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Update on Laser Development for Lunar Laser Ranging in South Africa

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ABSTRACT

A new fundamental space geodetic observatory for South Africa has been proposed. Lunar Laser Ranging (LLR) is one of the space geodetic techniques to be hosted on-site. LLR requires a pulsed laser that can operate at 100 to 400 mJ energy per ~ 20 pico-second pulses, at a pulse repetition frequency in the kHz region. It must also have excellent beam quality at $M^2 < 1.1$. Since no commercial laser matching the exact specifications could be obtained, it was decided to develop such a laser.

The most feasible candidate for such laser parameters was found to be a crystal-based diode pumped system. Several measures must be adhered to in order to obtain the required results: end-pumping will reduce losses and therefore minimise excess heat, a very good overlap between the pump and laser beams will further reduce losses, thermal lens effects must be kept to a minimum and corrections for astigmatism must be incorporated, to name a few.

Nd:YLF was identified as a suitable candidate for the gain medium crystal. 4 such crystals were used within a single resonator to multiply the output power. The setup was also built in such a way that the astigmatism of 2 crystals overlapped at right angles with the other 2 crystals'. This minimised the effect of the overall astigmatism. The total output power of this initial continuous wave laser was 87 W at 1053 nm, less than the anticipated 100 W. A revised setup with smaller pump beam diameter is underway.

A 4 crystal Nd:YLF laser still seems like the best candidate to achieve the required output for LLR. Future work includes a redesign of the resonator, pulsing the laser and frequency doubling it to green.

Key words: High-power, pico-second, laser, ranging, lunar

INTRODUCTION

A new fundamental space geodetic observatory for South Africa has been proposed and various workshops were held to date in this regard (Booth *et al*. 2007). The main drivers of this are the ageing and subsequent breakdown of current equipment as well as deteriorating atmospheric seeing conditions at the current centre of operations, HartRAO.

Lunar Laser Ranging (LLR) is one of the space geodetic techniques to be hosted on-site. This device will double up as a Satellite Laser Ranger (SLR) during the periods when LLR is unfeasible (daytime, full moon). We designed the overall system to anticipate a single photon return signal per laser pulse (when ranging to the moon). Because of this we must move away from the typical 5 Hz pulse repetition frequency to the kHz region. We are aiming to achieve an accuracy of 3 mm on each normal point of the Moons' orbit.

The current LLR system design requires a pulsed laser that can operate at 100 to 400 mJ energy per ~ 20 pico-second pulses, at a pulse repetition frequency in the kHz region. It must also have excellent beam quality at $M^2 < 1.1$ and be in the green wavelength region at around 532 nm. Since no commercial laser matching the exact specifications could be obtained, it was decided to develop such a laser.

The most feasible candidate for such laser parameters was found to be a crystal-based diode pumped system. Several measures must be adhered to in order to obtain the required results: end-pumping, a very good overlap between the pump and laser beams, thermal lens effects must be kept to a minimum and corrections for astigmatism must be incorporated. Each of these will be discussed in more detail.

Nd:YLF is a very suitable candidate for the gain medium crystal. Our approach thus far was to first build up our knowledge on this relatively unknown crystal by using it in various laser setups and then build the prototype for the LLR laser. This prototype laser should have output powers about 200 times smaller than the required laser (thus delivering ~ 1 mJ per pulse), with all other parameters the same. The final design will require additional amplification of the laser pulses. The prototype is implemented initially as a Continuous Wave (CW) laser, and then components are added intracavity to achieve pulses with the desired specification. After various lasers with Nd:YLF as gain medium were built and investigated, an initial design for the prototype could be decided on. 4 Nd:YLF crystals were used within a single resonator to multiply the output power.

METHOD AND RESULTS

With the chosen active medium Nd:YLF, several measures need to be adhered to in order to obtain the required results:

a. Laser diodes are used as pump sources at the absorption peak at ~ 805 nm,
b. end-pumping is employed rather than side pumping,
c. a very good overlap must occur between the pump and laser modes within the active medium,
d. pumping must occur from the lower doping side of the active medium,
e. thermal lens effects must be kept to a minimum
f. corrections for astigmatism must be implemented since Nd:YLF is birefringent

Measures a, b, c and d relate to the overall heating of the crystal. Lowering the overall heating achieves a higher efficiency and minimises the risk of crystal fracture due to thermally induced stresses. Flash lamp (broadband or continuous spectrum emission) pumped systems have a very high thermal load – the energy not used in the stimulated emission process is basically converted to heat within the crystal. By pumping only at the absorption peak of the active medium, a limit is placed on the heating thereof. End-pumping limits the storage of energy in the active medium to the region where the extraction of energy by the laser beam will occur. Closely correlating the pump region diameter with the laser beam diameter in the crystal further reduces losses of energy to heat. Nd doped YLF crystals all have a doping gradient from one side to the other, resulting from the doping process itself. A lower doping effectively leads to less heating, therefore pumping must occur from the lower-doped side.

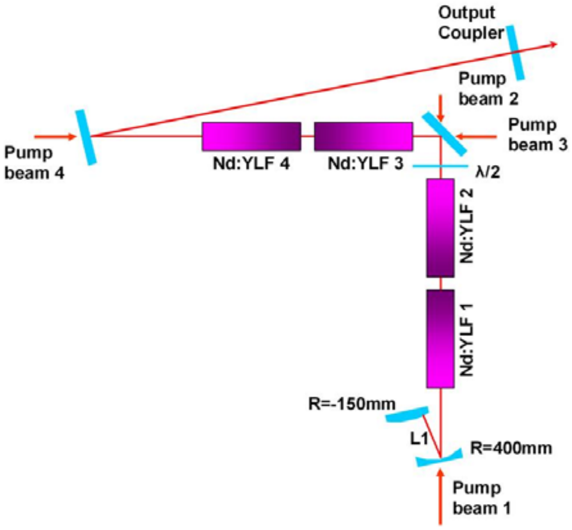

Figure 1. Resonator layout schematic.

Thermal lensing arises from the bulging of the crystal faces due to the non-uniform heating and degrades the laser beam quality. The resonator design (Figure 1) specifically caters to minimise the effect of thermal lensing through control of the short-arm length (between the 2 curved mirrors, L1 in Figure 1).

Astigmatism arises from the natural birefringence of Nd:YLF. The 2 polarisations lase at 1047 and 1053 nm respectively. We employ the sigma polarisation at 1053 nm, because it has a much smaller thermal lens. A correction for this effect is achieved by overlapping the astigmatism to achieve a near-circular laser beam as result. Of the 4 crystals, two crystals must be placed so that the sigma polarisation is horisontal, and two crystals with this polarisation in the vertical direction.

Using 4 crystals in the resonator enables one to achieve more power in a single laser beam. This provides a much better option than either beam combination which severely degrades beam quality, or multi-stage amplification which increases pulse length.

A resonator with a short and long arm, using a convex and concave mirror in the short arm and a flat output coupler in the long arm, caters for many of the requirements mentioned. The long arm must be folded by flat mirrors to cater for the end-pumping scheme. Figure 1 depicts the schematic of the resonator. This scheme uses a pump beam waist radius of 1.3 mm in the crystals, with a laser beam radius of 1.0 mm. The long arm caters for the components needed to achieve pulsing via Q-switched mode-locked operation.

Implementation of this design delivered 87 W of CW laser power at 1053 nm (Bollig *et al.* 2008). This is the highest reported CW output power of a diode end-pumped Nd:YLF laser. Beam quality was very good (Figure 2). The M^2 was unfortunately not measured but it is clear that a TEM_{00} beam is present. No crystal fracture due to thermally induced stresses occurred even at full pump power of ~ 280 W. The laser did however not deliver the anticipated power of 100 W and the overall efficiency was also lower than expected. Fluctuations in output power and pointing were also observed.

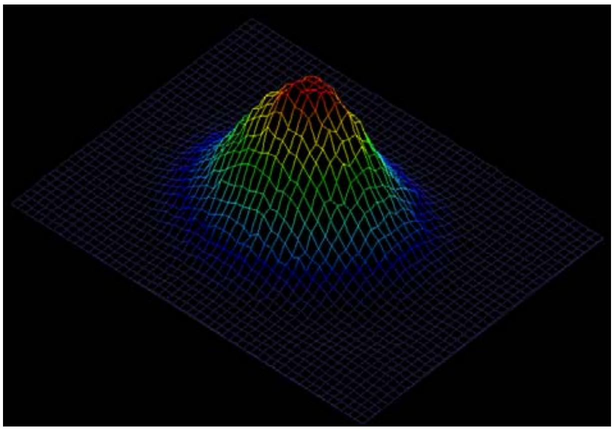

Figure 2. Intensity profile of the laser beam at 87 W of CW power.

Further investigation showed that several factors could be accountable: previously uncatered for intracavity losses and slightly damaged crystal faces seem to be some of the main contributors to this. Also, the resonator design is as such that it operates right on the stability boundary. This leads to increased sensitivity (Magni, 1986). Changing the pump beam waist radius to 1.0 mm inside the active medium should increase the total CW output power achievable. Therefore a redesign of the resonator and pump setup was done to address these problems, as well as to make the laser more compact. The implementation of this new design is currently underway.

CONCLUSIONS

Nd:YLF as an active medium seem like a good choice for a laser to be used in LLR. Such a laser seems to be able to deliver on the specifications depicted by the preliminary LLR design. Further investigation into resonator design and layout is needed. Additional steps for the prototype laser are:

a. Achieve pulsed output via a combination of Q-switching and mode-locking
b. Optimise the system
c. Frequency double to green

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