurements reveal almost no axial gradient.

Figure C 3-5 illustrates the temperature achieved by tuning the pressure between 1 and 1000 mbar. It demonstrates the large exploration zone around the nominal 160K value the cryostat was designed to operate into.

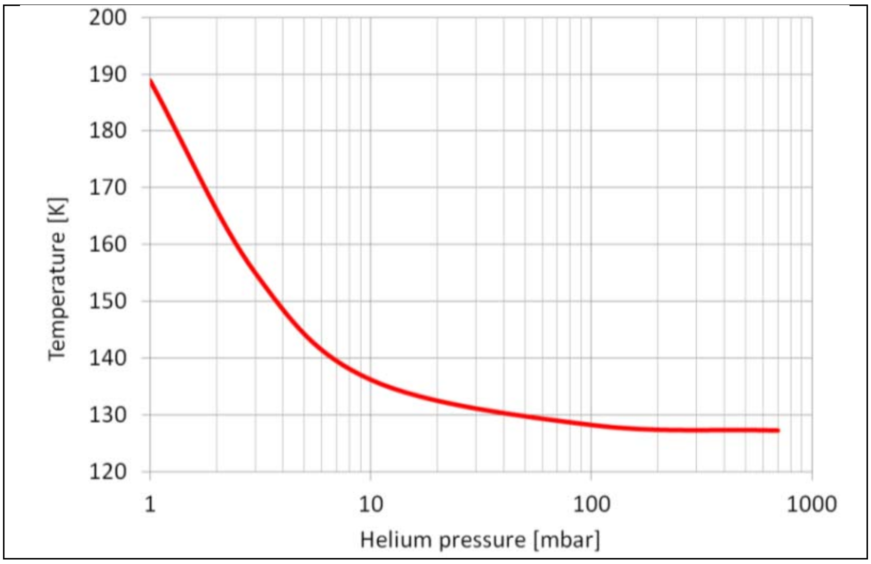

Figure C 3-5: Temperature dependence (front surface electrode) of the gain medium versus the pressure within the helium gas cell.

In order to evaluate the impact of the chromium doping level of the disk cladding, we have ordered a set of copper surface electrodes of various diameters as illustrated on Figure C 3-6. A flat temperature distribution is expected within the central Yb doped part whereas a slight radial gradient is expected in the peripheral part.

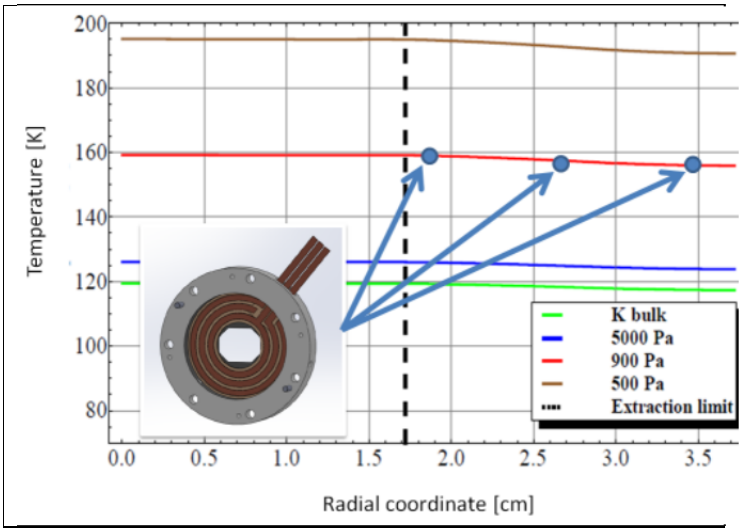

Figure C 3-6: Predicted radial temperature distribution and localisation of future temperature measurements to be performed with flat circular copper electrodes (blue dots).

3.3 Pumping head

The gain medium pumping is performed with a diode laser head manufactured by Lastronics (Jena, Germany). It delivers 33 kW over a 6 cm² elliptical area as illustrated on Figure C 3-7. The pump module is shown in Figure C 3-8

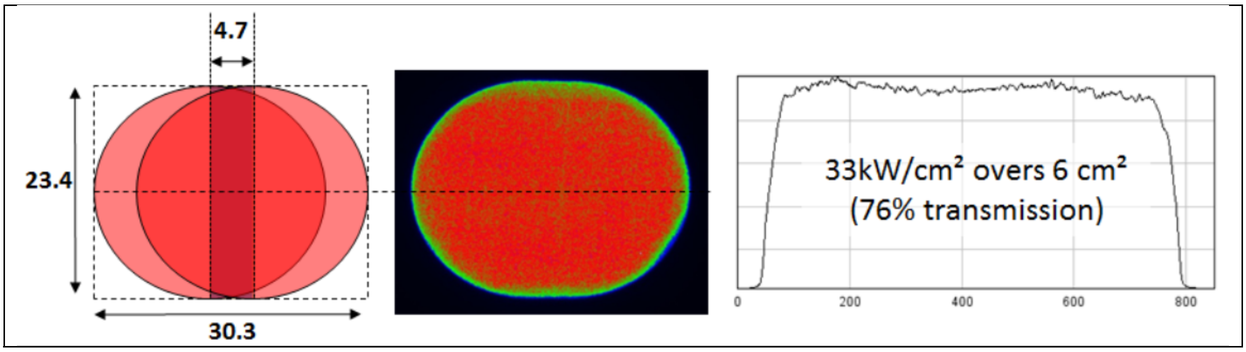

Figure C 3-7: Pump distribution for Lucia cryogenic amplifier head

The measured homogeneity is satisfying.

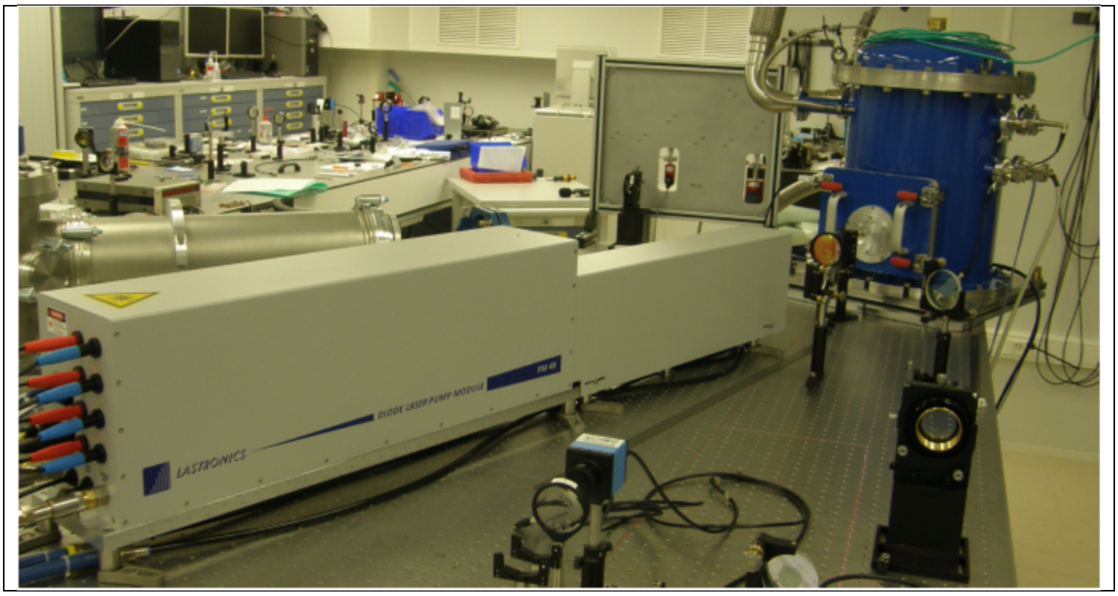

Figure C 3-8: Pump module by Lastronics (grey housing, left) for Lucia cryogenic amplifier head pumping (blue cryostat right)

4 Conclusions

The 33 kW Pump module and the cryostat have been commissioned. Both performed as expected. Only one over three ordered co-sintered ceramics has been commissioned and a very high absorption was observed. Expected therefore a potentially too high radial gradient, we have ordered a set of electrode to measure this effect.

5 References/Publications

[1] A.Lucianetti et Al., “Active-mirror-laser-amplifier thermal management with tunable helium pressure at cryogenic temperatures”, Optics Express, Vol.19, No. 13, pp. 12766-12780, 2011 http://dx.doi.org/10.1384/OE.19.012766