MASTER COPY KEEP THIS COPY FOR REPRODUCTION PURPOSES

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1995

3. REPORT TYPE AND DATES COVERED
Final Report (May 1, 1992 - July 31 1995)

4. TITLE AND SUBTITLE
Pulsed power plasma devices based on hollow and super-emisive cathodes

5. FUNDING NUMBERS
DAAL03-92-G-0231

6. AUTHOR(S)
M. Gundersen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Southern California
Dept. of EE-Electrophysics
Los Angeles, CA 90089-0484

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U. S. Army Research Office
P. O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ARO 29595.16-PH

11. SUPPLEMENTARY NOTES
The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The understanding of emission and transport in the pseudospark is complex because these are related to a transition between two fundamentally different modes of electron emission. During the previous year we have conducted probe measurements of plasma parameters. We found that fluctuations related to a glow-to-arc transition can occur wherein smooth current growth is interrupted by cathode spot formation resulting in very rapid rise in current. These results support a view that quenching observed in the pseudospark is a double-layer phenomenon that occurs when emission cannot exceed secondary emission produced by ion bombardment. These results are new in that they provide a new explanation of quenching, and demonstrate a valuable probe method.

19960209 094

14. SUBJECT TERMS
Back-Lighted Thyratron, electron beam, electron emission, cathode spot formation, semiconductor lithography, spark gaps, pseudospark, GaAs-based power switches

15. NUMBER OF PAGES
11

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

DTIC QUALITY INSPECTED 1 8

PULSED POWER PLASMA DEVICES BASED ON HOLLOW AND SUPER-EMISSIVE CATHODES

FINAL REPORT

MARTIN GUNDERSEN

September 26, 1995

U.S. Army Research Office

Contract/Grant No.: DAAL03-92-G-0231

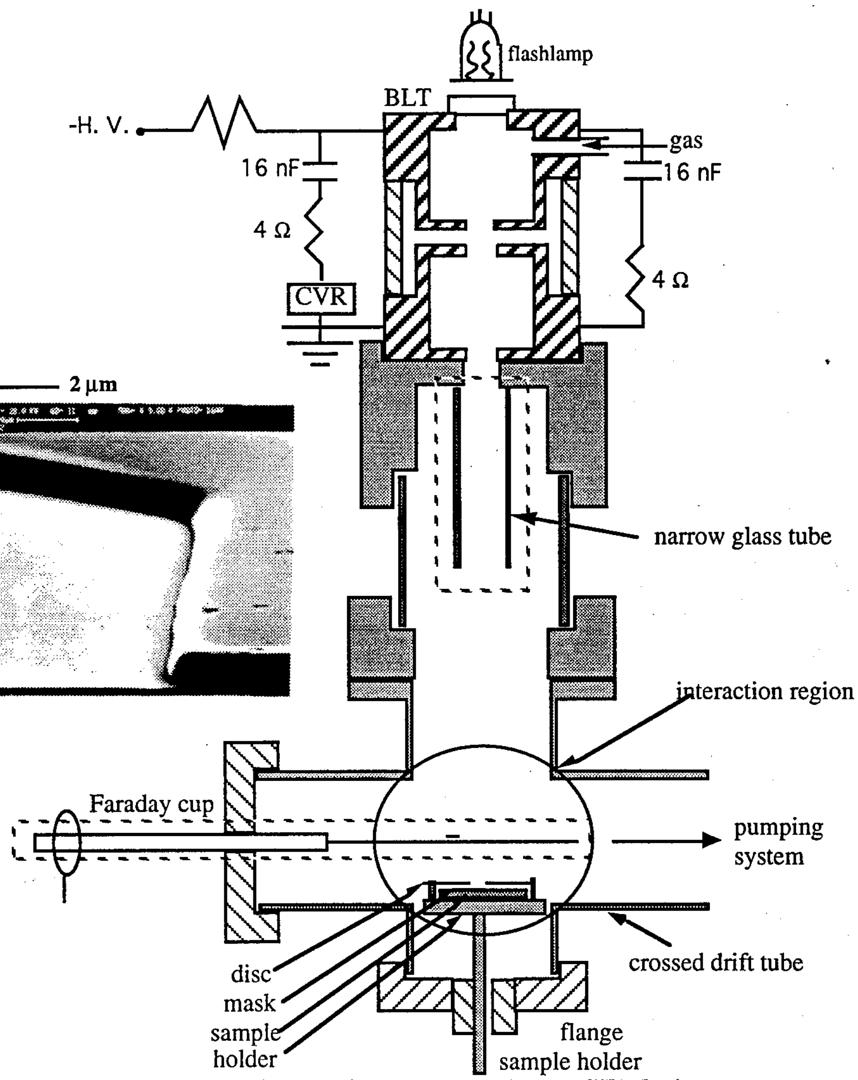
University of Southern California

REPORT OF RESEARCH FINDINGS

ELECTRON BEAM RESULTS

A simple, robust, plasma-based, variable pulse-length electron beam source that produces 10's nsec to 100's msec pulses has been developed. Three distinct modes are identified: a transient hollow cathode discharge, a quasi steady-state hollow cathode discharge and a super-emissive cathode mode. During the transient hollow cathode discharge an electron beam with duration ~ 50 nsec, current ≈ 60 A, normalized brightness ≈ $4*10^{10}$ A/m^2rad^2 was measured. The device appears to be directly applicable for applications including jammers, intense microwave sources, and accelerators.

During the previous period we have applied the research into hollow cathode electron beam sources to the development of a broad area, intense electron beam source for high resolution, high throughput semiconductor lithography. We have made significant progress. Electron beam lithography using a robust, high current density (>10 A/cm^2), high brightness (>10^{10} A/m^2rad^2), broad area (>1 cm diameter) electron beam source is reported. The electron beam is produced during the hollow cathode discharge phase of a back-lighted thyratron. The generated beam propagates in soft vacuum (<200 mTorr) and is collimated using cylindrical dielectric waveguides, resulting in uniform intensity over an area exceeding ~1 cm^2, along with a small divergence angle (<1.5 degrees). Masked lithography for replication of fine line structures has been achieved, demonstrating the potential for a high throughput (~30-40 wafers/hour), high resolution (<0.25 μm) lithography system that is competitive with much more sophisticated x-ray and short wavelength optical systems.



Schematic of the electron beam lithography system. Inset: SEM picture cross section of the replicated PMMA structure at higher magnification, indicating sharp wall profiles.

BACK-LIGHTED THYRATRON (BLT)

The Back-Lighted Thyratron (BLT)[1] is a high power switch that was partially developed under research supported the ARO. The programs that supported development of the switch included basic research[2] funded at USC, and a subsequent SBIR grant at Integrated Applied Physics, Inc., a small business in Torrance CA.

The BLT is at this stage a switch that fits in the area between high power thyratrons and spark gaps. It has life advantages relative to spark gaps, and conducts higher current than thyratrons. Related versions are under development in Germany, England, Russia, France, and Japan--for example, development underway at Siemens and at Aachen in Germany is attempting to extend the life by approximately a factor of 10 through modification of electrodes. The switch is at a stage that commercial versions are now available for applications including pulsed CO_2 and excimer lasers.

Research related to the BLT has explored electron beam production for applications including microlithography[3], fusion sources (electron beam ion trap, or EBIT[4]), and high brightness accelerator applications[5]. However, it is remarkable that following transition of the pulsed power research to development of the switch, the remarkable emission properties of the BLT cathode led to fundamental studies, and exploration of new emission properties, particularly of hollow cathode emission properties, and a so-called super-emission. During super-emission current densities in excess of 10,000A/cm^2 are produced over macroscopic areas >1cm^2. The physics behind this emission process[6] is leading to new areas for development, and improved understanding of fundamental processes related to the formation of arcs and emission of current.

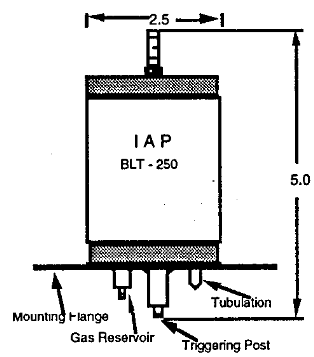
The Back Lighted Thyratron

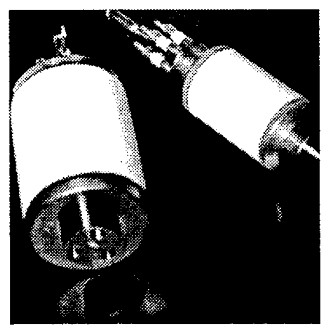
Advantages

Low pressure glow
Low forward, reverse drop
Reverse current
Robust
High Current -- 1 to >100 kA
Simple for implementation
Very fast (>10(12)) current rise rate
Low standby power
Optical control
Very isolatable

References:
"High power pseudospark and BLT switches,"
K. Frank, et al, IEEE Trans. Plasma Science, 16, 317 (1988).
"Fiber optic triggered high-power ...,"
C.G. Braun, et al, IEEE Trans. Elec Dev, 35, 559 (1988).
"A flashlamp triggered high power thyratron type switch"
G. Kirkman, et al, App. Phys. Lett. 52, 613 (1988).

Patented





Summary of BLT properties. The BLT switches are 2.5" and 1 5/8" in diameter.

A key issue relating to the life and erosion rate of the back-lighted thyratron was resolved, and published in Physical Review Letters.

Work on this problem has been going on simultaneously at Ekaterinburg and Ryzan Russia, Siemens in West Germany, Lawrence Laboratory, and at USC. It was found that the type of emission, the "super-emission", is a critical function of cathode field, and cathode heating conditions. This translates conceptually to the design of electrodes for high power BLT switches, and is being used to select electrodes. In addition, a geometrical configuration of the cathode has been found that is advantageous for very high current (>100kA)

A remarkable effect related to the super-emissive process in the back-lighted thyratron and pseudospark has been discovered. Self-sustained self-sputtering occuring during high current operation ($\approx 10^4$ A/cm^2, I>10^3 A) was shown to be a possible mechanism for the superdense glow. The mean-free-path for ionization of cathode material sputtered in the low-current hollow-cathode phase can be shorter than the cathode-anode gap distance, and ionized atoms can return to the cathode surface, self-sputtering with a yield greater than one. The self-sputtered cathode atoms become ionized in the beam of electrons accelerated in the cathode sheath. A large fraction of the discharge current at the cathode surface can be carried uniformly over the surface by ions, and a very high electron emission density is not required to maintain the high current.

GaAs-Based Power Switches

Initial devices were single channel, surface gate type prototypes which had breakdown voltage of 200 volts and conduction current of ~ 1 mA. The specific on-resistance, and the blocking gain of these devices were 20 mΩ.cm^2 and 2, respectively. In addition, optical triggering using a compact semiconductor laser diode array was demonstrated. The next generation devices were fabricated during the previous year, and were of the interdigitated, buried gate structure, designed for 1 ampere current conduction capability. Experimentally, breakdown voltage of 200 volts, and specific on-resistance of 20 mΩ.cm^2 were obtained. This demonstrated that GaAs static induction transistors have significant potential for high efficiency power electronics switching applications. The devices being presently fabricated are of the recessed-gate type, with breakdown voltage ranging from 150-300 volts, and conduction current of 1 ampere. These devices are optimized, and address the key issues of improved efficiency and low gate drive requirement. As compared to older generation prototypes, they exhibit significantly lower values of specific on-resistance (1-3 mΩ.cm^2), and considerably higher blocking gains, ranging from 25 in the 300 volt devices to 75 in the 300 volt devices.

Pollution Abatement

The possibility of using electrical plasmas to reduce NOx, particulate and hydrocarbon emission from diesel engines is receiving attention within the diesel community, as well as for other applications including incineration and utility power plants. Particularly attractive aspects include potential for operation without modification of the engine, in the form of an attachment, such as a muffler. A key requirement for implementation is efficiency; producing high voltage, high current pulses with fast risetime and short pulse length at high repetition rates–repetitive pulsed power systems in the past have been limited in efficiency and life. We report here observation of improved efficiency in terms of fraction of required engine power ($\approx$2%). Various other aspects of research into the pulsed plasma treatment process are discussed.

Plasma processing provides an exciting prospect for control of effluents from many different sources including diesel engines, power plants, vehicular sources, and reduction of toxic metals and hydrocarbons. If successful, this method will have broad and very significant impact on the reduction of many forms of air pollution. Current research seeks to understand the fundamental plasma chemistry that occurs in the plasma cell, and improve the electrical efficiency. Ultimately a central issue is the need to produce efficient processisng, in terms of engine power required. In this paper we report efficient operation of a plasma processing device. Considerable improvement in efficiency can be achieved with plasmas using fast, short, high voltage pulses and producing higher energy electrons, if this form of pulsed power can be efficiently generated and applied to the load. Success is expected to provide a cost-effective, reliable method to reduce NO_X and hydrocarbon emission for engines and other sources, such that these sources will meet the NO_X emission standards set by the environmental regulations.

The pulsed plasma system provides flexibility in design to accommodate all kinds of processing requirements. When fully developed, it will be a viable and competitive system for engine exhaust treatment. The pulsed plasma system will be easily retrofitted to existing engines, including those that are not manufacturer supported. Also, the pulsed plasma system will be easily incorporated with new diesel engines. Compared to other exhaust gas treatment systems, the pulsed plasma treatment system will be very inexpensive to fabricate. The pulsed plasma system is quite versatile in treating various pollutants because the plasma chemistry is dominated by the high energy electrons. Readily scalable, it can be applied to treatment of exhaust gases from sources of any size. Military bases and other federal installations that discharge hazardous solid wastes must also comply with FFCA requirements. Pulsed plasma processing is very attractive for treatment of flue gases from fossil-fuel-burning power plants to reduce SO_2 and NO_X emissions. Currently, there are over 1600 power plants with greater than 50 MW generating capability, and flue gas emission of these power plants are a major concern for environmental protection.

The pulsed plasma method has several potential advantages relative to other approaches. For example, techniques for NO_X removal are often suitable only for stationary sources because of the difficulty of handling and injecting a reductant chemical. Exhaust gas recirculation, examined as a means of eliminating the NO_X component in mobile sources, is apparently most effective when combined with lowering of the combustion temperature in the engine cylinder. The combustion efficiency is decreased, the formation of soot is increased, the engine output decreases, and fuel consumption increases. Thus these techniques are not yet mature, and research must still address their ultimate feasibility.

Nearly all mechanical or combustion cycle modifications to reduce NO_X emissions (e.g. guel mixture, timing, water injection, EGR, compression or combustion modifications) decreases efficiency, or may increase particulate or hydrocarbon emission–effectively increasing operating costs. Modifying existing power sources can also be expensive. The "plasma muffler" approach reduces the degree of modification required, and is a broadly applicable approach. Successful development may be applied to many different systems and fuels (gasoline, methanol, diesel, natural gas, etc.), and is equally applicable to stationary and mobile sources (for example, VOC sources may be treated). The plasma treatment approach deserves the most serious consideration because it is extremely general in approach, and if successful, will have enormous impact on emission reduction.

The pulsed plasma approach is based on the use of higher energy electrons, wherein the electron temperature is much greater than the gas and ion temperatures, and/or the electron energy distribution is highly non-Maxwellian. The process uses highly reactive radicals, which can be efficiently produced by collisions with sufficiently energetic electrons ($E \geq \approx 50eV$). This method has been studied widely by various groups to treat waste gases including SO_2, NO_X, and hydrocarbons. The system has advantages of simple and flexible design, scalability, potential for high energy efficiency, mature technology (as in ozone generators), and high pressure operation (≥ 1 atm) which translates into high rate of chemical reaction and large reactor throughput. The plasma process has been applied to the treatment of diesel engine exhausts by the Japanese group led by Fujii. They were able to obtain 70% reduction of NO_X and SO_X components, and complete elimination of soot, from the exhaust from a 2-liter diesel engine.

Investigation of the non-thermal plasma approach requires a broad range of studies including basic pulsed power modulator design for efficient power conditioning, sophisticated diagnostics for the plasma reactor, and advanced modeling of related plasma chemistry (Figure 1).

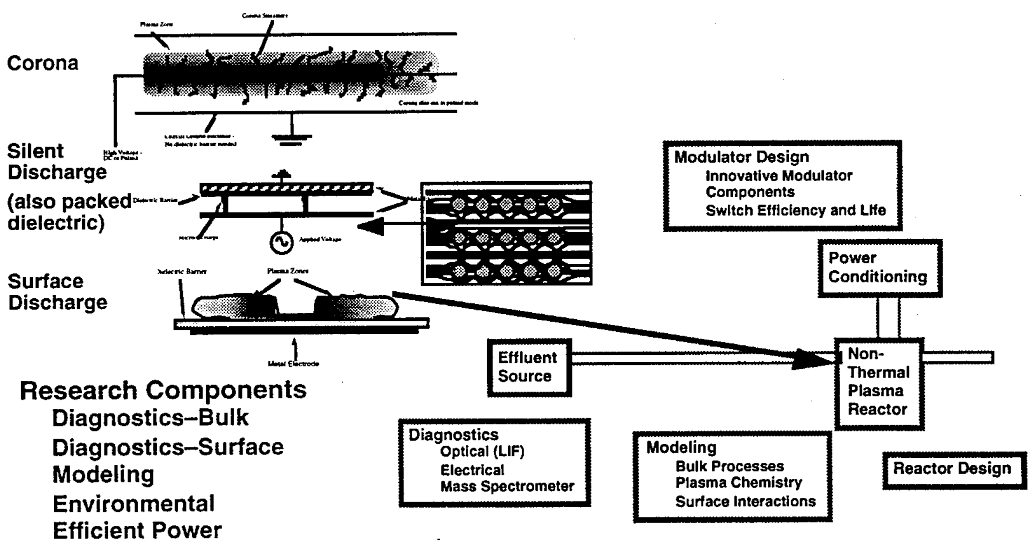


Figure 1. Schematic of elements required for investigation of fundamental physical processes occuring in a plasma reactor. Upper left: Representation of types of plasma cells under investigation.

In order to significantly improve the efficiency and effectiveness of the non-thermal plasma reactor and substantially increase the reactive volume of the plasma, it is desirable to have a uniform discharge occurring in the non-thermal plasma reactor to distribute evenly the radical concentration throughout the reactor volume. In order to investigate these processes directly, a technique such as laser induced flourescence (LIF) must be used. A primary target is NO.

In Fig. 2 is shown *in situ* treatment of a diesel engine in a Volkswagen automobile. Results from these studies suggest that it will be possible to obtain efficient operation of the plasma treatment system (≈2% engine power).

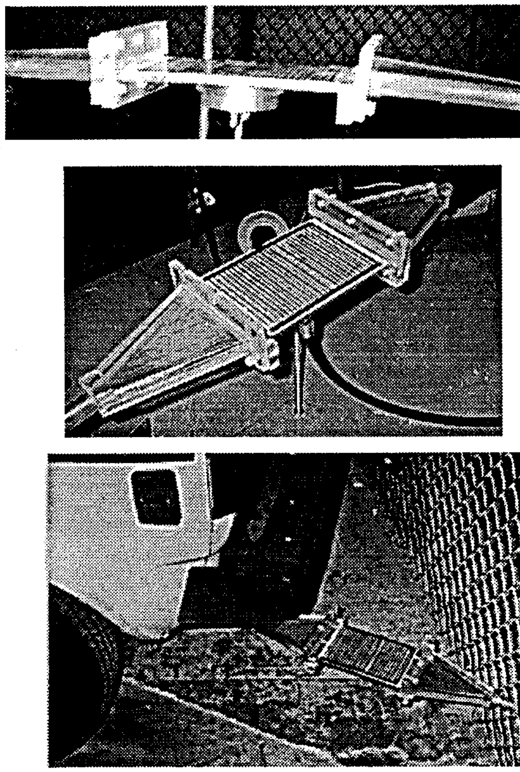


Figure 2. Implementation of surface discharge cell with Volkswagen car.

There is at present theoretical research underway involving detailed multidimensional modeling of the plasma chemistry, reactor geometry and pulsed power. In previous work, a plasma chemistry model was developed for examining plasma removal of SO_2/NO_x from coal fired power plants and oxidation of organic wastes. The model includes a full accounting of electron impact, ion and neutral chemistry at atmospheric pressure, surface reactions, an extensive data base, and external circuitry. The densities of all species are tracked during and after repetitive electrical discharge pulses. Important issues to be investigated are the mode of power deposition as a method to select chemical reduction or oxidation, the effects of aerosol particles and the effects of reactor geometry.

Plasma aftertreatment of diesel exhaust principally relies on the removal of nitrogen oxides (NO_x) and other hazardous components by the highly reactive radicals produced in a non-thermal plasma. These chemical reactions occur mainly in the gas phase, but the plasma composition and characteristics can be affected by heterogeneous reactions of ions, electrons, radicals, and molecules with the electrode surfaces and reactor walls. Surface processes must also be modeled in numerical simulations necessary to understand reactions in the gas stream. However, detailed data on the kinetics, thermodynamics, and mechanism of the surface interactions of such species is essentially nonexistent and the foundations for understanding these reactions are not developed nearly as well as for the comparable gas phase reactions. Thus, hard data needed for modeling is not available and is extremely difficult to predict. There is a very serious need for sophisticated modeling of the plasma chemistry, and the data to support such modeling.

Plasma treatment has demonstrated considerable promise, and a broad range of applications. There are in addition to engineering and development issues, some very attractive scientific problems that require study. Thus there are many exciting, useful, and potentially very beneficial aspects to the development of the non-thermal plasma that will become more apparent as this work receives attention in the future.

---

[1]"Low pressure, light initiated, glow discharge switch for high power applications," G.F. Kirkman and M.A. Gundersen, Appl. Phys. Lett. **49**, 494 (1986), "High current back lighted thyratron switch," G. Kirkman and M. A. Gundersen, Appl. Phys. Lett. **60** (3), (1992).

[2] "Determination of electric field and electron temperature in the positive column of a high-power hydrogen thyratron from non-intrusive measurements," D.A. Erwin, J.A. Kunc and M.A. Gundersen, Appl. Phys. Lett. **48**, 1727 (1986).

[3]"Broad area, intense electron beam source for high resolution, high throughput semi-conductor lithography," T. Y. Hsu, P. Hadizad, R. L. Liou, M. Baik. G. Roth, K. Frank, and M. A. Gundersen, J. of Vacuum Science and Technology B **11** (5), 1868 (1993).

[4]"Long pulse electron beam generation from the back-lighted thyratron," R-L. Liou, T-Y. Hsu, and M. A. Gundersen, Appl. Phys. Lett. **61** (22), 2647 (1992).

[5]"Electron beam generation from a superemissive cathode," T. Y. Hsu, R. L. Liou, G. Kirkman, and M. A. Gundersen, Proc. 1991 Particle Accelerator Conference. 1990 (1991)., "Plasma lenses for SLAC final focus Test Facility," D. Betz, P. Chen, D. Cline, M. A. Gundersen, C. Joshi, T. Katsouleas, J. Norem, S. Rajagopalan, J. Rosenzweig, J. J. Su, R. Williams, *ibid.*, 619.

[6]"Origin of anomalous emission in superdense glow discharge," W. Hartmann and M.A. Gundersen, Phys. Rev. Lett. **60** (23), 2371 (1988)., "Model for explosive electron emission in a pseudospark "superdense glow", A. Anders, S. Anders and M. A. Gundersen, Phys. Rev. Lett. **71** (3), 364 (1993).

LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP:

Refereed Publications:

"A high-power electron beam source based on the superemissive cathode," T-Y. Hsu and M. A. Gundersen, Appl. Phys. Lett. **61** (21), 2515 (1992).

"Long pulse electron beam generation from the back-lighted thyratron," R-L. Liou, T-Y. Hsu, and M. A. Gundersen, Appl. Phys. Lett. **61** (22), 2647 (1992).

"Emission of microwave and millimeter wavelength radiation during hollow cathode discharge operation of the back lighted thyratron," by R. Liou, H. Figueroa, A. H. McCurdy, G. Kirkman-Amemiya, R. J. Temkin, H. Fetterman and M. A. Gundersen, Appl. Phys. Lett. **61** (23), 2779 (1992).

"Avalanche injection model for the lock-on effect in photoconductive power switches," H. Zhao, J. H. Hur, P. Hadizad, and M. A. Gundersen, J. Appl. Phys. **73** (4), 1807 (1993).

"A high voltage optoelectronic GaAs static induction transistor," P. Hadizad, J. H. Hur, H. Zhao, K. Kaviani, M. A. Gundersen, and H. R. Fetterman, IEEE Elec. Dev. Lett. **14** (4), 190 (1993).

"Broad area, intense electron beam source for high resolution, high throughput semi-conductor lithography," T. Y. Hsu, P. Hadizad, R. L. Liou, M. Baik, G. Roth, K. Frank, and M. A. Gundersen, J. of Vacuum Science and Technology B **11** (5), 1868 (1993).

"Model for explosive electron emission in a pseudospark "superdense glow", A. Anders, S. Anders and M. A. Gundersen, Phys. Rev. Lett. **71** (3), 364 (1993).

"Electron emission from pseudospark cathodes", A. Anders, S. Anders and M. A. Gundersen, J. Appl. Phys. **76** (3), 1494 (1994).

"Triggered breakdown in low pressure hollow cathode (pseudospark) discharges), L. C. Pitchford, N. Ouadoudi, J. P. Boeuf, M. Legentil, V. Puech, C. Thomaz, and M. A. Gundersen, J. Appl. Phys. **78** (1), 77 (1995).

"Spatial and temporal distribution of potential in the pseudospark switch," V. F. Puchkarev and M. A. Gundersen, IEEE Trans. Plasma Sci. **23** (3), 318 (1995).

"Acceleration of electrons to > 0.5 MeV during space-charge neutralization of a 20 keV transient electron beam," K. Frank, J. Christiansen, T. Redel, R. Stark, M. Setter and M. A. Gundersen, submitted to Appl. Phys. Lett.

Other Publications:

"Lock-on effect in GaAs photoconductive switches," H. Zhao, J. Hur, P. Hadizad, and M.A. Gundersen, Proceedings of the OE LASE '92, Los Angeles, CA, January 19-24, 1992.

"High brightness hollow cathode electron beam source," G. Kirkman, N. Reinhardt, B. Jiang, M. A.Gundersen, T. Y. Hsu, R. L. Liou, and R. J. Temkin, Proceedings of the Workshop on Advanced Accelerator Concepts, 729 (1992); Proceedings of the 9th International Conference on High-Particle Beams, Vol. II, 1123 (1992).

"The hollow cathode phase of pseudospark discharges," L. C. Pitchford, J. P. Boeuf, V. Puech, R. L. Liou, and M. A. Gundersen, Proceedings of the 20th International Power Modulator Symposium, 368 (1992).

"A high voltage GaAs static induction transistor," P. Hadizad, J. H. Hur, H. Zhao, K. Kaviani, M. A. Gundersen, and H. R. Fetterman, Proceedings of the 20th International Power Modulator Symposium, 262 (1992).

"Back-lighted thyratron research: Technology transfer, new spin-offs," M. A. Gundersen, G. Kirkman, T. Y. Hsu, and R. L. Liou, Proceedings of the 5th SDIO/ONR Pulsed Power Meeting, 144 (1992).

"A comparative study of SI and GaAs-based switching devices for pulsed power and a high voltage optoelectronic GaAs static induction transistor," P. Hadizad, J. H. Hur, H. Zhao, M. A. Gundersen, and H.R. Fetterman, Proceedings of the 5th SDIO/ONR Pulsed Power Meeting, 117 (1992).

"Robust, plasma-based variable pulse-length electron beam source," R. Liou, T. Hsu, G. Kirkman, R. Temkin, and M. A. Gundersen, Proceedings of the 17th International Conference on Infrared and Millimeter Waves, 58 (1992).

An article describing an application of my research appeared in the Wall Street Journal, April 13, 1993, pg B-3.

"A variable pulse-length electron beam from the back-lighted thyratron," R. L. Liou, T. Y. Hsu, G. Kirkman, G. Roth, and M. A. Gundersen, Proceedings of the 1993 Particle Accelerator Conference, 3072 (1993).

"High density plasma source for plasma lens experiments," K. Nakamura, R. Liou, and M. A. Gundersen, Proceedings of the 1993 Particle Accelerator Conference, 3537 (1993).

"High current low energy electron beams produced during the high current phase of a pseudospark," T. Y. Hsu, R. L. Liou, G. Kirkman, and M. A. Gundersen, Proceedings of the 1993 Particle Accelerator Conference, 3066 (1993).

"Theoretical and experimental study of pseudospark electron beam generation," L. Pitchford, J. Boeuf, V. Puech, R. Liou, and M. A. Gundersen, Proceedings of the 1993 Particle Accelerator Conference, 3069 (1993)

"A robust cathode for producing high-power, high-current electron beams," T. Hsu, R. Liou, M. A. Gundersen, and G. F. Kirkman, Proceedings of the 9th IEEE Pulsed Power Conference, 954 (1993).

"The hollow cathode phase of pseudospark operation," L. Pitchford, J. Boeuf, V. Puech, R. L. Liou, and M. A. Gundersen, Proceedings of the 9th IEEE Pulsed Power Conference, Albuquerque, NM, June 21-23, 1993.

"High power GaAs static induction transistor," P. Hadizad, M. Baik, and M. A. Gundersen, Proceedings of the 9th IEEE Pulsed Power Conference, Albuquerque, NM, June 21-23, 1993.

"Parametric studies of time to breakdown in pseudospark switches," V. Puech, M. Legentil, and J. C. Thomaz, N. Guadoudi, L. C. Pitchford, and J. P. Boeuf, R. L. Liou, and M. A. Gundersen, Proceedings of the 21st ICPIG, Bochum, Germany.

"High power GaAs static induction transistor," P. Hadizad, M. Baik, P. A. Kanjamala, and M. A. Gundersen, Proceedings of the 6th SDIO/ONR Pulse Power Meeting, 37 (1993).

"A spin-off application of the back-lighted thyratron -- An electron beam source for high resolution, high throughput semiconductor lithography," T. Y. Hsu, P. Hadizad, R. L. Liou, M. Baik, G. Roth, K. Frank, and M. A. Gundersen, Proceedings of the 6th SDIO/ONR Pulse Power Meeting, 31 (1993).

"Explosive emission model for super-emission in the pseudospark and back-lighted thyratron," A. Anders, S.Anders, and M. A. Gundersen, Proceedings of the 6th SDIO/ONR Pulse Power Meeting, 156 (1993).

"A novel electron beam source for high resolution, high throughput microlithography," T. Y. Hsu, P. Hadizad, P. Ashok Kanjamala, R. L. Liou, M. G. Baik, G. Roth, and M. A. Gundersen, Proceedings of the SPIE International Symposium on Microlithography '94, San Jose, CA Feb. 27 - March 4, 1994.

"A predictive model for life-limiting cathode emission in the pseudospark and back-lighted thyratron," A. Anders, S. Anders, V. Puchkarev, and M. A. Gundersen, Proceedings of the 1994 Power Modulator Symposium, 240 (1994).

"High voltage, recessed-gate GaAs field-effect transistors," P. Hadizad, M. A. Gundersen and F. Ren, Proceedings of the 1994 Power Modulator Symposium, 78 (1994).

LIST OF PARTICIPATING SCIENTIFIC PERSONNEL

M. Gundersen

M. Baik
P. Hadizad
T. Y. Hsu
R. L. Liou
V. Puchkarev
G. Roth
F. Zhang

REPORT OF INVENTIONS:

USC File # 2570 -- "Pollution treatment self-energized by short pulses" (Patent filed August 8, 1995) (with V. Puchkarev and I. Yampolsky)