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# LASER-INDUCED DAMAGE IN OPTICAL MATERIALS: 1994

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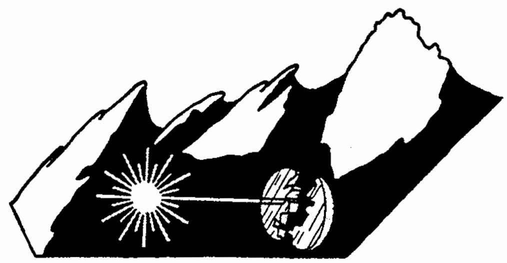

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Accelerated GLAS exposure station

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## ABSTRACT

The Geoscience Laser Altimeter System (GLAS) is being developed by NASA/GSFC to measure the dynamics of the ice sheet mass balance, land, and cloud and atmospheric properties. An instrument altimetric resolution of 10 cm per shot is required. The laser transmitter will be a diode pumped, Q-switched, Nd:YAG laser producing 1064 nm, 100 mJ, 4 ns pulses at 40 Hz repetition rate in a $TEM_{00}$ mode. A minimum lifetime goal of 2 billion shots is required per laser transmitter. The performance of the GLAS laser can be limited by physical damage to the optical components caused by the interaction of intense laser energy with the optical coatings and substrates. Very little data exists describing the effects of long duration laser exposure, of 4 ns pulses, on an optical component. An Accelerated GLAS Exposure Station (AGES) is being developed which will autonomously operate and monitor the GLAS laser at an accelerated rate of 500 Hz. The effects of a large number of laser shots will be recorded. Parameters to be monitored include: laser power, pulsewidth, beam size, laser diode drive current and power, Q-switch drive voltage, temperature, and humidity. For comparison, one set of AGES sister optical components will be used in the non-accelerated GLAS laser and another will be evaluated by a commercial optical damage test facility.

**Keywords:** optical damage, accumulated laser exposure effects, space optics

## 1. MISSION REQUIREMENTS

The Geoscience Laser Altimeter System[1] (GLAS) is being developed by NASA/GSFC to measure the dynamics of the Earth's ice sheet mass balance, as well as cloud and atmospheric properties. This five year mission is scheduled for launch in 2003. The GLAS laser transmitter is required to produce pulse energies of 100 mJ at 1 μm and 50 mJ at 0.5 μm at a repetition rate of 40 Hz. Pulsewidths of 4 - 6 ns must be maintained and be stable within ± 5%. An overall wall plug efficiency of 6% and lifetime of 5 years (7 billion shots distributed among three redundant lasers) are also required. The projected performance of the GLAS laser can be limited by physical damage to the optical components caused by the interaction of intense laser energy with the optical coatings and substrates. This performance depends upon understanding the multi-billion shot, short pulse, effect a laser has on its optical components. Relatively little damage threshold data exists for Q-switched pulsewidths in the 4 ns regime. NASA and industry share the need for data describing the effects of long duration laser exposure on an optical component.



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## 2. AGES

In order to investigate these effects, an Accelerated GLAS (laser) Exposure Station (AGES) is being developed which will autonomously control and monitor the multi-billion shot exposure of the GLAS test laser (Figure 1). The laser power, pulsewidth, beam size, laser diode drive current and power, Q-switch drive voltage, temperature, and humidity will be recorded as a function of the number of laser shots. Given the time required for this experiment and the volume of data, all the laboratory instruments will interface to a 486 based computer running LabVIEW. Each diagnostic instrument will be automatically read by the computer every million shots. Upon periodic analysis of the stored data, effects such as a slow reduction of the laser power, decrease in diode pump power, lengthening of the rise time of the Q-switch pulse, etc. will be observed and de-coupled to identify any optical component degradation. In the case of a dramatic decrease of laser performance (e.g. catastrophic optical damage) or thermal runaway, the computer will shut down the experiment. For independent verification of results, three sets of "sister" optics are being tested. One set will be installed within the AGES laser, a second within the GLAS breadboard, and a third will be sent out for standard commercial damage threshold testing (Figure 2).

The current GLAS laser transmitter baseline design is a diode-pumped, Q-switched, Nd:YAG oscillator[2] followed by two stages of amplification.[3] The 10 cm long oscillator is Q-switched to produce the required 1.5 mJ necessary for efficient amplification of the pulses. This oscillator has an intracavity fluence of ~ 3.6 J/cm$^2$ within a 4 ns pulse (900 MW/cm$^2$). A standard commercial optical damage threshold test consists of irradiating an optical sample with the output from a Q-switched laser. To externally expose the GLAS optics to 4 times the expected intracavity fluence (14.4 J/cm$^2$) and accumulate billions of shots in a convenient amount of time (months rather than years), a 500 Hz laser emitting 72 mJ within a 800 μm spot and 4 ns would be required. This 18 MW peak power and 36 W average power $TEM_{00}$ laser does not commercially exist.[4] The standard lasers that do exist suffer from one or more of the following: repetition rates are too slow (~ 20 Hz), pulsewidths too long (~10 ns), and/or energy too low. Using a laser with not enough output energy would require focusing to too small of a spot size to reach the required fluence. The laser spot size on an optical sample should be ≥ 700 μm in diameter.[5] If too small of a spot is used, defects may either see a larger than usual fluence or be completely missed, leading to erroneous damage thresholds.

Our solution is to use a copy of the GLAS test laser operating at an accelerated repetition rate of 500 Hz. Since the high fluence already exists intracavity, all of the optical components will be tested with the ideal spot size, simultaneously, under actual operating conditions. The laser optics will be exposed to intracavity electric field and modal effects which are lost in standard external damage testing. By changing the output coupler reflectivity, the intracavity fluence can be varied. At 500 Hz, 2 billion shots are acquired within 47 days. The effect of increasing the repetition rate required minor changes in the GLAS oscillator components and more attention to thermal management. A water cooled 100 W QCW laser diode bar (SDL-3255-C1) operating at 10% duty factor, 2.5 times the vendor recommend value, was chosen as the pump source. The output power and spectrum were recorded for four such lasers running at 500 Hz and 200 μs and appears nominal. An Analog Modules 820-49/50 Pockel cell driver provides the required 3 kV differential across the Q-switch at 500 Hz. Rise and fall times of 15 ns were measured. The Nd:YAG slab is mounted to a water cooled heat sink using a silicon elastomer.

## 3. DAMAGE AVOIDANCE

Initial steps were taken to increase the laser's long term performance. Since the dielectric coatings, in many cases, are the limiting factor lowering an optic's damage threshold, the Nd:YAG slab was cut with Brewster faces to eliminate the need for coatings. The remaining optics were coated with $HfO_2$, the highest damage threshold material available.[6] This coating has shown preconditioned damage thresholds as high as 40 $J/cm^2$ at commercial test facilities. Since $LiNbO_3$ has a history of low and inconsistent damage thresholds, a Sol-Gel coated KD*P Q-switch was selected. High quality Nd:YAG was sought from a number of vendors. It has been shown that ramping-up the fluence on an optic when it is first irradiated has the effect of raising its damage threshold.[7] The exact mechanism for this preconditioning is still under investigation, though it is believed that small defects or nodules are ablated from the optic's surface at low fluences with little effect to the surrounding region. If the number and size of these defects is "small enough," then at full fluence no further degradation occurs. A plan for preconditioning the laser transmitter has been initiated.

AGES is being assembled on an optical bench under a laminar flow to reduce the number of airborne particulates capable of landing on the optics. Each of the mounts are cleaned in an ultrasonic bath before use. A study of twelve optical grade lens tissues was initiated to determine the quantity and identity of non-volitale residue (NVR) when samples were extracted with Acetone and Methanol. Correlation of the extracted contaminants to induced optical damage is under investigation. Upon assembly and proper operation of AGES, the experiment will be enclosed in a box continuously purged with dry, clean, air.

AGES should be completely on-line by December, 1994. The laser will operate continuously until either 25% power degradation or complete failure. The optical components will be analyzed by a committee of in and out-of-house materials and damage experts. Results and recommendations for future experiments and GLAS laser component selection will be reported.

## 4. ACKNOWLEDGMENTS

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# Accelerated GLAS Exposure Station (AGES)

**Purpose: Design and build an autonomous station which will expose and monitor continuously, the multi-billion shot exposures on GLAS critical optics.**

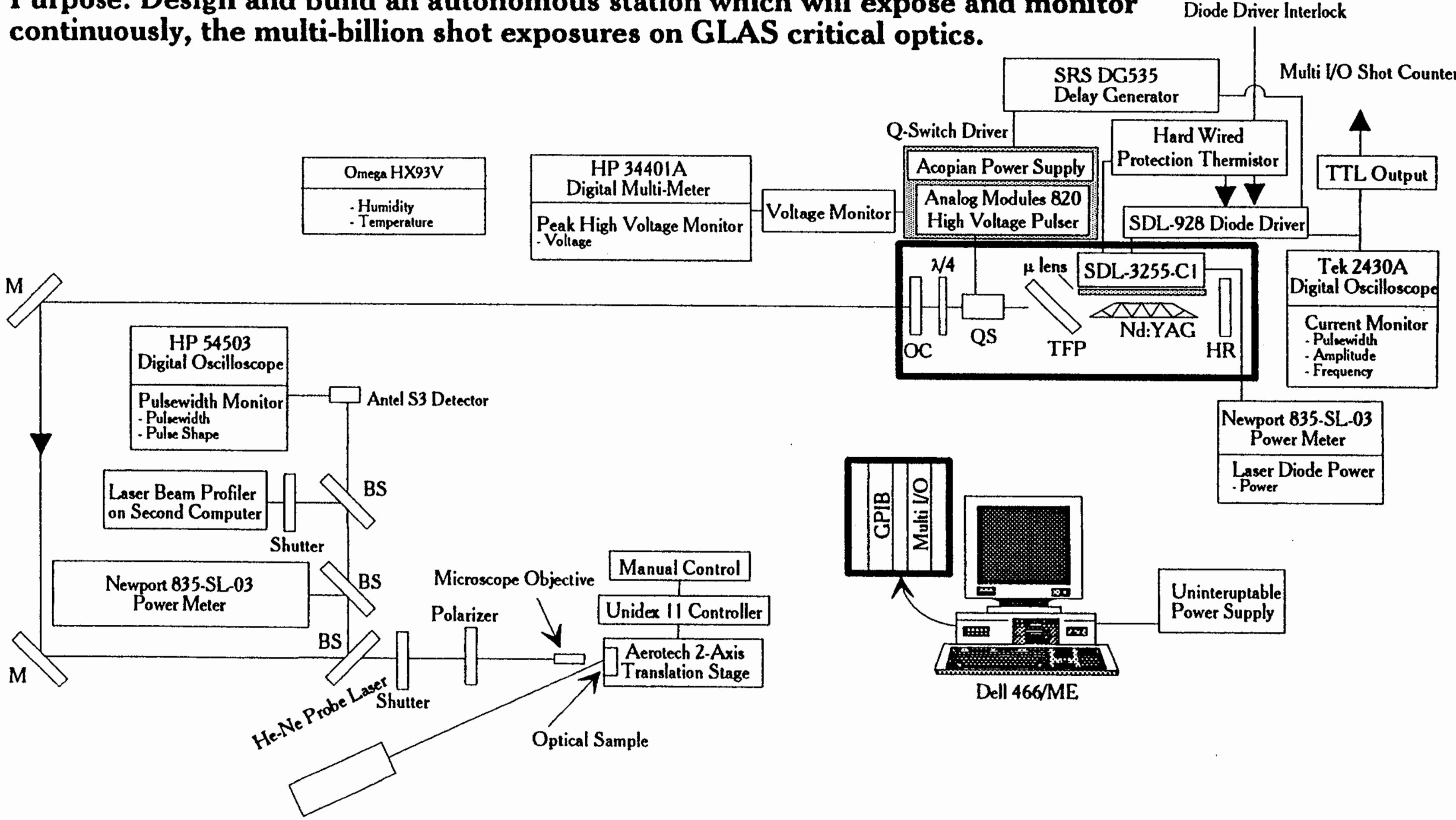


Figure 1.

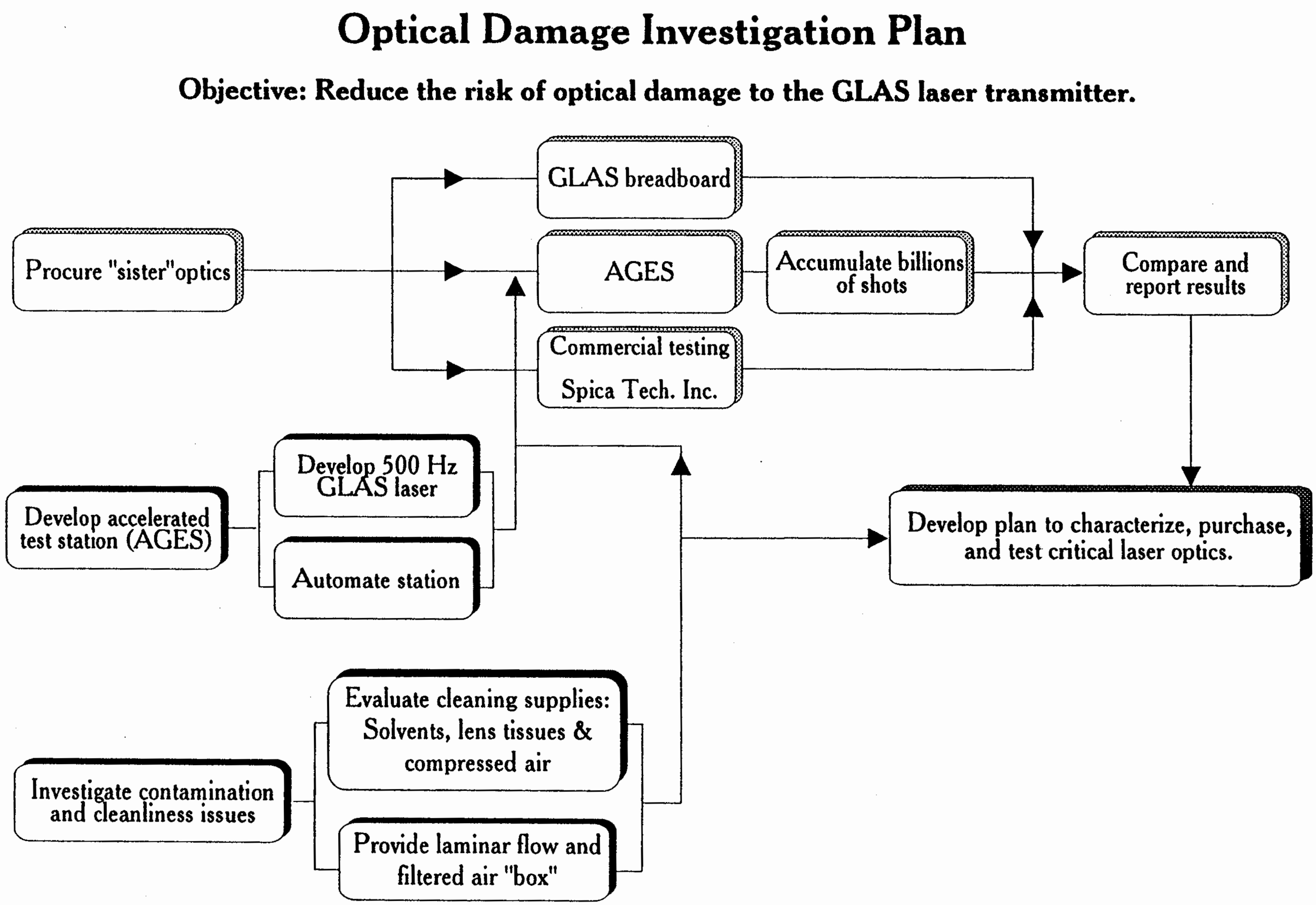
Optical Damage Investigation Plan
Objective: Reduce the risk of optical damage to the GLAS laser transmitter.
GLAS breadboard
Procure "sister"optics
AGES
Accumulate billions of shots
Compare and report results
Commercial testing
Spica Tech. Inc.
Develop 500 Hz GLAS laser
Develop accelerated test station (AGES)
Automate station
Develop plan to characterize, purchase, and test critical laser optics.
Evaluate cleaning supplies: Solvents, lens tissues & compressed air
Investigate contamination and cleanliness issues
Provide laminar flow and filtered air "box"

Figure 2.