:ORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. ______

›ject No./(Center No.) E-21-J25 R5962-AC5 GTRC/XXX DATE 5 / 12 / 87

›ject Director: Dr. D. T. Paris School/XXX Electrical Engineering

onsor: Naval Coastal Systems Center, Panama City, FL

reement No.: Delivery Order No. 0025 under IQC N61331-85-D-0025 (OCA File 93)

vard Period: From 4/3/87 To 1/13/88 (Performance) 1/13/88 Reports

onsor Amount:	New With This Change	Total to Date
Contract Value:	$	$ 57,255
Funded:	$	$ 57,255

ıst Sharing No./(Center No.) ______ Cost Sharing: $ ______

tle: Technology Demonstration of Scaled-Up Transverse Discharge Copper Vapor Laser

)MINISTRATIVE DATA OCA Contact E. Faith Gleason x4-4820

Sponsor Technical Contact:	2) Sponsor Issuing Office:
:dward Pipkin/Code 4120	A. Hottel/Code 0654
[aval Coastal Systems Center	Naval Coastal Systems Center
'anama City, FL 32407-5000	Panama City, FL 32407-5000
(904) 234-4993	(904) 234-4309

ilitary Security Classification: Unclassified ONR Resident Rep. is ACO: X Yes ____ No

r) Company/Industrial Proprietary: ______ Defense Priority Rating: DO-S10

:STRICTIONS

e Attached Government Supplemental Information Sheet for Additional Requirements.

avel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

quipment: Title vests with Government

)MMENTS:

Subcontract to the University of New Mexico

MAY 1987

OPIES TO: SPONSOR'S I.D. NO. 02.103.001.87.011

roject Director	Procurement/GTRI Supply Services	GTRC
esearch Administrative Network	Research Security Services	Library
esearch Property Management	Contract Support Div.(OCA)(2)	Project File
ccounting	Research Communications	Other C. Stanford

ORM OCA 55:1986

EORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 3/9/88

roject No. E-21-J25 School/~~Lab~~ EE

ncludes Subproject No.(s) N/A

roject Director(s) D. T. Paris GTRC/~~GIT~~

ponsor Naval Coastal Systems Center

itle Technology Demonstration of Scaled-Up Transverse Discharge Copper Vapor Laser

ffective Completion Date: 1/13/88 (Performance) 1/13/88 (Reports)

rant/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice or Copy of Last Invoice Serving as Final
- [x] Release and Assignment
- [x] Final Report of Inventions and/or Subcontract: Patent and Subcontract Questionnaire sent to Project Director [X]
- [x] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

ontinues Project No. Continued by Project No.

OPIES TO:

roject Director
esearch Administrative Network
esearch Property Management
ccounting
rocurement/GTRI Supply Services
esearch Security Services
eports Coordinator (OCA)
rogram Administration Division
ontract Support Division

Facilities Management - ERB
Library
GTRC
Project File
Other

The UNM
University of New Mexico

CENTER FOR HIGH TECHNOLOGY MATERIALS
EECE Building, Room 125
Albuquerque, NM 87131
Telephone (505) 277-3317

November 25, 1987

Ms. Kathy Knighton
Research Administrator
School of Engineering
Georgia Institute of Technology
Atlanta, GA 30332

RE: Contract No. N61331-85-D-0025-0025

Dear Ms. Knighton:

Please find enclosed three progress reports for the periods of 4/3/87 - 7/2/87, 7/3/87 - 8/17/87, and 8/18/87 - 10/1/87, respectively, as required. Financial reports will be provided by our accounting office.

Thank you for your cooperation and please accept our apology for the delay.

Sincerely,

Jin J. Kim
Associate Professor

JJK:bh
XC: Mr. Rowland Wildman
Mr. Mike Cooper, NCSC

Contract No. N61331-85-D-0025-0025

Technical Progress Report

A001

April 3, 1987 - July 2, 1987

In this period no work was performed on this contract because the contract was not approved until July 10, 1987. The policy of the University of New Mexico is not to work on a contract until a formal contract has been approved.

Contract No. N61331-85-D-0025-0025

Technical Progress Report

A001

July 3, 1987 - August 17, 1987

In this period the design of a new improved system of the transverse-discharge copper-vapor laser (TD-CVL) was completed and manufactured. Also a new type of hydrogen thyratron for the TD-CVL system has been purchased from EEV, Inc. and tested. The thyratron driver that we have been using has been modified for the new thyratron.

Contract No. N61331-85-D-0025-0025

Technical Progress Report

A001

August 18, 1987 - October 1, 1987

In this period, the design of new electrodes for the second laser system (System II) was completed. These electrodes are designed for use in discharge-heated high-pressure transverse-discharge copper-vapor lasers (TD-CVL's). They will be manufactured from K-10 which is tungsten with 10% copper. After manufacturing the copper contained in the electrodes should be extracted from the electrode before baking. These electrodes were ordered to Schwartzkopf Development Corporation in August and the machining has been completed. But the company that initially agreed to extract the copper from the electrodes refused to do it after the electrodes were manufactured. Therefore, Schwartzkopf Development Corp. had to send them back to its home plant in Austria. Owing to customs processes they have to go through, the electrodes have not been delivered as of the middle of November. We expect them shortly.

In the meantime, the first system of our TD-CVL (System I) has been repacked using electrodes that are made of tantulum foils as before. We have been operating System I in the last few weeks of October and in early November. Some problems with the heater power supply hindered full operation. However, we managed to operate System I with a charging voltage of 10 kV for a 13.5-nF capacitance at 1 kHz. The average power of the laser was 230 mW which was not optimized at all.

It was significant, however, that the system was for the first time operated for more than four hours continuously, demonstrating that it is now possible to develop self-heated TD-CVL systems. The laser beam had a rectangular cross section of 1/4 in. x 1/4 in. The active length was 10 in. The intensity of the laser beam was quite uniform across the cross section. At present we are working to remove the arc problem.

When System I or System II is fully operational, we will conduct experiments to characterize the laser and to measure the time-resolved population inversion by the hook method. Most of the optical components are now available. Plasma diagnostics will be also carried out to measure the plasma parameters such as the electron density and temperature.

Publications and Presentations

1. "Collisional Mixing of the Two Upper Levels of the Copper-Vapor Laser," J. J. Kim, and N. Sung, presented at the Annual Meeting of the Optical Society of America, Rochester, NY, October 18-23, 1987.

2. "Stimulated Emission in Optically Pumped Atomic Copper Vapor," J. J. Kim and N. Sung, presented at the Third International Laser Science Conference (ILS-III), Atlantic City, NJ, November 1-5, 1987.

3. "Transversely Excited Atmospheric-Pressure Copper-Vapor Laser," J. J. Kim, J. Baker, R. Najafzadeh, N. Sung, and M. J. Kushner, submitted to SPIE O-E LASE '88 to be held in Los Angeles, CA, January 11-12, 1988.

4. "High Pressure Transverse-Discharge Copper-Vapor Laser," J. Baker, R. Najafzadeh, N. Sung, J. J. Kim, and M. J. Kushner, submitted to CLEO '88 to be held in Anaheim, CA, April 25-29, 1988.

5. "The Effect of Collisional Mixing on the Temporal Behavior of the Optically Pumped Copper-Vapor Laser," N. Sung and J. J. Kim, submitted to CLEO '88 to be held in Anaheim, CA, April 25-29, 1988.

6. "Stimulated Emission in Optically Pumped Atomic-Copper Vapor," J. J. Kim and N. Sung, Optics Lett. 11, 885 (1987).

E-21-J2

The UNM
University of New Mexico

CENTER FOR HIGH TECHNOLOGY MATERIALS
EECE Building, Room 125
Albuquerque, NM 87131
Telephone (505) 277-3317

February 19, 1988

Ms. Kathy Knighton
Research Administrator
School of Engineering
Georgia Institute of Technology
Atlanta, GA 30332

RE: Final Technical Report - E-21-J2~~1~~5-S1
(Contract No. N61331-D-0025-0025)
"Transverse-Discharge Copper-Vapor Laser"

Dear Ms. Knighton:

Please find enclosed nine copies of the final technical report on the contract "Transverse-Discharge Copper-Vapor Laser."

Thank you.

Sincerely,

Jin J. Kim
Associate Professor

JJK:bh
XC: Mr. Roland Wildman, UNM
Mr. Mike Cooper, NCSC

FINAL TECHNICAL REPORT

Contract No. N61331-85-D-0025-0025

(Contract Period: April 1, 1987 - Jan. 31, 1988)

I. INTRODUCTION

The main objective of this project has been to develop a high-pressure transverse-discharge copper-vapor laser (TD-CVL) system that can generate short green and yellow laser pulses (5-8 ns) at high repetition rates (> 5 kHz) for naval applications in bathymetry and surveillance. The compact size of the system, the short pulse length, and the high specific laser energy density that can be obtained are some of the advantages of TD-CVL's. Significant progress has been made in our effort to develop such a TD-CVL system here at the University of New Mexico. The TD-CVL system that has been developed by the principal investigator is only one of its kind in the free world outside the U.S.S.R.

A number of technical problems remain to be solved and work is in progress to resolve these problems. In addition to the work involved in developing the TD-CVL system itself, we have also been involved in design and testing of the electrical circuits that can be used for high-repetition rate TD-CVL systems. In this report technical achievements made during the period of the current contract are presented. Also, some of the important problems identified for scaled TD-CVL systems that should be solved in the future work will be discussed.

II. TECHNICAL ACHIEVEMENTS

A. Description of the System

A cross-sectional view of the TD-CVL is shown in Fig. 1. The high voltage cathode electrode was made of 127 μm thick molybdenum foils which were wrapped around a zirconia board. These foils are 0.5 cm wide and they form a 30 cm long electrode. The grounded anode electrode was also made of molybdenum foils similar to the cathode. The reasons that narrow strips of foils were used were that the electrodes formed by these foils do not buckle up when heated to a high temperature, and the gaps between the foils of the grounded electrode facilitate efficient heat transfer from the tungsten ribbon heater which is placed behind the grounded electrode. The cavity was well insulated by zirconia boards and was enclosed in a water-cooled aluminum box. The heater was made of thin tungsten foils powered by a low voltage (0-12 V) and high current (0-1000 A) transformer. An electrical power of roughly 1.8 kW was needed to obtain an operating temperature of 1600°C. The active zone is estimated to be approximately 20 cm long and its cross section to be roughly 1 cm^2.

The laser cavity was formed by a 99 percent reflecting flat mirror and an 8 percent reflecting glass plate separated by 1 m. The total storage capacitance was roughly 20 nF and was usually charged to 7-10 kV. The peaking capacitance was 10 nF. A hydrogen thyratron was used for the triggered gap.

It is essential to develop discharge heated TD-CVL's for practical applications. For this objective we also have been developing appropriate electrodes. We identified K-10 (tungsten with 10% copper embedded) as the material to manufacture the electrodes. After K-10 is machined to a desired shape, the embedded copper should be extracted out before baking it at a high temperature. We ordered a pair of K-10 electrodes in August, 1987, to Schwarzkopf Development Corporation which has its plant in Austria. Their initial mistakes in manufacturing and some bureaucratic problems involved in the customs procedures in Austria unduly delayed the shipment of the material. We had to order the material from Austria because, as far as we know, no U. S. company can make it. At this writing the finished electrodes have been shipped out of Austria and they are expected to be delivered in the middle of February, 1988.

We believe that the electrodes we designed will be the ultimate solution for practicable TD-CVL's. The first pair of the electrodes is made in cylindrical shape mainly because of the budget restrain. However, additional work should be done to optimize the profile of the electrodes. In fact we have been designing a Rogowski profile K-10 electrodes for more uniform discharge in a scaled volume of the active zone of the TD-CVL system. After the preliminary testing with the circular cylindrical K-10 electrodes other electrodes with different profiles will be tried to study the effect of the discharge pattern on the laser performance.

One other major problem that hindered progress in the present work has been the thyratron driver that triggers the hydrogen thyratron for the pulse-forming Blumlein circuit. The equivalent circuit for the laser is shown in Fig. 2. High voltage spikes generated in the laser discharge backfire and often damage the driver and power supply. Extensive work has been done to modify and test existing thyratron drivers. The protective circuit for the driver is shown in Fig. 3. This circuit now works very well and it can trigger the hydrogen thyratrons (EEV model CX1535x or CX1735x) at high repetition rates of up to 5 kHz.

B. Parametric Studies

Under this contract extensive testing has been conducted to characterize and improve the present high pressure transverse-discharge copper-vapor laser (TD-CVL) system that was developed at the University of New Mexico. The key feature of the system is in the design of the transverse-discharge laser cavity that can be coupled to the low inductance pulse-forming circuit and can still be operated at high temperatures of up to 1800°C.

As demonstrated earlier, this system can generate a laser specific energy density of more than 50 $\mu J/cm^3$. This is an order of magnitude higher than that produced by conventional CVL's. Fig. 4 shows the total laser energy output as a function of the temperature. It clearly shows the advantage of transverse discharge CVL's in that the high electric field to number density ratio (E/N) in the discharge allows operation at high temperatures. Conventional CVL's operate near 1450°C, whereas our TD-CVL can be operated at temperatures above 1700°C. The high plasma electron temperature that can be obtained in the transverse discharge allows the plasma electrons to penetrate deeply into the high density copper vapor. Indeed the E/N ($\sim 10^{-14}$ V-cm^2) in the TD-CVL is about two orders of magnitude higher than that in the conventional CVL's.

Another advantage of the TD-CVL is its capability of operation with high buffer gas pressure. Again, this is possible because of the high E/N only attainable in the TD-CVL systems. Fig. 5 shows the pressure dependence of the laser output. As we can see, more laser energy is produced at higher buffer gas pressure up to atmospheric pressure. The obtainable pressure was limited only by the equipment. We note that conventional CVL's operate only around 50 Torr.

There is one other important reason that higher buffer gas pressure is advantageous. The two end zones of the laser tube near the windows are kept cool and the actual number density of the neon in these zones is six times higher than that in the middle of the laser cell where the temperature is six times higher. Therefore, the copper atoms are more efficiently confined in the hot laser cell. Indeed, we were able to operate the system for more than sixteen hours without circulating the gas. It is now possible to develop a sealed-off TD-CVL system.

In January, 1988, we successfully operated the TD-CVL system at 1 kHz, generating an average power of 560 mW for an extended period of time. A practical efficiency of 0.2% was achieved in this unoptimized operation. Although the present electrodes did not provide a uniform discharge in the active zone, this operation was in a way a milestone for our effort to develop a self-heated TD-CVL system. It was demonstrated in this operation that self-heated TD-CVL's can be developed.

The laser pulse shape is shown in Fig. 6. The laser pulse usually has a full width at half maximum of 8 ns. The pulse length was measured with a Hamamatsu biplanar phototube (R1193U) coupled with an oscilloscope (Tektronix 7904) which provides a detector channel rise time of approximately 1 ns. Fig. 7 shows oscilloscope traces of typical voltage and current pulses in the laser discharge.

III. SUMMARY

Significant progress has been made to develop a transverse-discharge copper-vapor laser. A specific laser energy density of 50 $\mu J/cm^3$ was achieved in low repetition rate operations. This is an order of magnitude higher than that in conventional CVL's. A steady state operation was also demonstrated. In an unoptimized operation an average power of 560 mW was achieved at 1 kHz with a practical efficiency of 0.2%. It is now feasible to develop self-heated TD-CVL's with a scaled volume that can be operated at high repetition rates.

IV. PUBLICATIONS

1. "Transverse-Discharge Copper-Vapor Laser," J. J. Kim, K. Im, and N. Sung, SPIE Vol **737**, 31 (1987).

2. "Stimulated Emission in Optically Pumped Atomic Copper Vapor," J. J. Kim and N. Sung Optics Letters **12**, 885 (1987).

3. "Optically Pumped Copper-Vapor Laser," J. J. Kim and N. Sung, CLEO Technical Digest, p. 10 (1987).

4. "Collisional Mixing of the Two Upper Levels of Copper-Vapor Lasers," Opt. Soc. Am. Annual Meeting Technical Digest, p. 22 (1987).

5. "High Pressure Transverse-Discharge Copper-Vapor Laser," J. Baker, R. Najaf-zadeh, N. Sung, and J. J. Kim, to be published in SPIE Proceedings on Gas and IR Laser Technology.

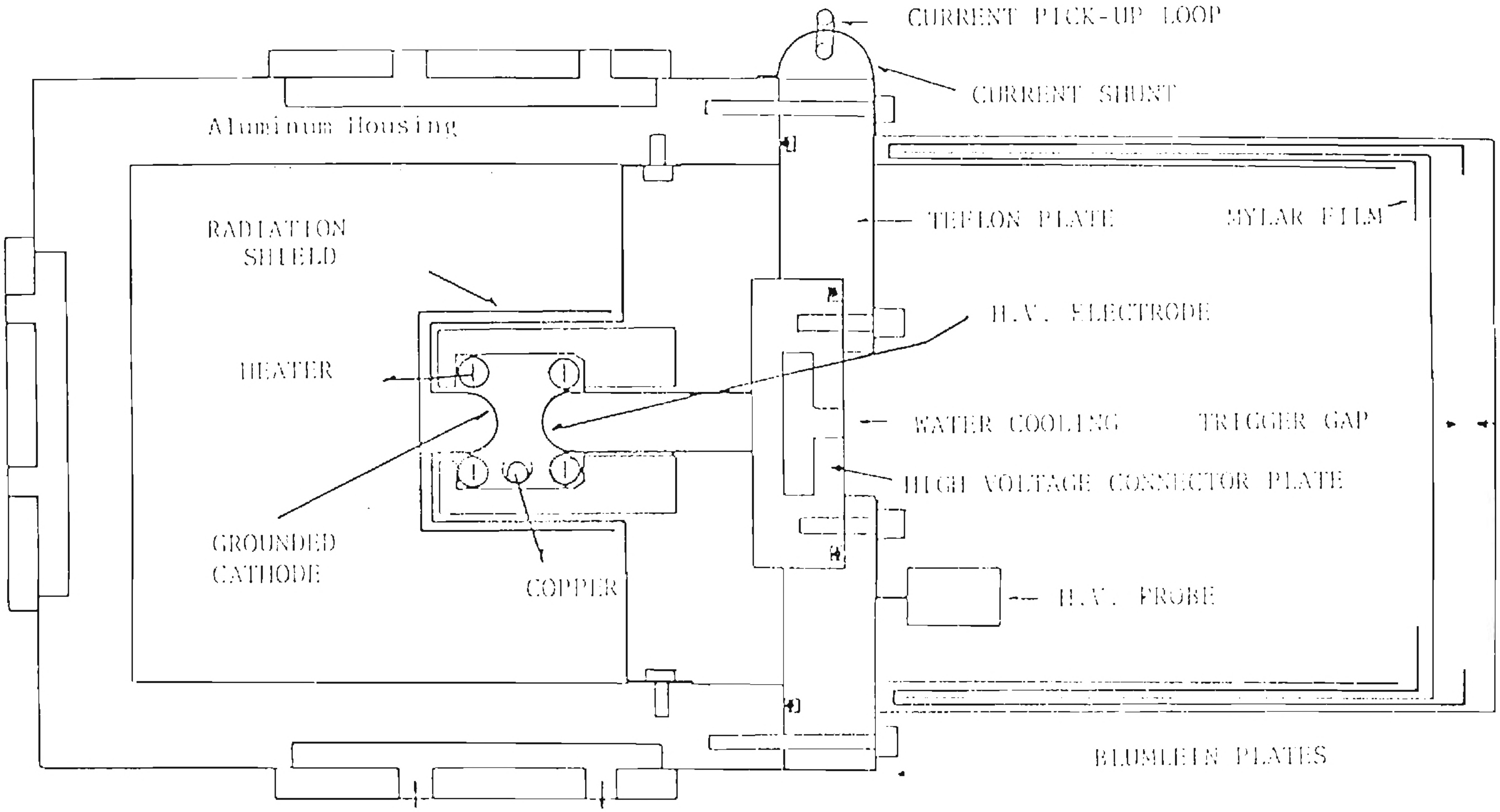

Figure 1 Cross-sectional view of TD-CVL oscillator

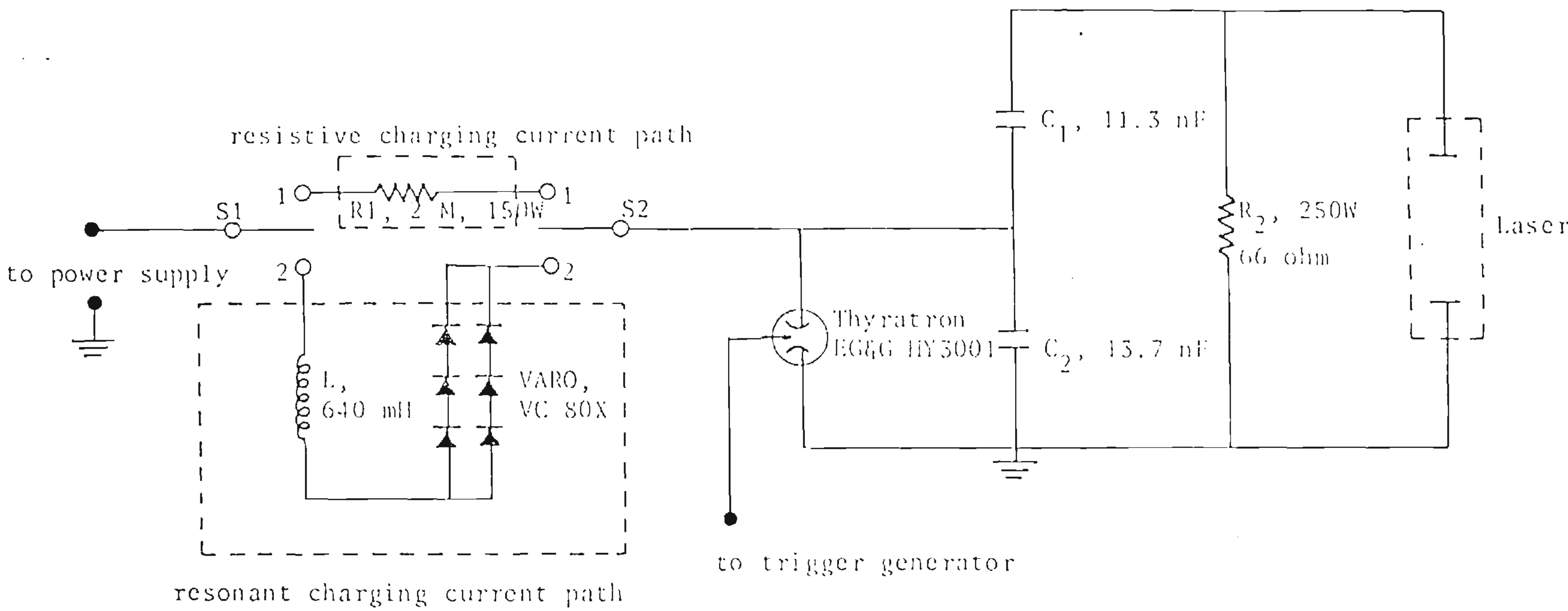

Figure 2   Electric discharge circuit diagram of TD-CVL system.

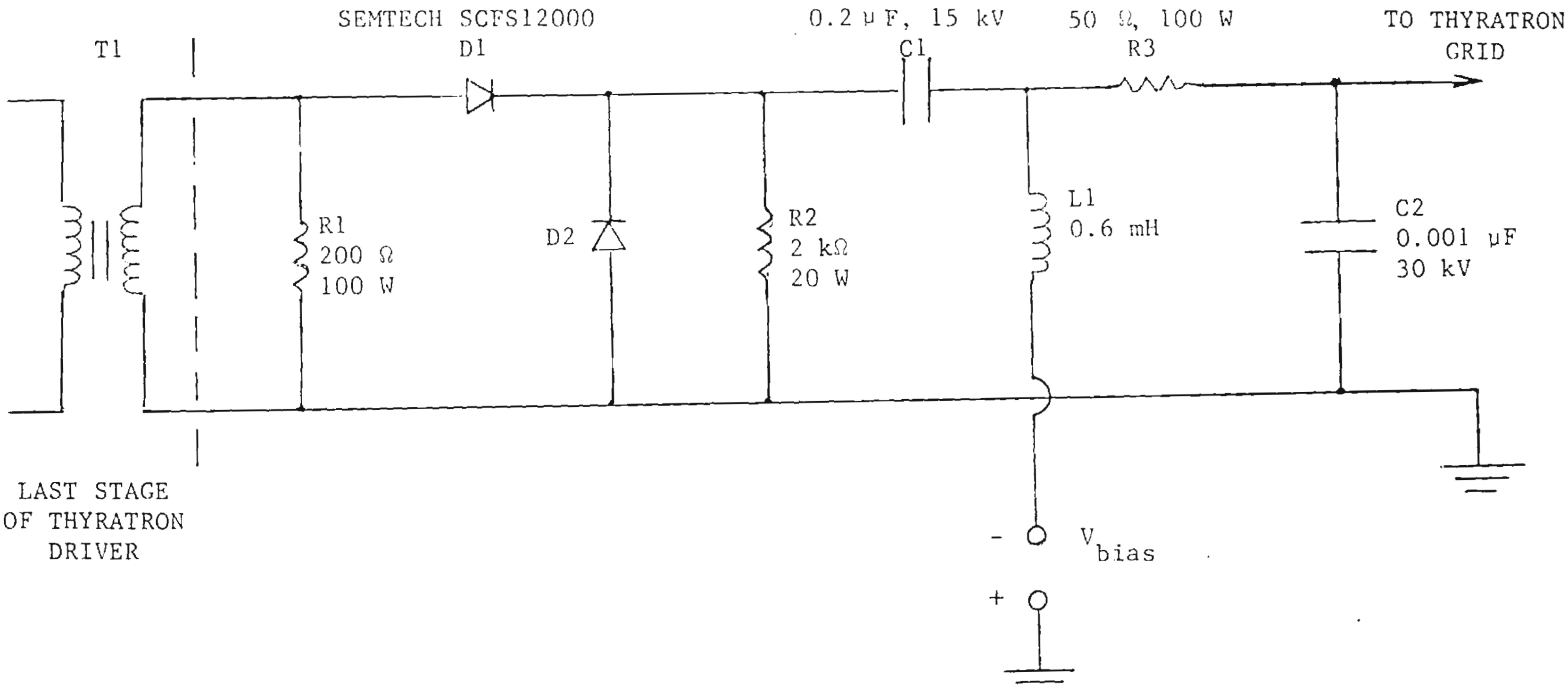

Fig. 3. Thyratron Driver Protection Circuit

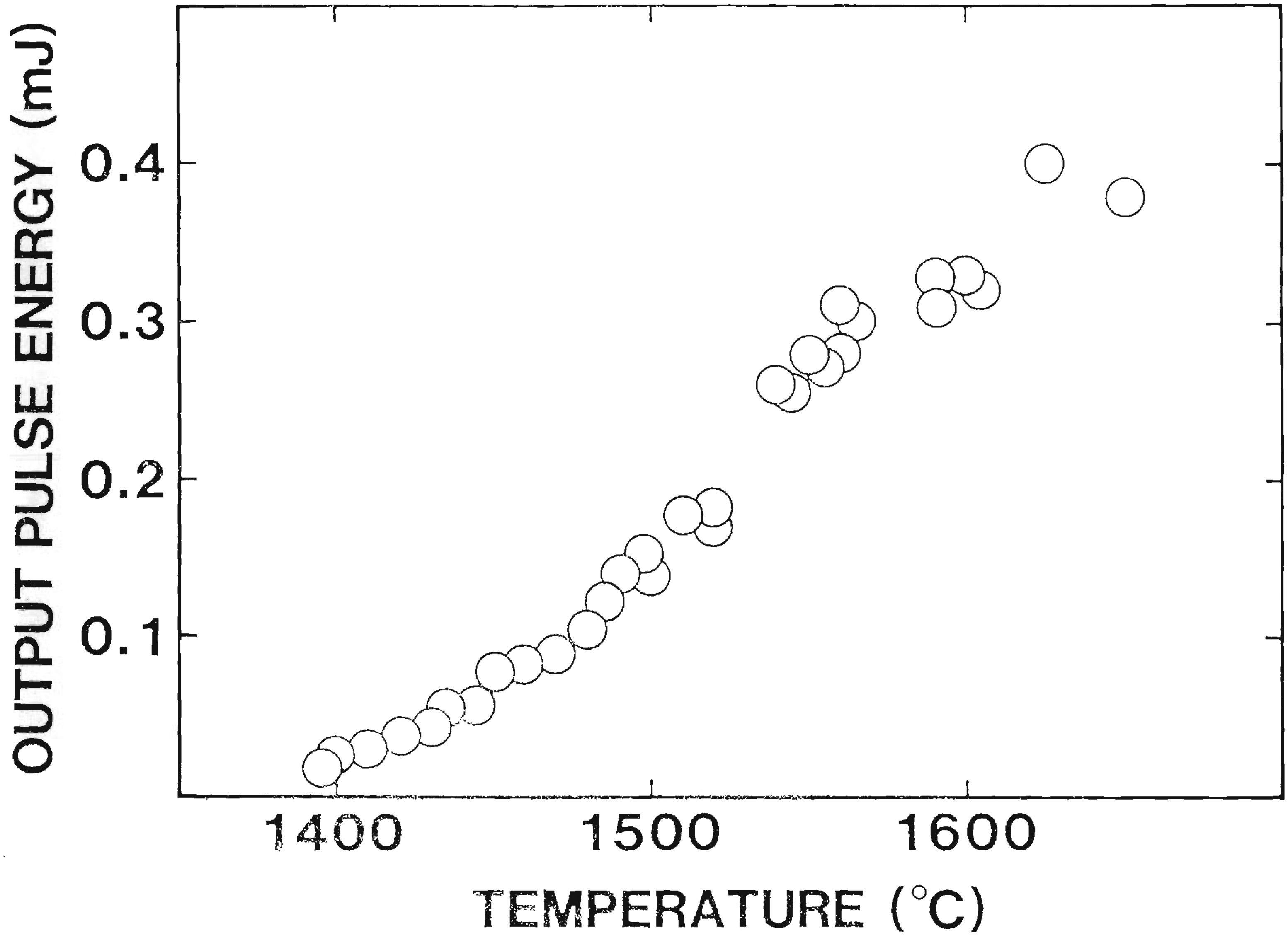

Figure 4 Laser output versus temperature

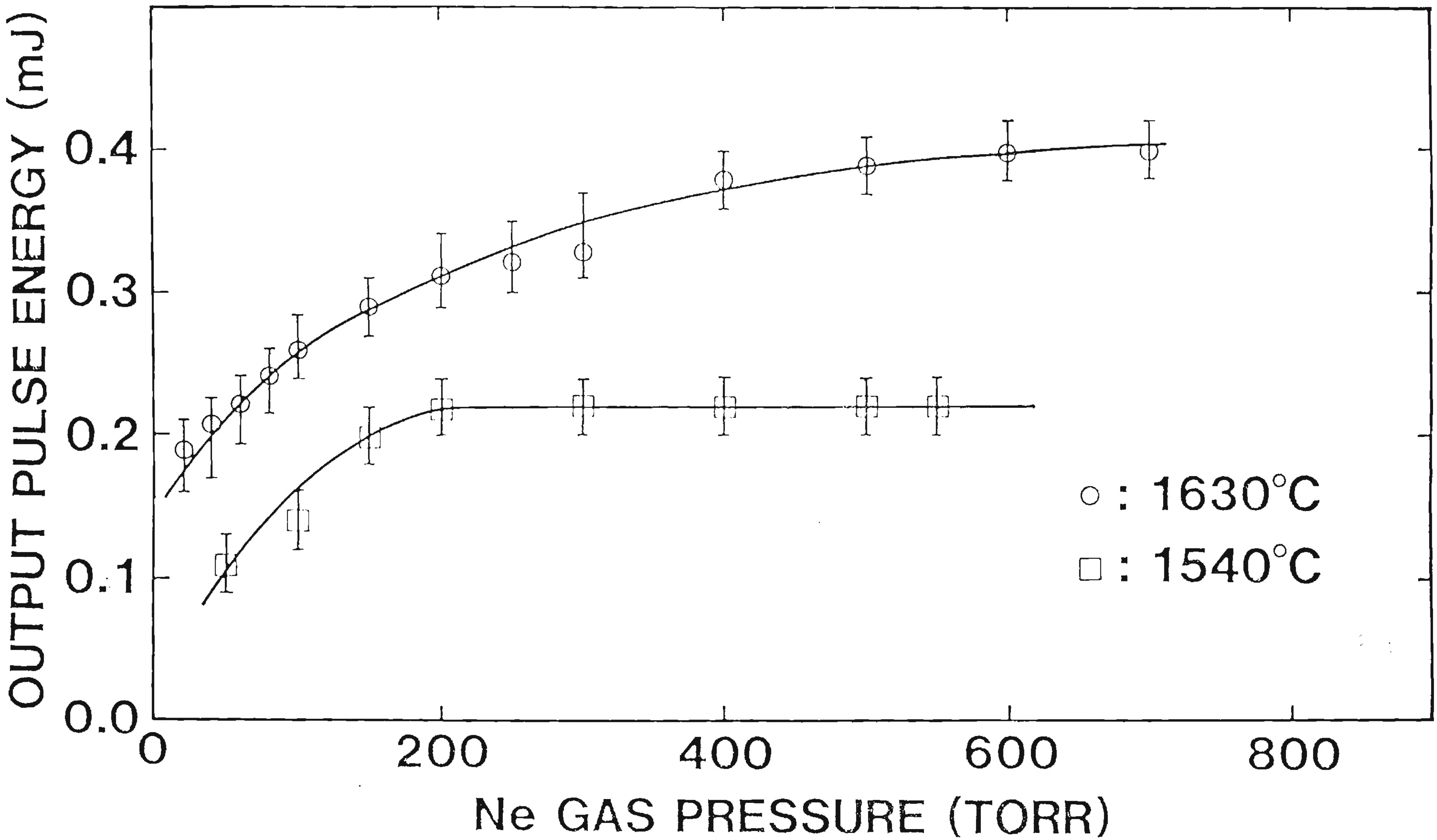

Figure 5 Laser output versus Ne pressure

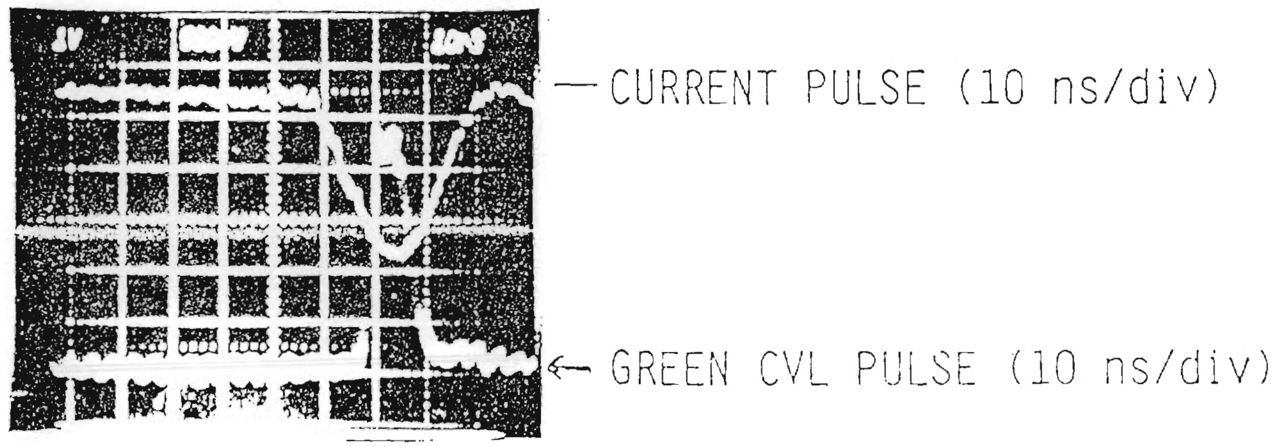

Figure 6 Laser pulse shape

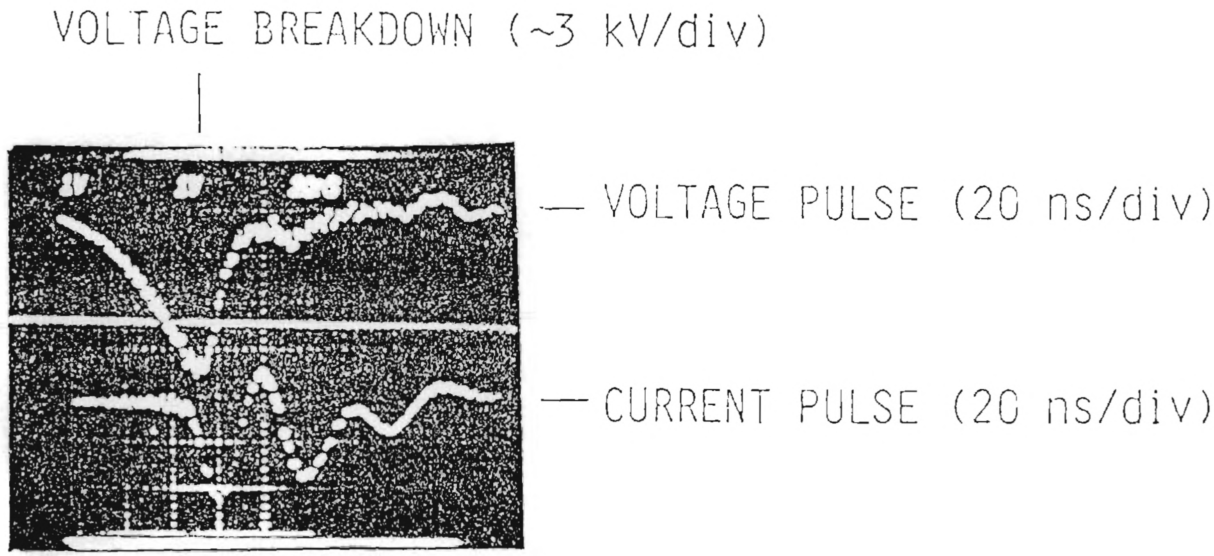

Figure 7 Voltage and current pulses