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Multi-Billion Shot, High-Fluence Exposure of Cr^{4+}:YAG Passive Q-switch

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ABSTRACT

NASA's Goddard Space Flight Center is developing the Geoscience Laser Altimeter System (GLAS) employing a diode pumped, Q-switched, Nd:YAG laser operating at 40 Hz repetition rate. To meet the five-year mission lifetime goal, a single transmitter would accumulate over 6.3 billion shots. Cr^{4+}:YAG is a promising candidate material for passively Q-switching the laser. Historically, the performance of saturable absorbers has degraded over long-duration usage.[1] To measure the multi-billion shot performance of Cr^{4+}:YAG, a passively Q-switched GLAS-like oscillator was tested at an accelerated repetition rate of 500 Hz. The intracavity fluence was calculated to be approximately 2.5 J/cm^2. The laser was monitored autonomously for 165 days. There was no evidence of change in the material optical properties during the 7.2 billion shot test.. All observed changes in laser operation could be attributed to pump laser diode aging. This is the first demonstration of multi-billion shot exposure testing of Cr^{4+}:YAG in this pulse energy regime[2].

Key words: Cr^{4+}:YAG, passive Q-switch, optical damage, saturable absorber

1. MOTIVATION

NASA's Goddard Space Flight Center is developing the Geoscience Laser Altimeter System (GLAS) to measure the polar ice sheet mass balance. This LIDAR system employs a 40 Hz, 110 mJ, diode-pumped, Q-switched, Nd:YAG laser.[3] GLAS will accumulate 6.3 billion shots during its five-year mission. Achieving these stringent requirements while minimizing mass and power necessitates a simple design, limiting the risk of component and system failures.

The GLAS laser oscillator is Q-switched, providing a short pulse of low energy, good beam quality light which is amplified in successive stages. A solid-state Cr^{4+}:YAG saturable absorber is used to passively Q-switch the oscillator. This passive Q-switch eliminates the need for high voltage pulses and reduces the number of intracavity optical elements[4]. Despite the advantages and potential for a highly reliable system, there is little evidence supporting the survivability of Cr^{4+}:YAG in high fluence lasers for billions of shots.

2. EXPERIMENT

To investigate the performance of Cr^{4+}:YAG as a passive Q-switch under multi-billion pulse, high fluence operation, a copy of the GLAS oscillator running at an accelerated repetition rate of 500 Hz was developed. The increase in pulse repetition rate provided faster data collection. The experimental setup is shown in Figure 1.

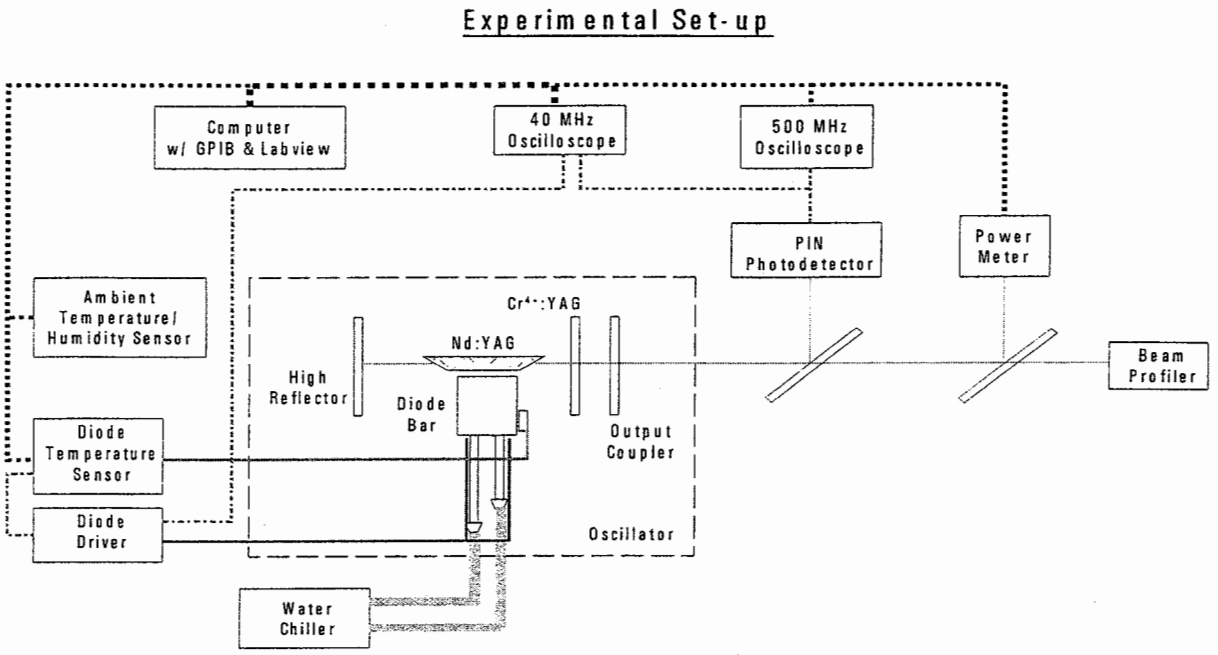

Figure 1. - Diagram of accelerated GLAS oscillator and testing station

The oscillator's output was divided, measured and autonomously recorded by a computer running Labview. Measured vital signs include pulse shape, power, diode temperature, ambient temperature and humidity, electrical input, and the temporal delay between the pump pulse rising edge and emitted Q-switched pulse.

Testing the Cr^{4+}:YAG in this manner exposes the material to the actual operational high fluence optical conditions; as opposed to standard optical damage threshold tests. While at the same time, this test procedure yields useful survivability information about the other laser components.[5]

3. RESULTS

Unlike an active (i.e. electro-optic or acousto-optic) Q-switch which opens at a pre-determined time, a passive Q-switch opens when the gain equals the loss; including the unsaturated loss of the Q-switch. For this reason the energy per pulse stays relatively constant but the temporal delay between the rising edge of the pump pulse and the emitted Q-switched pulse increases as the laser diode pump power decreases.

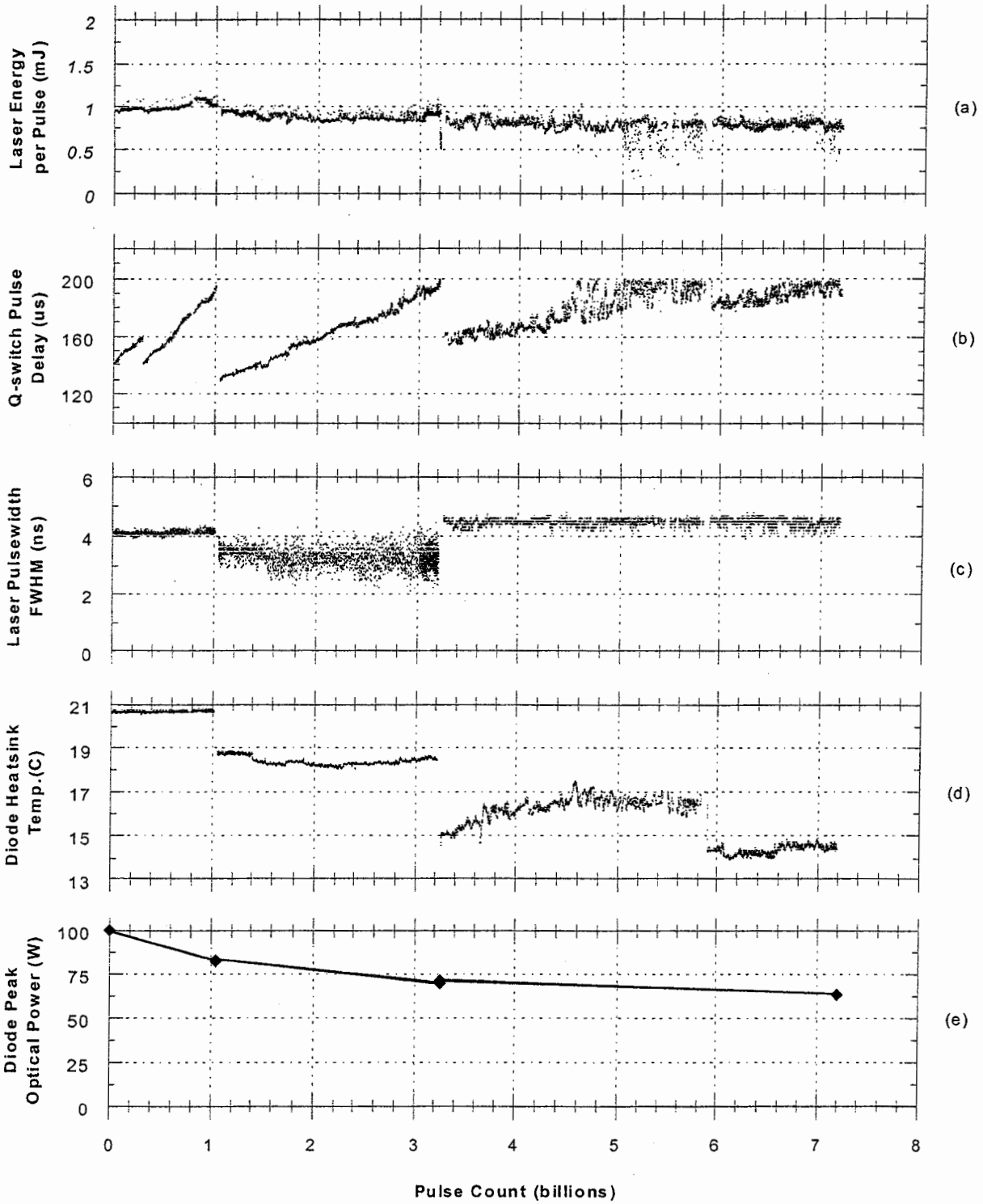

Figure 2. Results of 165 day performance test of a passively Q-switched Nd:YAG laser. Measured parameters include (a) laser energy, (b) temporal delay between the pump pulse rising edge and emitted Q-switched pulse, (c) pulsewidth, (d) pump laser diode heat sink temperature, and (e) pump diode peak optical power.

The accelerated GLAS oscillator ran uninterrupted for 1.05 billion shots (Figure 2). At this point, the diode had degraded such that at the end of the 200 μs pump pulse, there was insufficient gain to saturate the Q-switch and produce a laser pulse. The laser diode was removed from the cavity and its power measured (Figure 2-e). The peak optical power had degraded from 100 W to 83 W. The diode was returned to the pump head with slightly decreased distance between the Nd:YAG crystal and the laser diode. This created a higher gain density. No laser cavity elements were adjusted so the laser continued to operate on the same optical axis. Since laser diodes run more efficiently at colder temperatures, we decreased the diode coolant temperature to minimize the delay between the start of the pump pulse and Q-switch saturation. The changes in distance and temperature account for the revived laser operation.

The laser ran for an additional 2.2 billion shots before it once again stopped lasing. The same procedure was followed as before; remove laser diode, characterize pump power, return diode to pump head, and thermally optimize. The water chiller cooling the pump diode slowly degraded from 1.4 to 5.9 billion shots (Figure 2-d). At 5.9 billion shots, the chiller was replaced with a new unit.

The laser ran for an additional 1.15 billion shots accumulating over 7.2 billion shots in total. The laser diode was then removed again and characterized. All optical elements were visually inspected for damage and none was observed. During the entire 7.2 billion shot lifetime of the laser, no cavity elements were adjusted so the lasing axis remained unchanged. Using the equation:

$$IntracavityFluence = \frac{2\left(\frac{1+R}{1-R}\right)E_{out}}{\Pi \cdot r^2}$$

where **R** is the reflectivity of the output coupler, **r** is the $1/e^2$ radius of the laser beam, and $\mathbf{E_{out}}$ is the energy per pulse emitted; the intracavity fluence was calculated to be approximately 2.5 J/cm^2 over the life of the experiment.

4. CONCLUSIONS

After accumulating 7.2 billion, high fluence (2.5 J/cm^2) laser shots, there was no evidence of any change in the optical properties of the Cr^{4+}:YAG. All degradation observed in the laser operation could be attributed to changes in the pump laser diode; either through degraded output power or water coolant temperature. There was no sign of optical damage on any of the intracavity optical elements. This multi-billion shot performance test on our laser components provides further evidence against an accumulative exposure effect leading to pre-mature optical damage[6].

5. REFERENCES

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DISCUSSION

Q. Have all the parameters like the initial transmission and the saturated transmission been presented in the literature previously, and did you measure these? How much loss do you have at zero intensity, for example, and at saturation? How much loss does that Q switch pose on the cavity; what type of gain would you have to have to overcome the losses?

A. I'm not sure; I think we had 60% transmission, but that's a CW measurement. I don't think we characterized what you're interested in, but that was 60% transmission of the passive Q switch.

Q. You had the Q Switch material in front of the output coupler; usually people put those in front of the HR, between the laser rod and the high reflector. Was there a specific reason for that?

A. Not particularly; we tried it in both situations. We got higher power with the Cr^{4+} on the other side; the high reflector was not a flat surface, so it may have had something to do with the slightly positive curvature. The Cr^{4+} actually acts as a soft aperture in the laser, so it may have had to do with the spatial mode of the laser in this case.

Q. What was the energy per pulse, and what current did you run your diodes at?

A. The energy per pulse was 1 millijoule as demonstrated here. We tried the same set up in the 40 Hertz version and have gotten almost 2 millijoules per pulse. We ran our diodes (a quasi CW bar) at a current of 128 milliamps.