LIFETIME AND RELIABILITY DATA OF COMMERCIAL EXCIMER LASER POWER SYSTEMS MODULES

P. Melcher, D. Johns, R. Ness, and B. Partlo
CYMER Inc.
16750 Via Del Campo Court
San Diego, CA 92127

Abstract

Since 1996, CYMER has manufactured over 1500 excimer lasers for the application of integrated circuit photolithography. Because reliability and Cost of Operation (CoO) are critical in the semiconductor industry, it is extremely important to quantify these parameters for the laser and each of the primary modules. Lifetime and reliability data for the initial generation of Solid State Pulsed Power Module (SSPPM) units are presented from a number of sources, including more than 750 laser systems in the field in addition to a number of in-house module verification systems. Highly Accelerated Life Test (HALT) experiments have also been implemented at CYMER to help quantify the design margins of these modules with respect to operating parameters such as temperature and voltage. In addition, results will be updated from an experiment involving testing of a SSPPM to over 50B shots where the unit was characterized at several intervals in an attempt to detect any potential signs of degradation which might limit the operational lifetime or cause the unit to fail. To date, no such indications of degradation have been measured. The paper will compare actual reliability and lifetime data from these various sources compared to the original lifetime estimates.

I. BACKGROUND AND SSPPM DESIGN

The application of semiconductor photolithography places requires a long lifetime and high reliability. Cost of Ownership (CoO) is extremely important to the end-user chipmakers. As a result, the lifetime goals for the laser SSPPM are on the order of 5 years or 25B shots since that is the expected lifetime of the overall stepper / scanner.

Confirming actual lifetimes of SSPPM components is therefore an important, and yet difficult, project. Few examples exist of other lifetime experiments [1], particularly those associated with similar technology and similar lifetime goals. As a result, CYMER is taking multiple approaches to generating our own data that can help predict the lifetime, reliability, and robustness of the initial (5000 Series) and future SSPPM designs. This includes normal life testing, Highly Accelerated Life Testing (HALT), and several additional experiments.

The initial thrust is concentrating on the first generation SSPPM design. Over 1100 have been produced at CYMER since 1996 and they have been used in the 4000F and 5000 series excimer lasers since then. A simplified schematic diagram of the electrical power circuit is shown in Figure 1. A capacitor charging HVPS initially charges up the C0 capacitance to a voltage up to 1000 V. SCR switches then resonantly charge C1 from C0. Three stages of magnetic pulse compression and a pulse transformer are then used to convert the initial 10 μs pulse into the ~15-20 kV, 150 ns risetime pulse that is applied to the laser chamber and peaking capacitance (Cp). The power system is split up into three modules: a HVPS, the Commutator (containing the start circuit and 1st compression stage and pulse transformer) and the Compression Head (containing the last two stages of pulse compression).

II. FIELD AND IN-HOUSE DATA

One source of lifetime data is associated with existing CYMER lasers in the field and in-house. The field laser shot lifetimes are compiled by periodic software downloads from the individual lasers. The software downloads give us information about system and module shot counts as well as operating modes and conditions. This information allows us to monitor operating conditions and shot counts in order to predict and plan for system maintenance intervals.

As of April, 2001, 130 laser systems were operating in the field or in-house with shot counts of at least 10B shots. Ten of these systems had achieved at least 20B shot levels and one had even reached over 30B shots in field use. Each data point represents a laser system in which the system and SSPPM have approximately the same shot count, thus representing a laser system that has run without failure of its SSPPM.

III. FAILURE MODES

An additional source of reliability data is associated with field returns of SSPPM modules. The SSPPM Manufacturing group keeps track of all units returned from the field along with their dispositions from post-mortem analyses. Out of 1190 Commutators built to date, 19 units (1.6%) have been returned to manufacturing from the field for legitimate failure.

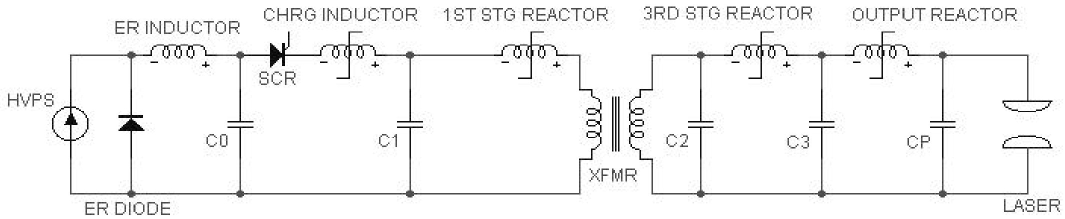

Figure 1. Schematic Diagram of Solid State Pulsed Power Module (SSPPM) with HVPS and Laser Chamber.

Of the observed failures, 68% were due to assembly errors, and have been resolved through training of manufacturing personnel and better quality control. Twenty one percent of the failures were due to arcing and carbonization of the output connector caused by incomplete engagement of the cable connector. These failures were mitigated by training of field service personnel and design improvements. Five percent of the failures were due to trigger to light timing variations out of customer specification which have been improved with better circuitry now in production. The remaining 5% of failures were caused by defective components.

Out of 1283 compression heads built, only 4 units (0.31%) have been returned to manufacturing from the field for legitimate module failure. The compression head is mechanically and electrically simpler than the Commutator, which results in better reliability. Of the observed failures, 2 were due to manufacturing errors, and have also been resolved through training of manufacturing personnel. One of the compression head failures were due to oil leakage caused by missing O-ring seals in the high voltage connector. The vendor error was resolved through corrective action. The remaining one failure was due to arcing and carbonization of the output connector. The Multi-Contact ribbon had slipped out of position, resulting in arcing and rapid degradation of the connection. This failure also was mitigated through training of field service personnel.

IV. HALT TESTING

HALT testing has also been used to quantify the SSPPM design robustness. In 1999, HALT testing was performed on the 5000 Series Commutator module in order to stress it with high air temperatures. No module failures were recorded up to 80 degrees C exhaust temperatures (the limitation of the HALT testing equipment at that time). Given the normal maximum exhaust at ~50 degrees C, substantial margin (~30 degrees C) exists in the operating temperatures. Even at these elevated temperatures, solid state component heat sinks were less than 110 degrees C. Vibration testing and accelerated voltage testing are envisioned for future generation designs as well as continued thermal stress testing.

V. 50B SHOT LIFE TEST

The 50B shot life test experiment actually began as a shorter test to identify any potential changes to SSPPM components during a 10B shot interval [2]. Several such intervals were later conducted with the same initial modules and the testing eventually consumed 50B pulses.

Initial assembly and characterization of the SSPPM components and sub-assemblies began in January, 1999. System measurements in the laser were then conducted and the 10B shot life testing began on February 4. By June 4, 1999, 10.086B shots were accumulated. At that time, the initial on-laser characterization measurements were repeated and the SSPPM was then disassembled, inspected, and re-characterized at the component and sub-assembly level. The 20B shot milestone was reached in October, 1999 and similar characterization was done. After re-assembly, the units were re-installed into the laser frame and run again, until the 50B shot milestone was achieved in May, 2001.

System level SSPPM characterization concentrated on comparing the output voltage, Vcp, against the input charging voltage, VC0, in order to estimate the transfer efficiency before and after the 10B 20B, and 50B shot intervals. As can be seen in Figure 2, the initial, post-10B, and post-50B shot transfer functions overlay within the measurement accuracy of ~5%.

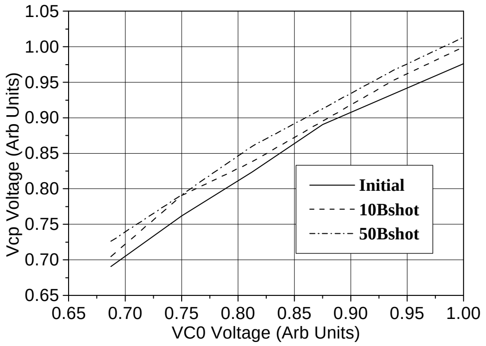

Figure 2. Vcp Vs. VC0 (SSPPM Transfer Function) Data Includes Initial , 10B, and 50B Shot Test Data.

SSPPM component measurements, as noted in Table 1, included capacitance, inductance, resistance, dissipation factor, Q, and B-H (Hysteresis loop) information for magnetic materials. Results of the component testing showed that no critical component had changed over 50B shots within the accuracy of the measurements. Physical examination further showed that no obvious degradation had occurred.

Numerous oscilloscope waveforms were also recorded at critical points internal to the SSPPM and then analyzed to detect any potential changes in performance. Voltage waveforms were taken at each critical energy storage node: C0, C1, C2 (XFMR primary), C2, and C3 with calibrated Tektronix voltage probes. Current waveforms from C0 to C1 as well as C1 to C2 (XFMR primary) were also taken with a Pearson current transformer. All of these measurements were taken at multiple voltage levels over the normal operating range of the SSPPM.

Figure 3 shows VC0 before and after the 50B shots. Figure 4 shows VC1 along with the current waveform for this energy transfer from C0 to C1.

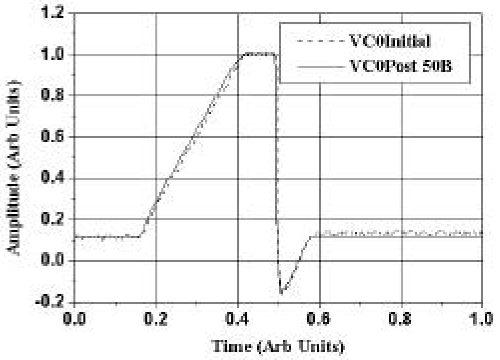

Figure 3. VC0 Voltage Waveform Data Before and After 50B Shot Testing.

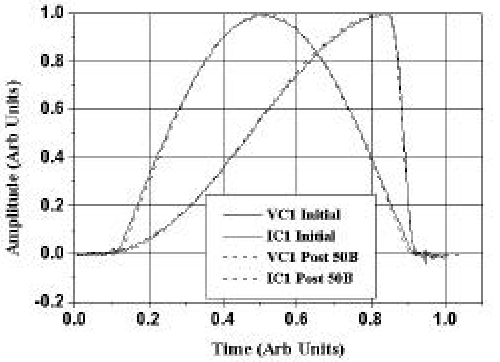

Figure 4. VC1 and IC0-1 Waveform Data Before and After 50B Shot Testing.

Figure 5 shows the B-H curves for the four magnetic cores that make up the 1st Stage Reactor with the initial data overlaid on top of the data taken after 50B shots.

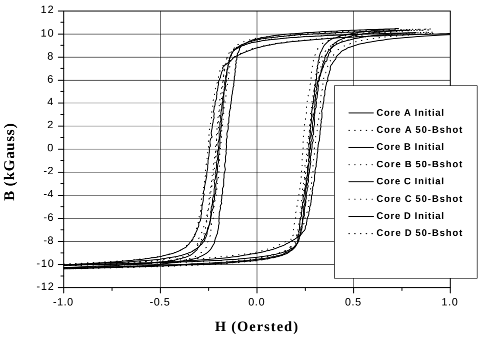

Figure 5. B-H Data for Four 1st Stage Reactor Cores Before and After 50B Shot Testing.

Figure 6 shows a similar comparison of the B-H data for the four cores in the Compression Head with the pre and post-50B shot data overlaid.

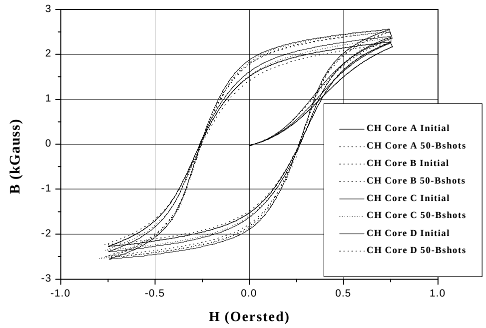

Figure 6. B-H Data for Four Compression Head Reactor Cores Before and After 50B Shot Testing.

Examination of the comprehensive oscilloscope data taken for this experiment further confirms that no measurable degradation in performance has occurred within the SSPPM during the 50B shot experiment. The system level voltage waveforms (VC0, VC1, VC2, VC3, and VCP) taken before and after the 50B shot test were also analyzed for changes in peak voltage and waveshape. Accounting for waveform variations due to probe positioning, calibration, and measurement uncertainty, comparison of pre and post-50B shots showed no systematic degradation in performance. Once again, this is consistent with the previously mentioned component and sub-assembly data.

Further analysis is also planned including chemical analysis of the Compression Head insulating oil and “post-mortem” analyses of the capacitors with vendor assistance.

Table 1. SSPPM Bench Measurement Summary of 50B Shot Life Test Experiment.

Component / Parameter	**Observed Changes**	**Observed Changes**	**Observed Changes**
Commutator	**At 10B Shots**	**At 20B Shots**	**At 50B Shots**
Module Visual Inspection	No visible degradation	No visible degradation	No visible degradation
C0 [Capacitance]	- 0.2%	- 0.2%	-0.26%
C1 [Capacitance]	- 0.05%	- 0.07%	-0.16%
ER Inductor[Inductance]	+ 0.14%	+ 0.3%	+0.59%
Bias Inductor [Inductance]	- 0.96%	- 1.1%	-1.1%
HV Connector [Resistance]	+ 1.05%	- 2.1%	Not recorded
Pulse XFMR Core [Bm]	- 0.02%	- 0.42%	+ 0.02%
Pulse XFMR Core [Hc]	- 0.31%	- 1.60%	+ 1.38
Chrg. Inductor Core [Bm]	+ 0.38%	- 0.35%	- 2.5%
Chrg. Inductor Core [Hc]	+ 0.88%	+ 0.38%	- 2.65%
1st Stage reactor core [Bm]	- 0.46%	- 0.45%	- 0.17%
1st Stage reactor core [Hc]	- 0.08%	+ 0.77%	- 0.91%
Compression Head			
Module Visual Inspection	No Visible Degradation	No Visible Degradation	No Visible Degradation
C2, C3 [Capacitance]	+ 1.33%	+ 1.11%	- 1.09%
C2, C3 [Dissipation Factor]	0%	0%	0%
+ Bias Inductor [Inductance]	- 2.74%	- 6.8%	+ 0.02%
+ Bias Inductor [Q]	- 6.28%	- 21.1%	+ 2.35
- Bias Inductor [Inductance]	- 0.74%	- 10.4%	+ 0.83%
- Bias Inductor [Q]	+ 0.79%	- 21.4%	+ 19.9%
Core Bmax	+ 0.41%	- 0.62%	- 1.45%
Core Hc	+ 0.33%	+ 1.28%	- 0.88%
Dielectric Fluid Breakdown Strength (>35kV)	- 6.70%	- 0.41%	- 2.57%

VI. SUMMARY

Numerous data sources have been collected and analyzed to confirm the reliability and lifetime goals for the CYMER SSPPM design. Over 130 lasers are now in operation around the world with accumulated shot counts of over 10B shots, some with as many as 30B shots. Failures rates have been calculated as 1.6% and 0.3% for the Commutator and Compression Head, respectively. HALT testing has confirmed an operating temperature margin of at least 30 degrees C. A 50B shot life test experiment has not only demonstrated that a SSPPM can achieve such lifetime requirements, but also shown that no obvious lifetime limiting mechanisms exist in this operating regime. As a result, we are extremely confident that the initial 5000 series SSPPM design has a very high probability of reaching it's desired 25B shot expected lifetime.

VII. ACKNOWLEDGEMENTS

This paper is dedicated to the memory of Dan Birx who worked with CYMER since 1990 and made immeasurable contributions towards the development of numerous SSPPM designs for CYMER's excimer laser systems. His enthusiasm for solving problems was infectious and his example has made an immeasurable impact on many of us at CYMER. He lived his life with the same drive that he gave his work. Rare is the man with so much intelligence, diligence, capacity for joy, and respect for life. The world has lost a brilliant individual, and many of us lost a very close and dear friend. It was a pleasure and an honor to have known and worked with him, both as a technologist and as a fellow human being.

Terry Houston also deserves significant thanks for his monitoring and assistance with the 50B shot experiment.

VIII. REFERENCES

[1] K. Reed, L. Schneider, G. Pena, and L. Martinez, "Magnetic Modulator Lifetime Tests Using the Sandia Reliability Test-Bed", 12th International IEEE Pulsed Power Conference, 1999.

[2] R. Ness, P. Melcher, B. Smith, W. Partlo, and D. Birx, "Performance Characterization for an Excimer Laser Solid-State Pulsed Power Module (SSPPM) After 20B Shots", IEEE Transactions on Plasma Science, Vol. 28 #5, October, 2000.