Operation and Maintenance Overview of the Gemini North Artificial Guidestar Laser.

Robert T. Wyman, Instrumentation Engineer, Gemini Observatory, rwyman@gemini.edu
Maxime Boccas, Optics & Adaptive Optics Group Leader, Gemini Observatory, mboccas@gemini.edu
Chris Carter, Senior Controls Engineer, Gemini Observatory, ccarter@gemini.edu
Celine d'Orgeville, Senior Laser Engineer-Deputy AO Program Manager, cdorgeville@gemini.edu
Kevin White, Senior Laser Technician, Gemini Observatory, kwhite@gemini.edu

ABSTRACT

This is an overview of technical issues, and operational and maintenance activities for the Gemini North Laser system, which currently operates in support of Laser Guide Star Adaptive Optics (LGS AO) science observations.

Discussion will detail various issues with laser pump diodes: failure analysis and reliability as well as techniques in spectral temperature tuning. Wavelength stability has been a major issue for operation of the laser and continuous monitoring of the laser is required to maintain power and wavelength within specification. Current investigation in to the problem will be reviewed along with the methods of managing the issue. The Sum Frequency Generation (SFG) Periodically Poled Stoichiometric Lithium Tantalate (PPSLT) crystal will be discussed with respect to performance, maintenance and future testing plans to commission spare crystals in the laser system should they be needed. Various improvements in software and hardware will be briefly discussed along with an overview of diagnostics tools that are in place or being developed.

Since the completion of science commissioning the operations model we follow to prepare and maintain the laser for LGS AO science observations has allowed for good uptime. During this time it has been an intensive training for those operating the system and some of the experience will be discussed along with the current laser operations support model.

Suggested session: Adaptive Optics.
Key words: adaptive optics, Laser Guidestar, laser pump diodes, wavelength control.

1. Introduction

LGS AO science queue observations have been ongoing at Gemini North Observatory since February of 2007. The last 1.5 years has seen considerable effort put forth to maintaining the laser to achieve necessary performance criteria to support adaptive optics engineering with Altair (Gemini North telescope adaptive optics module), science commissioning, and now science observations. The following review will touch on key technical issues with the laser from this last year and the general operation environment we have since assumed.

Difficulty with the laser system has been rooted in a lack of basic laser expertise specific to this design. We have sought training from various experts during the last year and made many in house efforts to apply existing knowledge to deal with performance and alignment issues. From this work a set of useful procedures has been created specific to the laser maintenance and operation to retain the current body of knowledge. Slowly our preparation periods between runs has shortened allowing focus on deeper system issues and reaching the goal of a turn key operation for the observatory as opposed to one that requires near constant operator interaction during night time laser propagation.

2. System overview

The reader may refer to other papers [1,2,3] detailing the laser construction and development and integration into the Gemini Observatory facility, however, a short review of the laser system design is given below. A summary of typical achieved performance and build specifications are:

Table 1

Typical performance results:	**System build specifications:**
Power: >10 W. Frequency tolerance: +/- 160MHz	Average Power: 14 W. Frequency: 589 nm (peak of the D2 sodium line.) Nominal frequency stability: +/- 100MHz. Beam quality: M^2 <1.4 Line width: <1 GHz.

2.1 Laser design and specifications

Two solid-state infrared (IR) modelocked lasers of 1064 nm and 1319 nm wavelength are frequency summed in a single pass non-linear PPSLT crystal to produce 589 nm laser light. Both IR lasers incorporate a ‘double bow-tie’ resonator optical layout incorporating two double-end pumped Nd:YAG rods. The rods are end pumped with fiber coupled Coherent Inc. FAP800 (Fiber Array Package) laser diodes each with 30 W output at 805nm wavelength. Each YAG rod is mounted in a proprietary design clamshell mount for cooling. Two diagnostic CCD cameras are provided to view the beam exit aperture and beam pre, post and waist profile images for evaluating the beam quality.

Acousto-Optic Modulators (AOM) operating at ~40MHz mode-lock the IR laser beams. The resonator HR mirrors are mounted to moveable stages, which allow the resonators to maintain their characteristic length for modelocking. The mirror positions are adjusted by a timing stabilization control loop or can be fine adjusted by the operator in open loop mode. The control error signals are generated by comparison of the phase of the AOM drive frequency and one half the frequency of the modelock pulse train as measured by high speed photo detectors.

Both IR resonators contain an etalon that is actively temperature controlled with a Peltier device. The 1064 nm etalon is maintained at a constant temperature and the 1319 nm etalon is controlled through the Wavelength Locker (WLL) control loop. 589 nm leakage light is passed through an electro optic modulator and then a sodium gas cell to a high-bandwidth photo detector. The control loop error signal is generated by an interaction of the phase-modulated signal from the EOM (Electro Optic Modulator) with the gas cell and the resultant incident intensity on the detector.

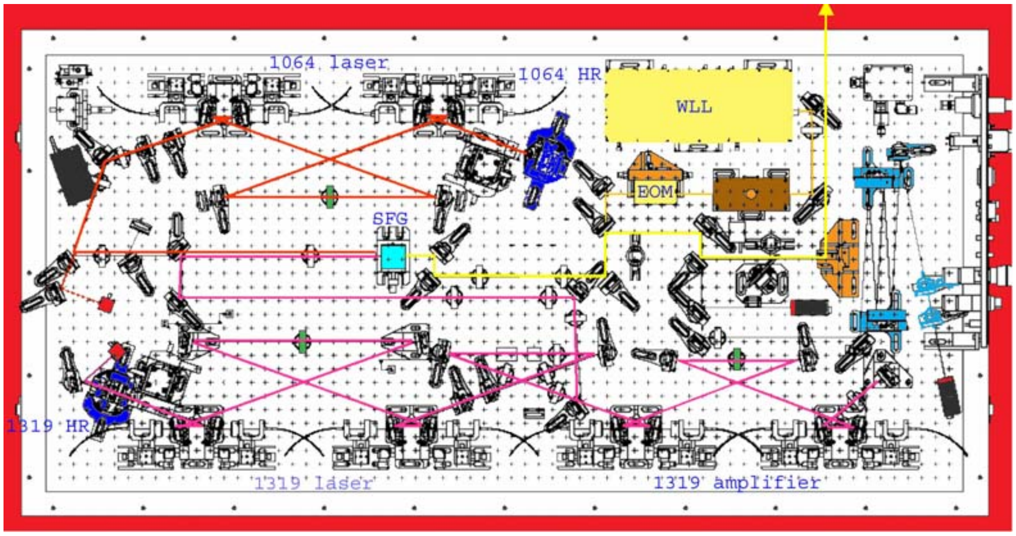


Fig. 1. Fully configured laser bench showing original AMP portion of 1319 laser.

2.2 Modifications to the system

The as-delivered system incorporates a double pass 1319 nm amplifier to boost the otherwise weak 1319 nm resonator. This amplifier portion of the laser was decommissioned in early 2006 due to optical feedback issues and subsequent effect on 589 nm wavelength stability. The output of the 1319 nm resonator now goes directly to

Fig. 2. Laser optics bench.

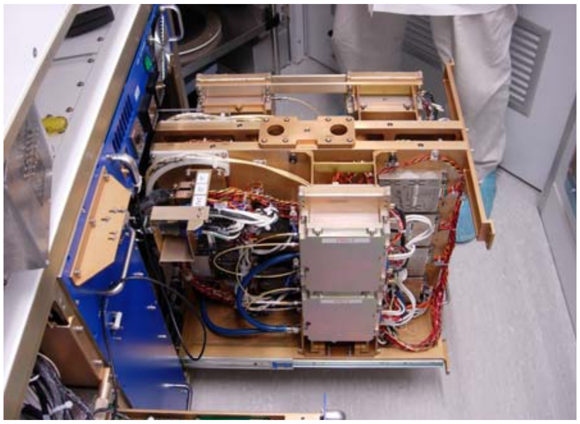


Fig. 3. Pump laser diode chassis.

the main beam line into the SFG (Sum Frequency Generation) crystal. The 1319 nm resonator output is typically 8.5 W with recent 11.0 W performance. Flexure issues appear to cause at least 1.0 W loss of power over the period of one night of telescope motion. This has been consistently observed and will be a factor in reaching the 12 W 1319 nm output goal. With the 8.5 W minimum, the 589 nm output is expected to be 10.6 W or greater. The re-commissioning of the amplifier portion of the laser will be considered in the case that future SFG crystals do not meet the current crystal performance.

Changes to the system made with the vendor include modification of software to allow selectability of displaying the control interfaces with or without the amplifier. A software bug was rectified that resulted in random shutdowns of the laser system often causing shutdown at night and time loss. Simultaneously the shutdown sequence was faulty and caused instant diode power shutdowns to occur while still at nearly full lasing power. This particular issue is considered a possible root cause to early diode failures and is discussed below.

3. Technical Issues

Several issues have existed with the laser, which had not become priorities until this last year when they began to impact science use of the LGS Facility. These were primarily laser pump diode failures, wavelength lock stability, and timing stabilization control loop operation. These are listed in order of priority below and are the primary obstacles to achieving autonomous laser operation.

3.1 Wavelength control

The highest priority issue with the laser system has been instability of the wavelength locker (WLL) control loop. The generation of 589 nm light occurs in an SFG crystal placed in the beam path of the co-aligned infrared lasers. 589 nm output power is dependent on the relative arrival of the two IR pulses into the crystals and the shape of those pulses. By varying the 1319 nm wavelength with an etalon the wavelength of the 589 nm beam is controlled. Leakage through one of the 589 nm fold mirrors passes through an EOM, a heated sodium cell and into a detector. A wavelength error signal is derived from these three components and used to drive the temperature of the etalon thereby closing the loop. During periods of wavelength instability the wavelength frequency shift will begin fluctuating with a period of 1 to 2 seconds. The amplitude of the shift varies considerably but has been successively reduced from a high of +/-400 MHz to less than +/-150 MHz. Discussions with the laser designer and other experts identified possible causes related to optic coatings, optical feedback, and mode hopping. An improved 1319 nm resonator high reflector (HR) mirror was proposed and then installed. This did not resolve the problem but did increase resonator power by 0.5 W. Gemini has pursued the problem by closely examining the control loops and their tuning, filtering signals in the loop and by examining oscillator alignment. This instability is accompanied by a matched 1319 nm pulse width fluctuation. Longitudinal mode hoping has been considered as the instability root issue. Fluctuations in the laser diode temperature control have occurred and are know to cause mode hoping. Improvements with the diode cooling control have been simultaneous with improvements in the WLL instability. The control problem is quite challenging due to the requirement for precise temperature control with good stability, in an environment with fairly substantial RF and electrical noise. It is certain that further improvements can be made in this area.

Recently the laser underwent an intensive alignment project to ensure the laser was operating at its design point followed by an investigation into the WLL issue. The instability was not eliminated, however, it appeared to have been attenuated and the nature of the instability was changed. The 1064 nm resonator become more sensitive to cavity length adjustments, whereas the 1319 nm resonator became less sensitive. Simultaneous with this work the instability had been managed through operator intervention to a point where several laser runs occurred without instances of the instability. However, the root issue still remains and investigation continues to identify and resolve it. The current mode of operation is constant operator attendance to ensure the drift of the laser does not cause power drops or wavelength instability.

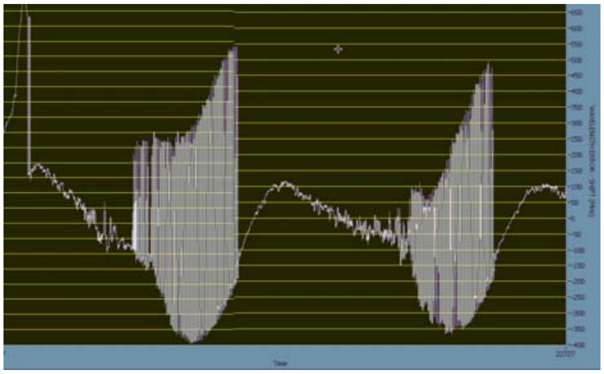


Fig. 4. Typical observed frequency instability of 589 around peak of D2 line.

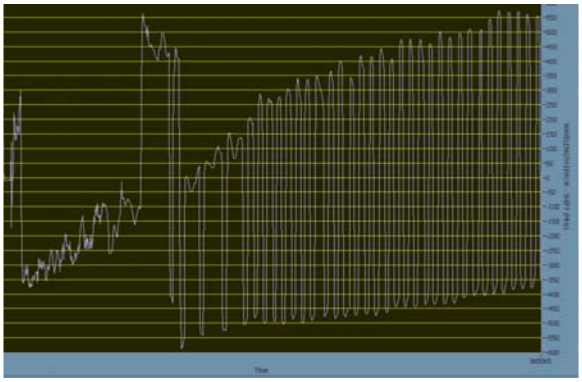
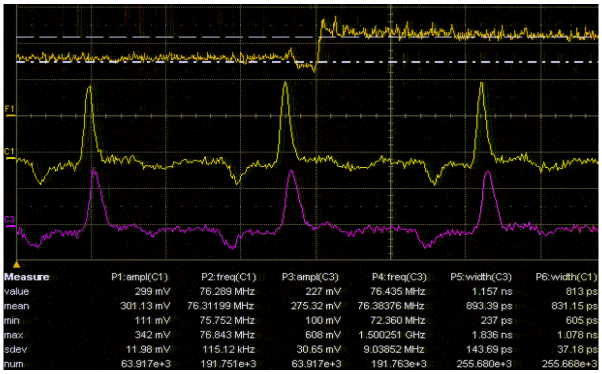


Fig. 5. Frequency instability.



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Measure   P1:ampl(C1)   P2:freq(C1)    P3:ampl(C3)   P4:freq(C3)    P5:width(C3)   P6:width(C1)
value          299 mV    76.289 MHz         227 mV    76.435 MHz        1.157 ns         813 ps
mean        301.13 mV  76.31199 MHz      275.32 mV  76.38376 MHz       893.39 ps      831.15 ps
min            111 mV    75.752 MHz         100 mV    72.360 MHz          237 ps         605 ps
max            342 mV    76.843 MHz         608 mV  1.500251 GHz        1.836 ns       1.078 ns
sdev         11.98 mV    115.12 kHz       30.65 mV   9.03852 MHz       143.69 ps       37.18 ps
num        63.917e+3     191.751e+3      63.917e+3    191.763e+3      255.680e+3     255.668e+3
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Fig. 6. 1319 nm modelocked pulse width shift during instability period.

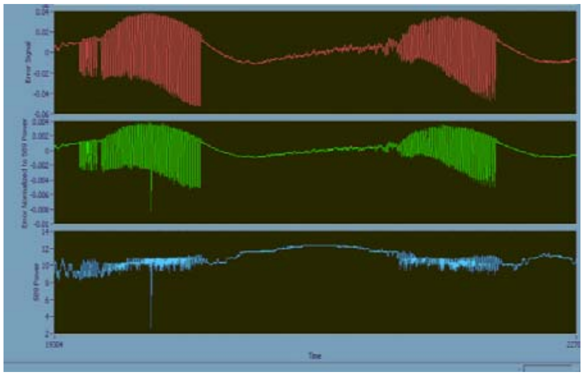

Fig. 7. Wavelength parameters strip chart.

3.2 <u>Laser Diodes</u>

Diode failures have become a serious issue since mid 2006. Table 2 is a list of diodes that have been removed from the system since May 2006. The laser diode lifetime expectancy per the supplier is 10000 hours. They are operated in the range of 22 to 30 W output continuous (non-pulsed) at 30 to 35 amps DC current. The vendor recommended handling procedures are strictly adhered to. Our current rate of use with the laser system is ~940 hrs/year, which is actual operating time for the laser diodes.

3.2.1 Pump Laser Diode failure modes and analysis

As mentioned the automated shutdown sequence was faulty resulting in immediate shutdown of the laser diode power supplies several seconds after the start of their normal ramp down at 0.1 amp/sec. The majority of diodes in the system currently have experienced these rapid shutdowns over the last 1.5 years and it is considered as one possible cause of early failure. Fiber contamination is another possible failure cause. Inspection of FAP noses on failed units found various levels of contamination along with existing burn marks on some units. The disassembly of fibers from the FAP noses during diode swaps and replacements is a common task and careful handling and cleaning has always been performed. A full inspection is underway on the current set of laser diodes to note existing fiber nose output conditions and establish a best practice for maintaining clean interfaces. An inspection was arranged with Coherent Inc. of Santa Clara, California and they identified fiber output surface burn marks as the root issue to power loss on three FAP assemblies that were submitted. Fig. 6 thru 9 are examples of these and similar types of damage. We are investigating the root failure mechanism with >30% power loss on two units and are in the process of further failure analysis work with Coherent. Potential causes are back reflection from the burn spots that could destroy or affects the performance of the diode lasing.

Other modes of failure have been considered such as breakdown due to out gassing of epoxies in the vicinity of the laser diode, an effect noted by discussions with Stanford Photonics Research Center. There is a small volume of '3M brand 2616 two-part epoxy' used to pot a temperature sensor (thermistor) into the FAP laser diode module base. Expected failure rates of the diodes cannot be established without further testing to see if there are any differences between the units. Most of the laser diodes have been classified as failed due to their low output. Our pass-fail benchmark is 25W output at 35 amps current. Currents can be increased when this criteria is not met as long as there is an associated lower performing diode that will share the common power supply and pump the rod ends with similar laser irradiance.

Table 2. Laser pump diode failures summary.

Date	S/N	Description of Failure.	Est. hours
2005	J17756	Low power.[1]	<1455
03/30/06	J17755	Low power but used temporarily in 1064.	1455
03/30/06	J17753	Low power.	1455
05/6/06	**J17760**	Low power.	~1600
06/29/06	**J17762**	**Rapid power loss**, >30% in several hours.	1709
07/26/06	**J15993**	Low power.	1647
10/24/06	J17751	Low power.	2022
12/29/07	J17764	Low power at installation.	~150
01/2/07	J17763	Low power at installation.	2245
02/20/07	J16282	No burn marks after cleaning.	~800
05/24/07	J15778	**Rapid power loss.**	2754

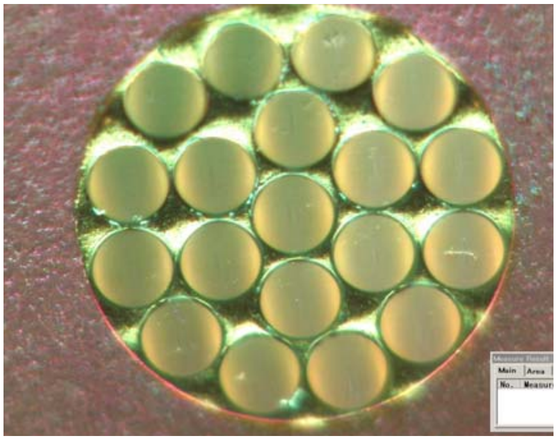

Fig. 8. Fiber output bundle burn and scratch damage, J17760.

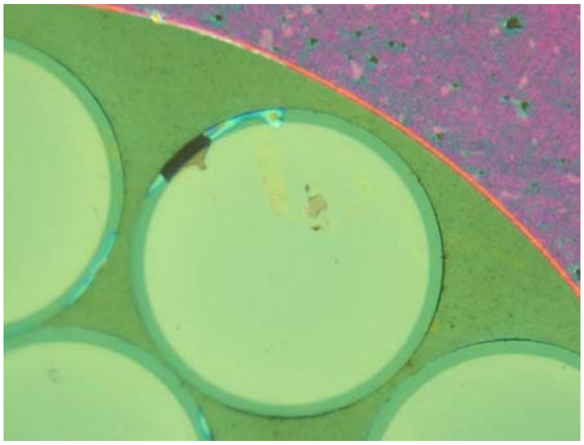

Fig. 9. Fiber burn damage and edge defects on perimeter of individual fibers, J17760.

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[1] Lower power output is defined as <20 W @ 35 A, or where resonator output fails to meet required levels due to the poor performing laser pump diode unit. Rollover (point at which gain curve deviates and output falls with increased current levels) is usually within 1A.

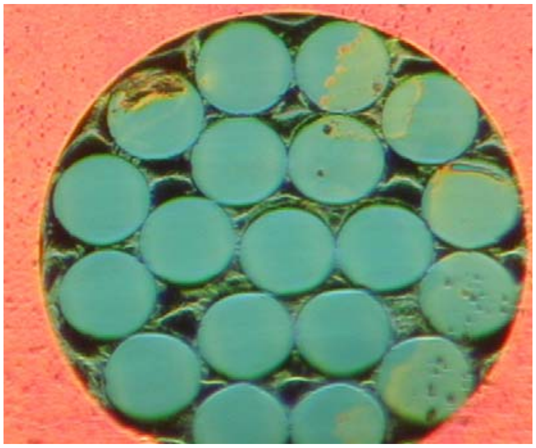

Fig. 10. Showing various burn marks, J17753.

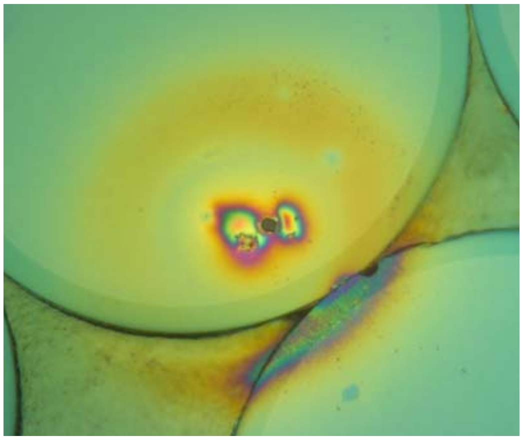

Fig. 11. Showing various burn marks, J17753.

3.2.2 Wavelength tuning of laser diodes

The original support arrangement with the laser system supplier provided calibration services for the laser diode assemblies. This arrangement was unworkable as far as maintaining up time on the laser system and the lack of spare parts to allow major components to ship to the US mainland for calibration purposes. A minimal two week turn around was required for this to achieve on-sky scheduling of the laser and to have additional time for laser preparations. Therefore the tools were assembled to perform these procedures at the observatory. Central to this task is a wavelength spectrometer purchased from Ocean Optics [4] and optimized for 0.17nm resolution in the 760 nm to 890 nm range, ideal for the 805 nm laser diode output tuning. It was decided to test and tune the diodes on the laser system itself as opposed to a separate test bench thus eliminating a second calibration step and variations between the test bench and system. The wavelength calibration is performed by directing the laser diode unit output fiber towards a power meter. The spectrometer samples the diffuse reflection from the power meter through a second fiber mounted adjacent to the first and is therefore protected from high power irradiance. This serves as well to allow measurements for diode power meter calibrations. The laser enclosure environment is typically 7.0 degree centigrade and causes a substantial shift in the spectrometer reading from normal room temperature. Wavelength calibrations are performed with a Mercury-Argon reference light source.

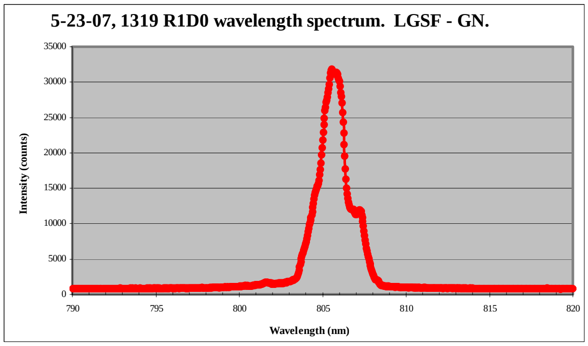

Fig. 12. Wavelength spectra of FAP 800 laser pump diode.

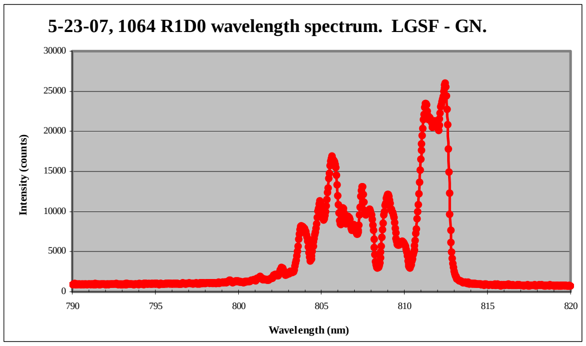

Fig. 13. Wavelength spectra captured during the instance of a diode failure.

When the spectrometer is ready for operation, the diode power supply and temperature controller are turned on and the current setpoint is stepped in 5 amps increments between 15 and 35 amps. The laser controller automatically ramps at 0.1amp/sec between these steps. Spectral data is collected at each step. At the nominal operating current determined by the power meter the temperature control for the diode is adjusted to center the output peak at 805 nm. 805 nm is chosen instead of 808 nm to reduce thermal birefringence in the YAG rods. It is not the optimal wavelength for rod excitation but it has advantages in avoiding thermal effect, which is favorable to stable laser design. However, when the spectrometer capability was first used it was determined that 5 of 8 diodes were operating at or near the 808 nm peak. Future alignment work of the resonators should improve their power output and allow for retuning of the diodes back to the specified 805 nm wavelength. Fig. 7 shows a typical wavelength spectra of the pump laser diode outputs. Fig. 8 is the wavelength spectra during a period of laser diode failure on May 24th, 2007.

3.3 Timing stabilization

The timing stabilization control loop maintains the individual laser cavity lengths for optimal SFG conversion efficiency. From a controls perspective, this corresponds to maintaining the desired phase error between the AOM RF oscillator and the laser pulses as detected at the HR mirrors. The timing stabilization error signal discussed earlier in the system overview drives a PID loop to regulate the position of the HR mirrors via a stepper motor that drives a high-resolution stage. When the loop is enabled, the current phase error signals becomes the respective setpoints for the two motors. The primary issue with its application is the increase of 589 nm wavelength shift error by approximately 50%. This noise typically exceeds the +/-100 MHz tolerance. Since regular adjustment of the cavity HR mirrors was required to manage the wavelength instability issue, the auto timing mode was never used during laser propagation. Key to reducing the operator intervention with the laser system is reintroducing this control and reducing the noise influence on the wavelength error.

Dynamic testing of the servo loops in the laser is always complicated by the need to perform tests that cannot damage the system, for example by causing instability. To this end, the tests initially employed are generally very simple and consist of static offsets and step responses, which are related to the types of demands the system sees in operation. These can often provide sufficient information to determine whether the system is performing in a stable way, at least at a fundamental level.

For more in depth analysis, data logging becomes important. Logged data can be subjected to detailed analysis from statistical, time- and frequency-based viewpoints which can pinpoint more subtle issues. Logging of this sort has been shown to be possible by modifying the underlying LabView code to store data to disk.

Current work with the servo loops has shown reasonable stability but highlighted areas where the dynamic performance could be improved. As mentioned earlier, there are also concerns about noise mitigation in the servo loops and whether the current sampling schemes are suitably robust in this respect. These and other issues are the subject of ongoing investigation.

3.4 PPSLT Crystal

The current SFG crystal in the laser system is reported to have exceptionally high conversion efficiency. Work with this crystal has been marked by extreme caution and only recently in the company of more experienced laser experts was invasive work performed. Several damage zones within the crystal have been identified from known incidents in the past and their total area is apparently very small, on the order of <5%. While moving the crystal in optical x-y space relative to the laser beams with the crystal actively converting, the damage areas are easily identified as well as good conversion immediately adjacent to the damaged zones. However, in the last several months the total combined area of damage zones, non-converting zones and areas near edges has totaled to a higher value than previously thought.

In the near future testing of a new series of crystals that have been procured will begin. It is expected that these crystals may not have as high a conversion efficiency as the current one. We have had acceptable on sky performance with the laser operating at ~8 W output of 589 nm. If expected gains in output of the two IR lasers are achieved in the next 3-6 months we could offset the lower conversion efficiency with the new crystals but it remains to be seen. The crystal testing will help define where we have been, what we have and what to expect in the future. Worst case could be re-commission of the 1319 nm amplifier with its previous feedback issue. This would strain our maintenance schedule with the additional alignment tasks and complicate the co alignment.

4. Operation and Maintenance

When the current laser team took over the system in mid 2006 we had just begun active scheduled laser runs for science commissioning and the scheduling and preparation routines were not fully defined. Laser expertise were lacking, there were few laser related procedures and alignment issues consumed most preparation times between runs. Training with on site visits from various experts during this last year and continuous efforts to document and apply procedures learned has stabilized preparation periods for the laser. There are now nearly thirty separate procedures in electronic format for on-line updating and referencing. Diagnostic tools have been acquired as well that allow better maintenance and testing of the laser.

Laser runs occur once per month and typically last 5-9 days. At the end of a laser run there is a period of rest followed with work on laser issues that are prioritized in monthly task meetings. Usually the next run preparations take priority, however, if the system is operating well then long term projects are developed. A checklist is used to confirm completion of critical steps in three main areas:

- **Propagation** – Items associated with notification to other observatories, to the Military Space Command, and to the FAA as well as submission of laser Guidestar target coordinates to the laser clearing house.
- **Laser –** The week before the laser run, certain tasks are performed to maximize the performance of the laser. The optics in the laser are inspected. Individual diode powers are checked to make sure that the YAG rods are being pumped sufficiently. The individual 1064 nm and 1319 nm laser cavities are checked to ensure that sufficient power from each cavity is being delivered to the 589 nm SFG crystal and the profiles are assessed for beam quality. If resonator output is low then alignments are performed to maximize power. The beam co-alignment is checked by reviewing the exit aperture and diagnostic beam profiles
- **BTO (Beam Transfer Optics) –** Three days before a laser run, alignment of the BTO and inspection/cleaning of associated optics is performed. The BTO mirrors direct the 589 nm laser beam from the laser enclosure to the top of the telescope through a vane structure containing a series of fixed and motorized mirrors. Using CCD cameras mounted along the path, beam alignment is achieved by moving the motorized mirrors and positioning the beam so that it is centered on the top fast steering mirror. This alignment is maintained during telescope elevation changes by a look-up table based flexure compensation model. Final alignment to the launch telescope is controlled by the telescope operator when the laser is on sky. This alignment is confirmed each day of the laser run prior to propagation.

4.1 Diagnostic tools

Laser system maintenance requires various diagnostics tools for profiling beams, measuring power and pulse rates, and measuring wavelength spectra. These tools are briefly discussed as follows:

- **Beam Profiling -** A frame grabber and Spiricon [5] beam diagnostic software operate on a laptop computer and are interfaced to any of three cameras on the laser system: two visible wavelength CCD cameras mounted to the laser bench and an SU-320 InGaAs detector array head with 0.9 to 1.8um wavelength range. The infrared detector array greatly simplifies imaging of the 1319 nm beam and requires no significant attenuation between either IR beam. The profiling camera is the most useful tool for evaluating beam alignments, thermal effects in the resonators, and spatial modes in the beam. Operating without this tool risks damage to components as the operator is not aware of root problems that might exist. The laser bench diagnostic cameras that view the exit aperture give good indication of beam profile issues as they appear in the crystal and on the sky in visible wavelength.

- **Wavelength Spectrometer -** This tool was recently purchased to evaluate the pump laser diodes output wavelength spectra. The laser diodes are temperature-tuned to produce the desired wavelength of 805nm. A sampling fixture is planned for a future upgrade to mount the power meter and fiber holders on one assembly that will reside on the laser bench. The spectrometer will also have a permanent mount within the laser enclosure to reduce handling issues.

- **GEA – Gemini Engineering Archive -** Gemini Observatory engineering operates a powerful data collection tool. Many of the observatory systems generate streams of data that are tagged and archived for later retrieval. Many parameters of the Laser Guide Star Facility are collected in this way and applied to later engineering analysis. By early 2008, all laser specific data is expected to be archived.

5. Conclusion

A laser guidestar facility for adaptive optics requires a dedicated team to work extensively with temperamental laser system and to manage the many sub tasks for successful on sky laser propagation. It must be acknowledged that much effort is required in the background to make the Gemini North laser system reliable and that operation has been very smooth and transparent to the astronomers. There is need for improvements in order to achieve the goal to have the laser technician at the summit for preparations in the afternoon, stay for the beginning of night operations and then to not touch the laser till the next day. The telescope operator (Systems Support Associate - SSA) would be in charge of operating shutters and shutting down the laser at the end of the night. This should be possible provided we obtain prioritized support we need in the observatory impacted engineering schedule.

6. Acknowledgements

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