Performance Characterization for an Excimer Laser Solid-State Pulsed Power Module (SSPPM) After 20B Shots

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Abstract—**An experiment has been designed to characterize a solid-state pulsed power module (SSPPM) during the initial manufacturing cycle and then repeat the same characterization measurements after the module has gone through several sequences of 10B shots of normal operation in an excimer laser. The goal of such an experiment is to determine what, if any, degradation occurs during these extended periods and to assist in the development of expected module lifetimes that can then be used to estimate the cost of operation of the overall excimer laser. Initial component and subassembly measurements include the capacitance and Q of energy storage capacitors; the inductance and Q of bias, charging, and energy recovery inductors; the B-H characteristics of magnetic cores; insulation breakdown strength; connection resistance; and the general physical appearance of the unit. Operational measurements also compare the efficiency of each pulse compression stage, the repeatability and accuracy of diagnostics, thermal management parameters, and the recovery and on-state characteristics of the silicon-controlled rectifiers (SCRs) and diodes. Each of these items is monitored before testing and after each sequence of 10B shots has been completed. Results of the experiment are described.**

Index Terms—**Excimer laser, life testing, magnetic pulse compression, magnetic switch, modulator, solid state switch.**

I. Introduction

The application of semiconductor photolithography places a large burden on the excimer laser and, in turn, the solid-state pulsed power module (SSPPM) to possess a long lifetime and high reliability. Cost of ownership (CoO) is becoming more and more important to the end-user chipmakers. Because unscheduled downtime can cost the chip fabrication plant significant amounts of money, it is desirable to have an essentially infinite lifetime for the SSPPM. In reality, the lifetime goals are ~5 years or ~25B shots because that is the expected lifetime of the overall stepper/scanner equipment.

Confirming actual lifetimes of SSPPM components is therefore an important, yet difficult, project. If the laser is allowed to run at its maximum rep rate of 1 kHz and 100% duty cycle continuously 24 hours a day and 7 days a week, it would still take 289 days to accumulate 25B shots. CYMER is therefore taking multiple approaches to generating data that can help predict the lifetime, reliability, and robustness of the current SSPPM. This includes normal life testing, highly accelerated life testing (HALT), and several additional experiments. One of these experiments was designed to identify any potential characteristics that change over the life of the module. An SSPPM was carefully characterized during the initial production and testing and then run in a laser for several series of 10B shot runs. These measurements exceeded the standard module performance verification tests that are done in normal production. At the end of each 10B shot increment, the same characterization process was conducted to see what parameters might have degraded. The remainder of this paper describes the test and the results.

The initial thrust is concentrating on the first generation SSPPM design. Over 1100 have been produced at CYMER (San Diego, CA) since 1996, and they have been used in the 4000F and 5000 series excimer lasers since then [1], [2]. A simplified schematic diagram of the electrical power circuit is shown in Fig. 1. A capacitor charging HVPS initially charges up the C0 capacitance to a voltage up to 1000 V. Silicon-controlled rectifier (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 rise-time pulse that is applied to the laser chamber and peaking capacitance (Cp). The power system is split into three modules: a HVPS, the commutator (containing the start circuit and first compression stage and pulse transformer) and the compression head (containing the last two stages of pulse compression).

Typical lifetime limiters for the SSPPM might include bulk dielectric breakdown, insulator surface tracking (flashover), thermal management, thermal cycling leading to mechanical fatigue, mechanical stress due to high magnetic fields, ozone, component infant mortality, and assembly errors. Of the ~1100 units produced to date, failure modes have been almost exclusively related to these last two issues. As a result, we believe that no real lifetime failures have been seen to date.

Specific examples of areas to examine during this test included loss of insulation voltage breakdown strength (i.e., increase in capacitance associated with self-healing film capacitors or a decrease in insulation fluid breakdown strength) or an increase in losses (i.e., increase in capacitor dissipation factor or connection resistance).

II. Initial 10B Shot Life Test

Initial assembly and characterization of the SSPPM components and subassemblies began in January 1999. System measurements in the laser were then conducted, and the initial 10B shot life testing began on February 4. In order to extend the life-

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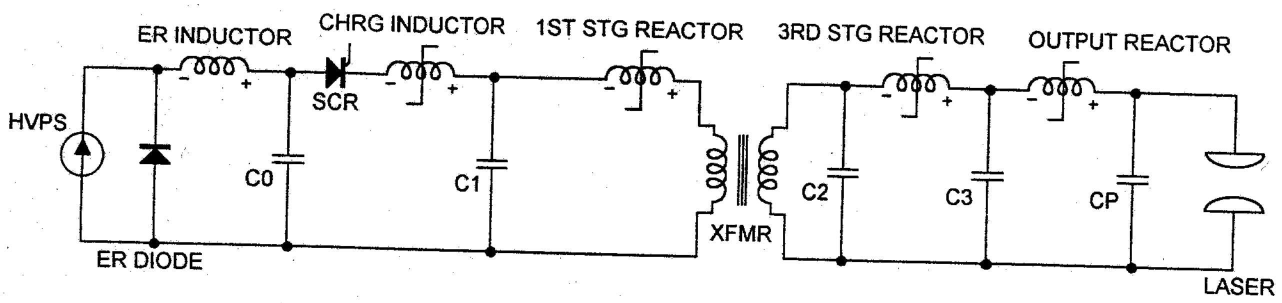

Fig. 1. Schematic diagram of SSPPM with HVPS and laser chamber.

times of other modules (optics and chamber), the laser was run in a broadband, constant energy mode. In this case, the energy target was adjusted to ensure that the operating voltage of the SSPPM was kept in the range of 700–800 V over the entire life test. This is somewhat higher than the typical average operating voltage because the normal operating range is from ~550 to 750 V as the laser chamber ages due to electrode wear. The life test duty cycle of 100% also exceeded the typical value of ~70%.

With the exception of chamber gas refills (~10 minutes in duration) twice a week and two periods of several hours where the facility ac power was shut down, the SSPPM ran continuously (~100% uptime) from February until June 4, with 10.086B shots accumulated. At that time, the on-laser measurements were repeated and the SSPPM was then disassembled, inspected, and recharacterized at the component and subassembly level.

Test equipment used during this experiment included a Walker Scientific (Worcester, MA) Hysteresisgraph, a Stanford Research (Sunnyvale, CA) LCR Meter, a Hipotronics (Brewster, NY) 100 A Micro-Ohm Meter, a Hipotronics Liquid Dielectric Insulation Tester, Tektronix (Beaverton, OR) 1 000 : 1, 100 : 1, and Differential Voltage Probes, and Pearson Electronics (Palo Alto, CA) Current Transformers.

III. SSPPM SYSTEM MEASUREMENTS

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

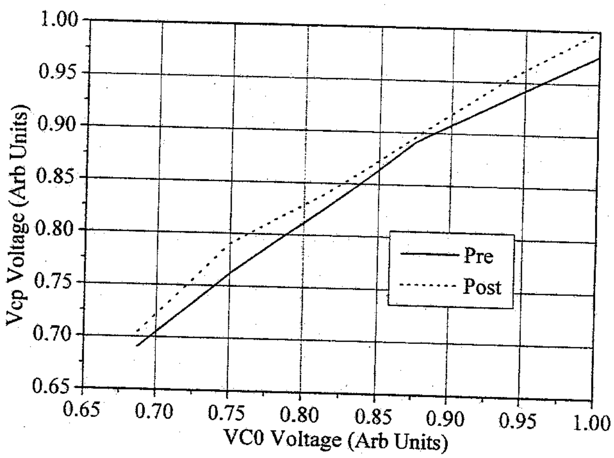

Fig. 2. Vcp versus VCO (SSPPM transfer function) data before and after 10B shot testing.

TABLE I
COMMUTATOR BENCH MEASUREMENT SUMMARY

Module Visual Inspection	No Visible Degradation
C0 [Capacitance]	- 0.2%
C1 [Capacitance]	- 0.05%
ER Inductor[Inductance]	+ 0.14%
Bias Inductor [Inductance]	- 0.96%
HV Connector [Resistance]	+ 1.05%
Pulse XFMR Core [Bm]	+ 0.4%
Pulse XFMR Core [Hc]	+ 1.2%
Chrg. Inductor Core [Bm]	- 0.4%
Chrg. Inductor Core [Hc]	- 0.9%
1st Stage reactor core [Bm]	+ 0.5%
1st Stage reactor core [Hc]	+ 0.03%

IV. COMMUTATOR MEASUREMENTS

As described previously, the commutator module contains the energy recover circuit (ER diode and ER inductor), C0 and C1 capacitor banks, SCRs, charge inductor, first-stage reactor and bias inductor, pulse transformer, and control circuitry. Critical parameters were measured for each component, including the capacitance, inductance, resistance, dissipation factor, Q, and B-H Hysteresis information for magnetic materials. Insulation fluid breakdown strength and chemical analysis was also performed. Results of the bench testing showed that no critical component had changed within the accuracy of the measurements. Physical examination further showed that no erosion or corrosion had occurred within the commutator, as noted in Table I below. Capacitance measurements in this case are lumped measurements of an array of individual components used for each bank. Core measurements are an average of sampled core data.

Numerous oscilloscope waveforms were also taken, both prior to and after 10B shots, at critical points internal to the commutator while operating in the laser. These oscilloscope data were then analyzed to see if any changes in performance had occurred. Voltage waveforms were taken at each critical energy storage node: C0, C1, and C2 (XFMR primary) with a calibrated Tektronix voltage probe. Current waveforms for the energy transfer from C0 to C1 as well as C1 to C2 (XFMR primary) were also taken with a calibrated Pearson current transformer. All of these voltage and current waveforms were taken at multiple charge voltage levels over the entire normal operating range.

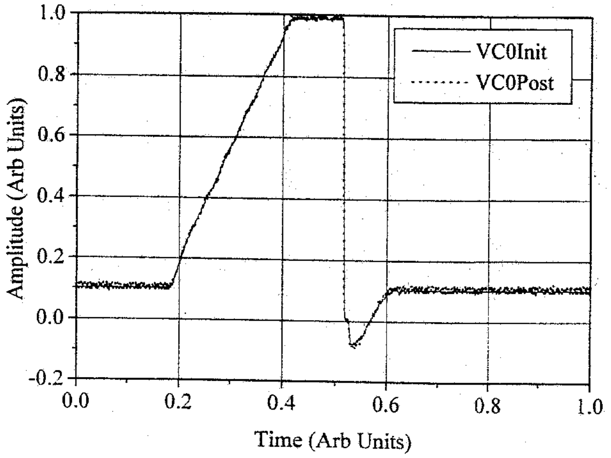

Fig. 3. VCO voltage waveform data before and after 10B shot testing.

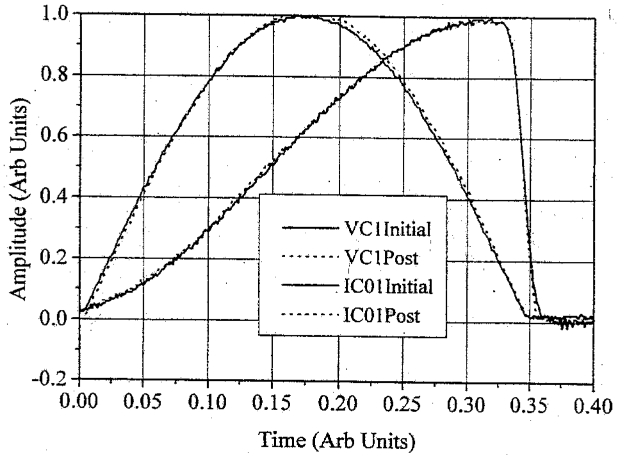

Fig. 4. VC1 and ICO-1 waveform data before and after 10B shot testing.

Figs. 3 and 4 show representative oscilloscope data taken before and after the 10B shot experiment. Fig. 3 shows VC0 before and after the 10B shots. Fig. 4 shows VC1 along with the current waveform for this energy transfer.

Fig. 5 shows the B-H curves for the four magnetic cores that make up the first-stage reactor with the initial data overlaid on top of the data taken after 10B shots.

Examination of the comprehensive oscilloscope data taken for this experiment further confirms that no measurable degradation in performance has occurred within the commutator during the 10B shot experiment.

V. Compression Head Measurements

The compression head consists of two magnetic pulse compression stages (C2, C3, and third-stage and output stage reactors) and the associated bias circuit. The components are submerged in dielectric cooling fluid to assist in proper thermal management. Fig. 1 shows the location of these components in the overall power system schematic. The reader should note that the compression head bias inductors and HV connectors have been omitted for clarity.

As with the commutator, each component and subassembly was tested prior to assembly in the unit. To document system level performance, the VC2, VC3, and VCP voltages were measured using a Tektronix 1000 : 1 voltage probe. The voltage breakdown strength of the dielectric cooling fluid was tested per ASTM 877 using a Hipotronics oil tester. The overall physical appearance of the unit was noted, along with close examination of the high current electrical connections.

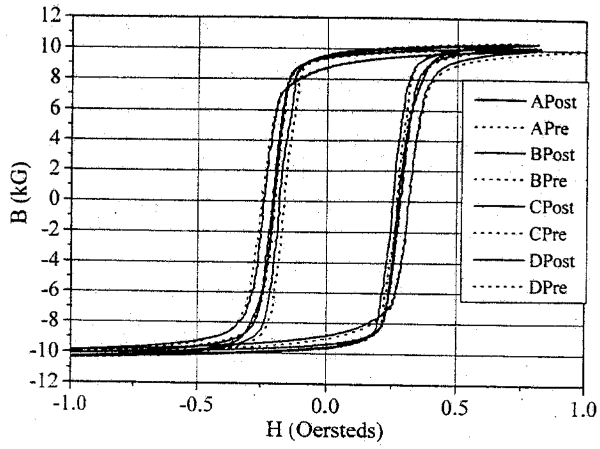

Fig. 5. B-H data for four first-stage reactor cores before and after 10B shot testing.

TABLE II
Compression Head Bench Measurements

Module Visual Inspection	No Visible Degradation
C2, C3 [Capacitance]	+ 1.33%
C2, C3 [Dissipation Factor]	0%
+ Bias Inductor [Inductance]	- 2.74%
+ Bias Inductor [Q]	- 6.28%
- Bias Inductor [Inductance]	- 0.74%
- Bias Inductor [Q]	+ 0.79%
Core [Bm]	+ 0.40%
Core [Hc]	- 0.34%
Dielectric Fluid Breakdown Strength (> 35 kV)	- 0.27%

Post-lifetest results showed no degradation in the component parameters. The overall physical condition showed no signs of excessive wear or degradation. All electrical connections appeared to be free of corrosion or erosion. Table II shows a summary of the component parameters and the percent change from the initial value.

Fig. 6 shows a comparison of the B-H data for the four cores in the compression head with the pre- and post-10B shot data overlaid. As can be seen from the data, no changes were observed in the core magnetic properties. As with the commutator data, the capacitance and core measurements in the table are an average of multiple component measurements. Samples of the dielectric insulating fluid from both the commutator and compression head were also taken before and after the 10B shot testing and are now being chemically analyzed to identify any possible changes to the fluid.

The system-level voltage waveforms (VC2, VC3, VCP) taken before and after the 10B 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-10B shots showed no systematic degradation in performance. Once again, this is consis-

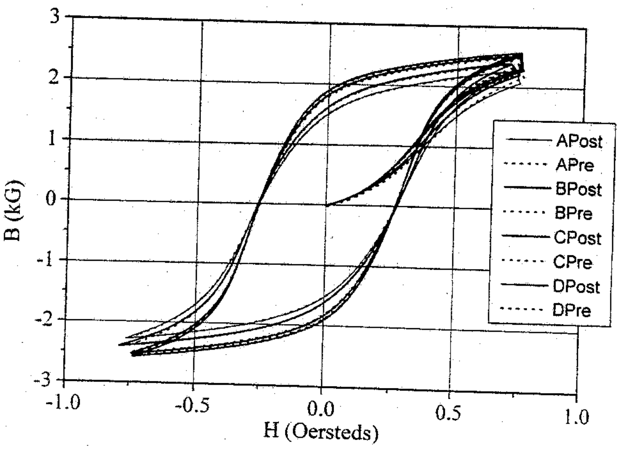

Fig. 6. B-H data for four compression head reactor cores before and after 10B shot testing.

tent with the previously mentioned component and subassembly data.

VI. SECOND 10B SHOT LIFE TEST

After completion of the second characterization measurements, this same test unit was again reassembled and tested for a second series of 10B shots. Testing began on August 2, 1999. By November 27, 1999, the modules had just completed 20B shots and were beginning the characterization measurements once again. As with the initial series of 10B shots, no failures have occurred to date. Overall, laser uptime was also in excess of 98% during this second testing series, with outages or down time required only for gas refills, a chamber replacement, and one period of time necessary for optics realignment.

VII. SUMMARY AND CONCLUSION

An experiment to investigate potential degradation mechanisms in a SSPPM over a period of several 10B shot increments has been conducted. No significant obvious lifetime limiting issues were discovered as a result of examining the data taken before and after the initial 10B shot interval. Test data taken at the system operating level was also consistent with component and subassembly data in confirming that no changes had occurred within the tolerances of the measurements during this period of time.

Although characterization measurements have not been completed yet following the second series of 10B shots, the modules have survived this period with no failures or faults. Initial visual inspection of the modules is consistent with earlier observations that no degradation has occurred during the testing to date.

Once the modules are recharacterized again, we intend to reassemble them once again and begin a third sequence of 10B shots toward an accumulated shot total of 30B pulses.

This data, in addition to HALT testing and other life test data, will aid CYMER in determining realistic module expected lifetimes to support CoO reduction efforts. Based on these experimental results and other performance data, we believe that the SSPPM design is capable of achieving operating lifetimes well in excess of 25B shots in normal operation.

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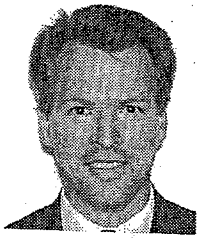
Richard Ness (S'80–M'81) received the B.S. and M.S. degrees in electrical engineering from Texas Tech University, Lubbock, 1981 and 1983, respectively.

He worked for 12 years at Maxwell Technologies Inc. on several large computerized data acquisition systems and a variety of pulsed power and power conditioning projects including a 6 kV, 80 A regulated power supply; a 0.5 MW average power, 60 kHz solid state modulator; a 10 MW average power Hard Tube Regulator; a 350 kW average power, 600 kV Thyratron modulator; and a variety of very compact, megavolt-class pulse generators. He joined CYMER Inc. in 1995 where he has staffed and led the Power Systems Engineering Group. His work has included the development of high average power capacitor charging power supplies with an outside vendor. He has also led the development of several solid state, magnetic pulse compression modulators in support of over 4 generations of excimer laser projects. He currently holds 8 patents related to pulsed power system development.



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He served as a Staff Scientist at GCA/TROPEL INC., in Rochester, NY from 1992 to 1993. He joined CYMER Inc. in 1993 as a Research Scientist. He has since served as a Program Manager from 1994 to 1996 and as a Senior Scientist from 1996 to 1999. Since 1999, he has been Vice President of research and Director of EUV development and was responsible for the development of an extreme ultraviolet (EUV) radiation source for next generation semiconductor microlithography. He holds over 25 patents related to photolithography and pulsed power systems.

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