Dye Cell used in Active-Passive Laser Oscillator replaced with a Cr^{4+}:YAG crystal Saturable Absorber for NASA SLR Stations

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Abstract

Since 1983, the current network of NASA Satellite Laser Ranging (SLR) stations used an Nd:YAG oscillator cavity in an active-passive configuration to generate 150-200 psec (2mj) 1064nm pulses for satellite ranging. This cavity (active-passive) used a liquid (chlorobenzene) dye cell as the passive saturable absorber. The dye consisted of Exciton (Kodak-9740) Q-Switch I dye and monochlorobenzene as a solvent. The dye mixture would degrade during use and would require daily maintenance. Chlorobenzene is a hazardous substance that requires special handling equipment and procedures.

The dye cell was replaced with a Cr^{4+}*:YAG crystal used as a saturable absorber in an active-passive mode-locked Nd:YAG laser. The new absorber requires little or no daily maintenance and the improved stability and laser performance is equal to or better than the dye cell. Pulse widths of 150psec were easily obtained and output energy variations of less than 10% shot to shot.*

Introduction

Since 1983, the current network of NASA Satellite Laser Ranging (SLR) stations [3] used an oscillator cavity in an active-passive configuration to generate 150-200 psec (200mj) 1064nm pulses for satellite ranging. This flashlamp pumped cavity used a liquid (chlorobenzene) dye cell as the passive saturable absorber. The dye consisted of Exciton (Kodak-9740) Q-Switch I dye and monochlorobenzene as a solvent. The dye mixture would degrade during use and would require daily maintenance. Chlorobenzene is a hazardous substance that requires special handling equipment and procedures.

Two types of saturable absorber were investigated: SAM and then Cr^{4+}:YAG. Testing of a SAM in the cavity produced only marginal results and unstable pulses at the nanojoule level. Flashlamp pumping of the modelocked cavity needs to produce pulses at the 2 mj level to make it useful in the single amplifier laser.

Research into an alternative saturable absorber led to a manufacturer of Cr^{4+}:YAG material for use as a Q-switch for generating giant pulses [1, 2] and in active-passive mode locked lasers.

A Cr^{4+}:YAG crystal with the dimensions of 7.5x7.5x4.0 mm with anti-reflective coatings for 1064nm on both surfaces was installed into the oscillator cavity as shown in Figure 1.

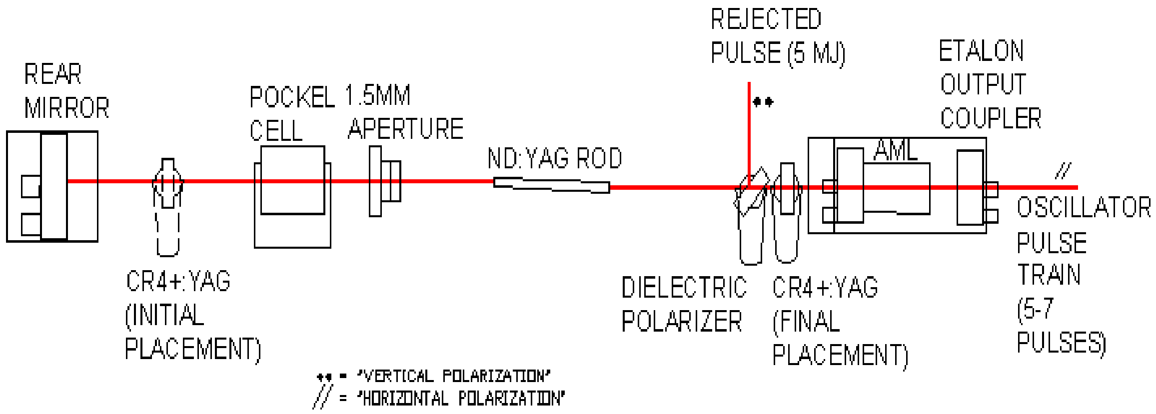

Figure 1. Laser Oscillator Cavity

Modification

The dye cell was part of the rear mirror assembly so the initial placement of the Cr^{4+}:YAG crystal was installed between the rear mirror and Pockels cell as shown in Fig. 1. During initial testing, approximately 1% of pulse leakage was being rejected from the cavity. Because of polarization effects caused by the anti-reflective coatings on the Cr^{4+}:YAG absorber, the placement (final placement) of the Cr^{4+}:YAG crystal was moved to the other side of the polarizer. In this case, any leakage cause by the anti-reflective coating was reflected off of the polarizer in the opposite direction of the rejected pulse.

The cavity mirrors consist of a 99% reflective rear cavity mirror and a solid etalon for the front cavity. Output pulse width can be controlled by changing the feedback into the cavity from the front reflector. By changing the etalon feedback reflector, the spectral line width narrows, effectively decreasing cavity feedback and narrowing the output pulse (See Table 1).

Table 1. Oscillator (Cr^{4+}:YAG) Pulse Width versus Etalon Thickness

Etalon Thickness (mm)	PulseWidth-1064nm (psec)	PulseWidth-532nm (psec)
5	348	238
3	289	218
2	260	160
1	230	140
0.5	179	115
0.25	153	105

The oscillator using the dye cell produced a pulse width shown below in Table 2.

Table 2. Oscillator (Dye) Pulse Width versus Etalon Thickness

Etalon Thickness (mm)	PulseWidth-1064nm (psec)	PulseWidth-532nm (psec)
5	225	90-138

For use with the Cr^{4+}:YAG crystal, the etalon that produced the pulse width closest to the original width using the dye cell was chosen. A 1mm etalon was selected. The Pockels cell is used in the cavity to reject a single pulse from the cavity. The output pulse train is fed into a detector that is used to fire a chain of avalanche transistors. The output high voltage pulse (1/4 wave voltage) is applied to the single crystal Pockels cell to rotate the polarization by 90 degrees and then reflect out of the cavity from the polarizer.

The original polarizer was a thin film dielectric polarizer mounted at 56 degrees with an isolation of 200:1. This was replaced with a CVI Melles Griot thin film dielectric polarizer mounted at 45 degrees with an isolation of 500:1. The coating also seems more robust and not as susceptible to damage.

The original cavity used two 1.5mm mode limiting apertures. During testing, it was difficult to align two apertures and the 2nd aperture was removed. The addition of a 2nd aperture seems to distort the output beam profile and appears to lose its Gaussian energy distribution.

The Nd:YAG rod remained the same for this modification. The rod is 7mm round, 115mm long with both ends cut at 2 degrees and AR coated on both surfaces.

The Cr^{4+}:YAG saturable absorber is cut to 7x7 mm square and 4mm thick. Both surfaces have anti-reflective coating optimized for 1064nm. Before the rod is pumped using 2 flashlamps (18J), the energy population of the saturable absorber is at the ground state and the transmission through the Cr^{4+}:YAG crystal is low. When the rod is pumped, energy in the cavity builds until all ions in the absorber are stimulated quickly to the first and second energy states. This causes the absorber transmission to increase allowing for unity gain and lasing to begin. Following lasing, the ions return to the ground state.

The acousto-optic modulator (70MHz) mode locks the cavity to produce a stable train of 5 – 7 pulses. The cavity length is optimized to generate the most stable narrow (150psec) and stable pulse.

Experimental Results and Analysis

The Cr^{4+}:YAG saturable absorber was installed into the NASA SLR Moblas-7 laser on September 11, 2007 and initial ranging began 2 days later. Initial data results had indicated that the number of rejected data points was higher than using the dye cell. It also appeared that the laser was outputting pre-pulses with a ratio of 100:1 of the main selected pulse. This caused the receive discriminator to trigger early on the pre-pulses with strong receive signal strength from the target. This can be seen in Figure 2 showing multiple line residuals for each laser pre-pulse.

On October 24, 2007 the position of the saturable absorber was changed (Fig. 1) to the opposite side of the 45 degree polarizer. Apparently the anti-reflective coating on the saturable absorber was affecting the polarization of the cavity beam causing the polarizer to reflect a small portion of the beam out of the cavity during each pass through the cavity. By moving the saturable absorber to the opposite side of the polarizer, the non linear component of the beam is reflected in the opposite direction of the amplifier and dumped. Figure 3 shows a time line of the number of rejected data points per pass. It indicates that after the relocation of the saturable absorber, the number of rejected data point decreased to acceptable levels.

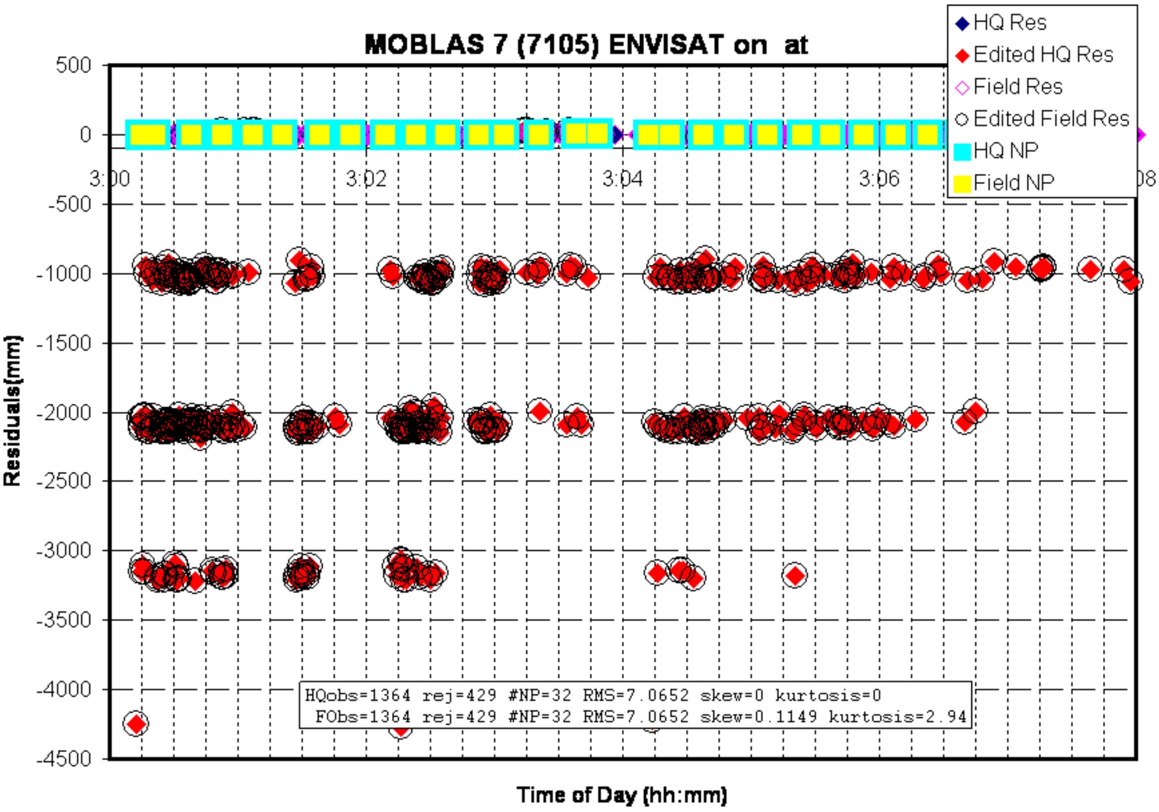

Figure 2. Initial Pass Results Showing Oscillator Cavity Leakage.

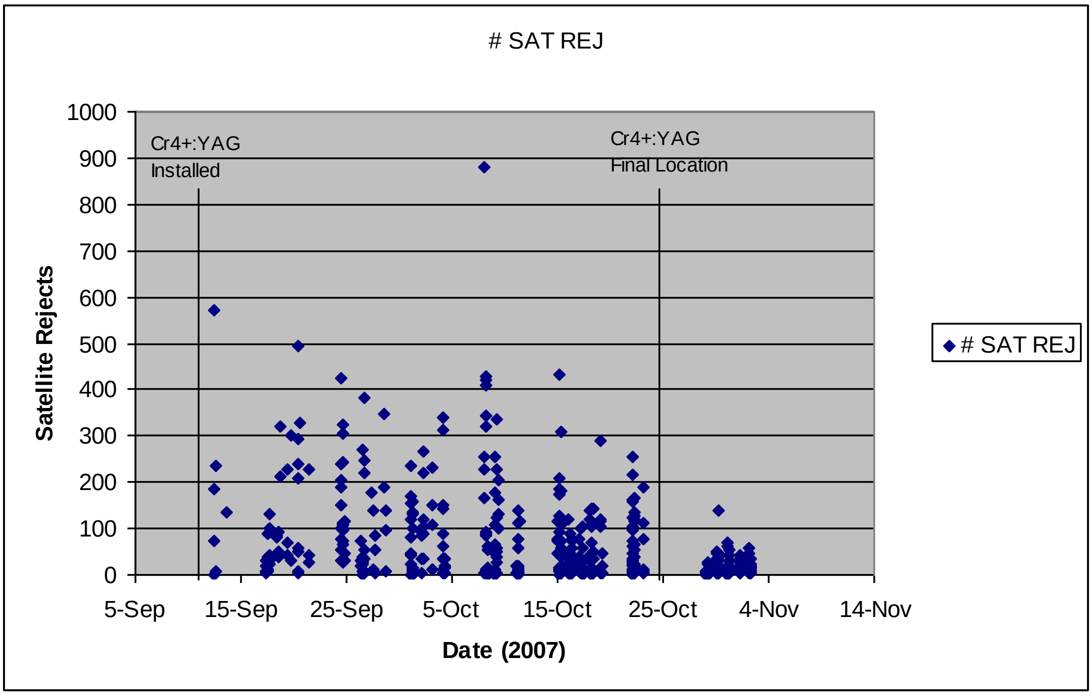

Figure 3. Time Line Showing the Number of Rejected Pulses per Pass.

Conclusion

The modification has been performed at three of the five Moblas SLR stations. The original intention of this modification was to be transparent to system performance; however, between the upgrade of the laser and improved alignments procedures, the system performance has actually improved. The number of data points per pass, data quality and system delay stability have all improved.

In addition, it has been reported that the usual daily laser maintenance has decreased from hourly/daily optimization alignments to weekly, monthly or in some cases 3 or 4 months. After a 15 minute warm-up, laser power and stability becomes optimal without alignments.

Because of the additional pulse width stability, this should also minimize the likelihood of exceeding the damage threshold of several optics on the laser table. This should reduce annual operational costs of the laser systems and reduce the likelihood of a laser failure and lost data opportunities.

Special thanks to the Moblas crews, data analysis and engineering group for making this successful improvement in safety and performance for all the NASA SLR stations.

References

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