REVISTA BOLIVIANA DE FÍSICA 20s, 54-56, 2011
ISSN 1562-3823. INDEXADA EN: SCIELO, LATINDEX, PERIÓDICA

THERMAL ANALYSIS OF LD PUMPED ND:Yag LASER SLAB AND FAILURE ANALYSIS

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SUMMARY

As part of the R&D effort conducted within the Laser Laboratory of the European Space Agency, various simulation tools are being developed to understand and correct the thermal effects of side pumping an Nd:YAG slab with multiple individual High Power Laser Diodes. The scope of the present activity, which complements the work reported elsewhere at this workshop, is to emulate the thermal effects of a real amplifier and study the effects of various combinations of laser diode stacks with different characteristics, such as operational wavelength, temperature of operation, transmitted energy and pumping efficiency on the dynamic temperature distribution inside the slab. The motivation of this analysis is to work towards a simplification of the phenomena of heat generation and convection inside the crystal which account for the thermal lensing effect. Transient analysis is performed at different pump intensities under variable boundary conditions and the results are compared with experimental data as well as other software such as Zemax and LASCAD. Also the effects of laser diode stack failures are investigated and reported. The algorithm developed is based on the finite element method using tetrahedral elements for the adjustable meshing.

Key words: space Lidar, thermal simulation, thermal lensing effect, Nd:Yag laser slab

INTRODUCTION

A critical parameter of the overall instrument performance for lidar missions and especially for space applications is the performance of the laser during operation. The high power amplifier is the center of this study based on diode pumping at 808 nm. This theoretical research was based on an 8-diode pumped Nd:YAg slab under variable operation conditions. For MOPA Lidar missions the beam quality plays a critical role and the major objective of this study is to introduce the impact on the beam quality and shape when the laser slab is heated under different heat distributions [Siegman 1998]. The main reasons for the decrease of optical output quality (M^2, divergence) are the effects caused by the inhomogeneous thermal gradient inside the slab, such as thermal lensing and thermal induced birefrigerence [Mansell 2001]. Secondary objective of this study is the determination of the thermal behaviour of the slab in case of failure of one or several diodes. The modes of failure studied are instant failure and gradual degradation. The main phenomena that are affecting the thermal gradient inside the slab are the volumetric heat generation due to the absorption of the pumping light, the surface heating caused by convection through air and the cooling from the cold plates.

THE MODELED CONFIGURATION

The setup consists of a zig-zag Nd:Yag slab pumped by 8 diodes positioned as shown in Figure 1. The two operational configurations considered are the 74 Hz repetition rate of pumping by the 8 diodes simultaneously and a 37 Hz repetition rate of pumping by 4 diodes at a time, namely a 4+4configuration.These two configurations where the original configurations for the ATLID PU. The input current for each diode is set at 66 A for emission and 10 A ± TBD for self heating to maintain the preferred temperature for optimal wavelength emission for the case of 8 LD's illuminating the slab simultaneously. In the case of 4+4 configuration there are separate input currents for each diode stack side. The upper one has 82 A total input and the lower 80 A current input, from which 10 A are consumed for self heating. The crystal is also heated by the operational high power laser diodes through convection since air is inhabitant inside the amplifier and transfers heat through conductance to the slab [Wynne 1999]. For cooling two heat sink plates made from Copper with Indium interfaces were simulated. The temperature of the diode stacks are matched for optimum wavelength emission. The center wavelength of emission and the optical power are subject to the input current amplitude for each diode and the design electro-optical efficiency. The temperature of each diode will be highly affected by the input electrical current as known by literature.

THE HEATING EFFECTS

The major procedures that cause heating of the material are the diode heating, the heat conductivity of the material and the heat conductance in respect to the boundary surfaces. The diode pump intensity is absorbed inside the slab causing the molecules of ND to excite and occupy the 4F5/2 Energy level. The energy difference between the absorbed photon and the fluorescent photon increases the kinetic energy of the molecules and therefore the temperature of the material is increased. The heat distribution (Figure 1 left) is dependent on the exponential absorption in the penetration direction and is modelled according to [Lascad Tutorial]:

$$\exp(2r^2/w^2)$$

The second phenomenon of heating is due to convective air currents that transfer heat between the hotter diodes and the slab in cases where there are no vacuum conditions. This phenomenon follows the law of fluid convection Q=h*(T0-T), where T0 is the temperature at the diode stacks and T the temperature among the slabs surface and h is the conductance of air [Heat Transfer Textbook]. The reason that the heat is not homogeneous is that the temperature below the diode stacks is hotter than on other locations and coldest near the boundaries (Figure 2 right). The assumption of steady state operation leads to the constraint that the pumping intensity and frequency will not cause depletion of molecules residing in the ground Energy state and also that the spontaneous emission is neglectable. For calculating the temperature field that is governed by the phenomena of heating, conductance and internal material conductivity the heat PDE was solved with FEM using the appropriate tetrahedral elements. The size of the elements is determined by the waist size of the diode pump emission and has to be dx<beamwaist/2.

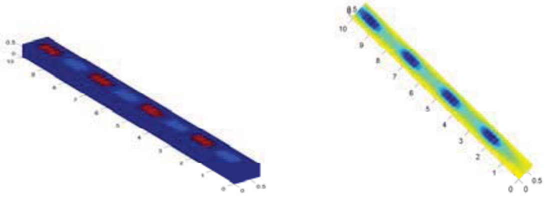


Figure 1: Left: The heat profile caused by diode pumping. Right: The convective heat exchanged with air in a.u.

RESULTS

To asses the impact of the boundary conditions and the diode temperature in the temperature distribution inside the slab some key cases where studied and reported. Secondarily two cases of diode failure where studied and compared with the other results. Figures 2 and 4 show the temperature distribution inside the slab under configuration 8 pumping for the cases of homogenous boundary conditions at 42 C and inhomogenous at 42 C and 45 C respectively. The two profiles show visible difference in the temperature distribution on the beam propagation path that is also visualised and compared in figure 3. In case 2 the wavefront is not exposed to symmetrical gradients at the edges as in case 1.

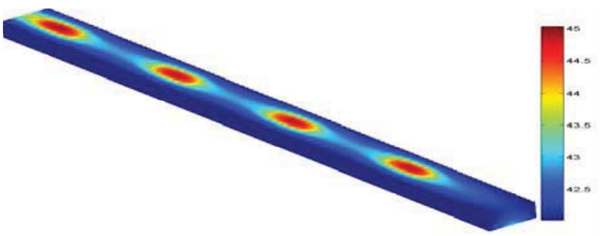
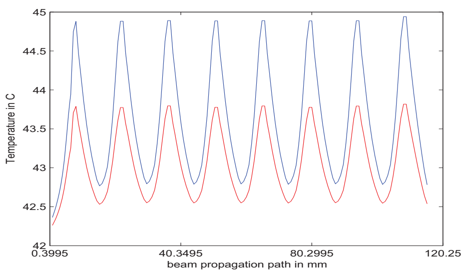


Figure 2: The temperature profile of the slab with homogenous boundary conditions



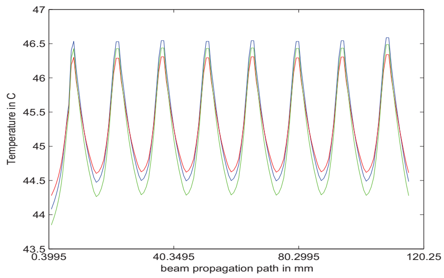


Figure 3: Left: Temperature distribution among the beam propagation path for the case of homogeneous boundary conditions. The blue line represents the temperature at the centre of the beam and the red represents the temperature at 2 mm distance from the centre along the x axis.
Right: Temperature distribution among the beam propagation path for the case of inhomogeneous boundary conditions. The blue line represents the temperature at the centre of the beam, the red represents the temperature at 1 mm distance from the centre along the x axis towards the hotter boundary and the green line represents the temperature at 1 mm distance from the centre towards the colder boundary.

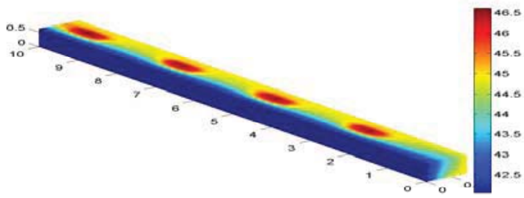


Figure 4: Temperature distribution inside slab using inhomogenous boundary conditions (42 C left boundary and 45C right boundary).

Further the process of heating through air convection was implemented for cases that diode operating temperature is considerably different than that of the slab and of course there is a heat convection carrier. This surface heating mechanism reduces the temperature gradient on the surface and the same time tends to make the local temperature distribution smoother [Koecher 1970]. This is illustrated in figure 5 for the whole body and in figure 6 (up) for the beam propagation path. It is visible that the peak temperature becomes marginally equal for all positions on the wavefront. The same cases were studied for the 4+4 configuration. Both configurations show identical response to the temperature changes of the environment apart from the fact that the temperature peaks differ according to the input current per side, which as mentioned defines the emitted optical power and the center wavelength and as a result also the absorption cross section (figure 6 down).

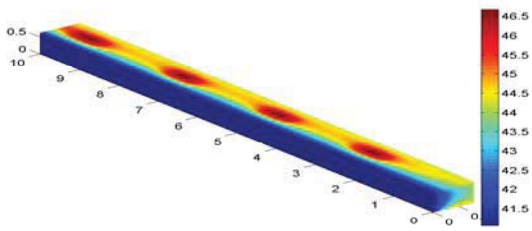


Figure 5: This case has also taken into consideration the heating from the hot air coming from the diodes. Although the maximum temperature has not changed a lot the temperature variation is different. As a consequence the hotspot temperature is close to the temperature of the rest of the upper surface but in the interior there is a larger temperature gradient. This is visualised in next figure were the upper peaks are at the same temperature but the lower peaks have a visible difference.

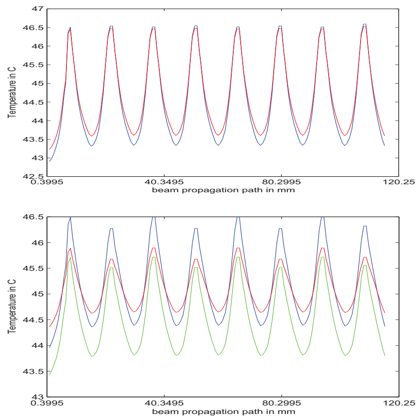


Figure 6: Left: Temperature distribution among the beam propagation path in case of inhomogeneous boundary conditions in 8 configuration. The blue line represents the temperature at the centre of the beam and the red represents the temperature at 1 mm distance from the centre along the x axis towards the hotter boundary. Right: Temperature distribution among the beam propagation path in case of inhomogeneous boundary conditions in 4+4 configuration. The blue line represents the temperature at the centre of the beam spot, the red represents the temperature at 1.3 mm distance from the centre along the x axis towards the hotter boundary and the green 1.3 mm towards the colder respectively.

Last to be presented are the thermal effects of diode failure. The first case with diode failure is under homogeneous boundary conditions. The 'dead' diode will stop emitting optical power and ideally will also not emit infrared or exchange heat with the environment. The effect of the temperature distribution on the beam propagation path can be observed in figure 7 up. In the second example of failure there are also non-homogeneous temperature gradient effects on the wavefront of the beam. At the region of the failed diode the temperature on one side of the wavefront (towards the hotter boundary) will be higher than that in the center (figure 7 down). An overview of the temperature results can be seen in table 1 and the temperature gradients on figure 8.

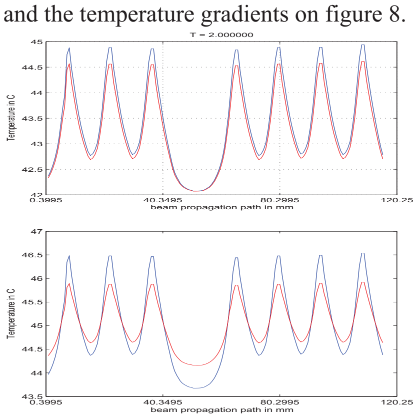


Figure 7: Left: Temperature distribution among the beam propagation path for the case of homogeneous boundary conditions with a failed diode. The blue line represents the temperature at the centre of the beam and the red represents the temperature at 2 mm distance from the centre along the x axis. Right: Temperature distribution among the beam propagation path for the case of inhomogeneous boundary conditions and a failed diode. The blue line represents the temperature at the centre of the beam, the red represents the temperature at 1 mm distance from the centre along the x axis towards the hotter boundary.

	Case 1	Case 2	Case 3	Case 4 (4+4)	Failure 1	Failure 2
Boundary 1	42	42	42	42	42	42
Boundary 2	42	43.5	45	45	42	45
Max Temp	44.9	46	46.8	46.8	44.7	46.5

Table 1: summary results from the cases presented

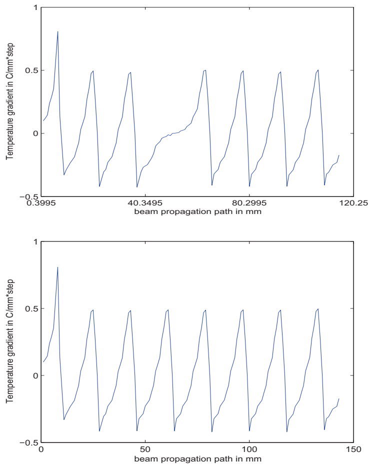


Figure 8: Up: Temperature gradient distribution among the beam propagation path for the case of homogeneous boundary conditions with a failed diode. Down: Temperature gradient distribution among the beam propagation path for the case of inhomogeneous boundary conditions.

CONCLUSIONS

The key achievement of this work is the modelling of the temperature fluctuation along the beam propagation path in regard to the boundary conditions, the material properties of the pu slab and the performance of the diodes. Some interesting cases applicable to the purpose of this work were studied and compared. The inhomogenous boundary conditions cause non uniform temperature gradient in the wavefront propagation path, which affects the beam quality of the output beam. The convective currents can partially counter this effect for the surface area of the slab. For the failure analysed cases the conditions on the boundaries play again an important role, since as illustrated they can significantly change the ratio of the temperature in the center of the wavefront to the temperature on the edge of the wavefront.

REFERENCES

"Evaluating the effect of transmissive optic thermal lensing on laser beam quality with a Shack-Hartmann wave-front sensor", Justin D. Mansell et al., Applied Optics/vol. 40.No.3, 2001

"Thermal lensing in a ND:Yag Laser Rod", W Koecher, Applied Optics/ vol. 9,No. 11, 1970

"How to measure Laser Beam Quality", AE Siegman et al, Stanford University issue, 1998

"Thermal coefficients of the expansion and refractive index in YAG", Rosalind Wynne et al, Applied Optics/ Vol 38, No 15, 199

"The FEA code of Lascad", Konrad Altman, Lascad tutorial

"A Heat Transfer Handbook", John Lienhard, Phlogistron Press, Cambridge