REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-02-

0336

1. REPORT DATE *(DD-MM-YYYY)*
8-7-2002

2. REPORT TYPE
Final Report

3. DATES COVERED *(From - To)*
April 1,2001-March 31, 2002

4. TITLE AND SUBTITLE
Instrumentation for Atmospheric Pressure Plasma Research

5a. CONTRACT NUMBER

5b. GRANT NUMBER
F49620-01-1-0219

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Office
Of Scientific Research
801 N. Randolph St.,
Rm. 732
Arlington, VA, 22203-1977

10. SPONSOR/MONITOR'S ACRONYM(S)
AFOSR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Unlimited

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This document describes the equipment and instruments acquired under AFOSR DURIP Grant F49620-01-1-0219. It highlights the use and impact of these instruments on our research program on atmospheric pressure, non-equilibrium plasmas.

20021031 009

15. SUBJECT TERMS
Glow discharge, Atmospheric pressure, Spectrum analyzer, Impedance matching network

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Dr. Robert J. Barker
a. REPORT	b. ABSTRACT	c. THIS PAGE	Unlimited		19b. TELEPHONE NUMBER *(include area code)*
Unclassified	Unclassified	Unclassified			(703) 696-8574

Final Report

Instrumentation for Atmospheric Pressure Plasma Research

AFOSR DURIP Grant F49620-01-1-0219

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Period Covered: April 1, 2001 to March 31, 2002

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Abstract

This document reports on the equipment and instrumentation acquired under AFOSR DURIP grant F49620-01-1-0219. The main objective of this grant is to provide needed equipment to be used in our research program on non-thermal plasma discharges at atmospheric pressure. This research program on the generation and application of cold plasmas has been mainly conducted under AFOSR sponsorship. Non-thermal plasmas at atmospheric pressure have direct applications in microwave communications, in shielding defense equipment against directed EM weapons, in biological and chemical decontamination, and in several industrial processes.

The discharges under investigation produce large volume, steady-state plasmas between electrodes which are energized either by DC, AC, or RF power sources. Only a relatively moderate amount of input power (few hundred Watts) is necessary to maintain plasmas at atmospheric pressure with a number density in the 10^{10}-10^{12} cm^{-3} range.

The research is carried out at The Applied Plasma Technology Laboratory of Old Dominion University, which is located at the ODU Applied Research Center.

Research Activities

The main aim of our research activities is the generation of large volume, non-thermal, atmospheric pressure plasmas with low power requirements. In addition, we have conducted investigations in the applications of this kind of plasmas to biological decontamination, pollution abatement, and its interaction with electromagnetic waves.

Several generation methods have been developed and tested. Figure 1 through Figure 3 show three different methods by which relatively large volume, non-thermal, atmospheric pressure plasmas have been routinely generated. Figure 4 and Figure 5 show photographs of diffuse-mode plasmas produced by the Resistive Barrier Discharge (RBD) and by our novel air plasma generator, respectively.

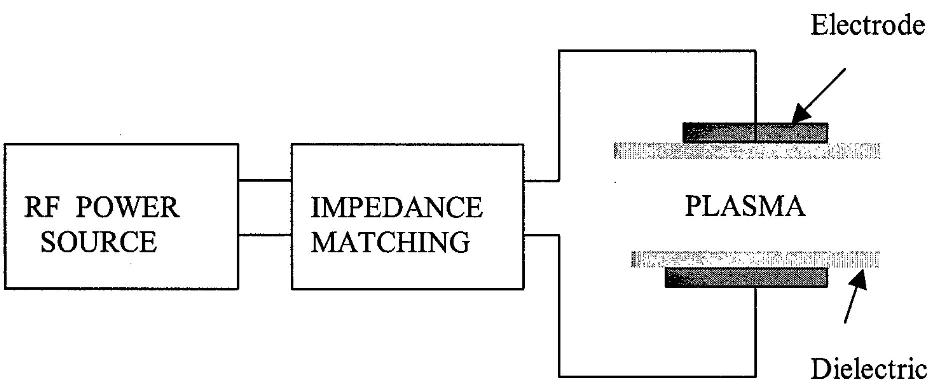


Fig. 1 Configuration of the Glow Discharge at Atmospheric Pressure

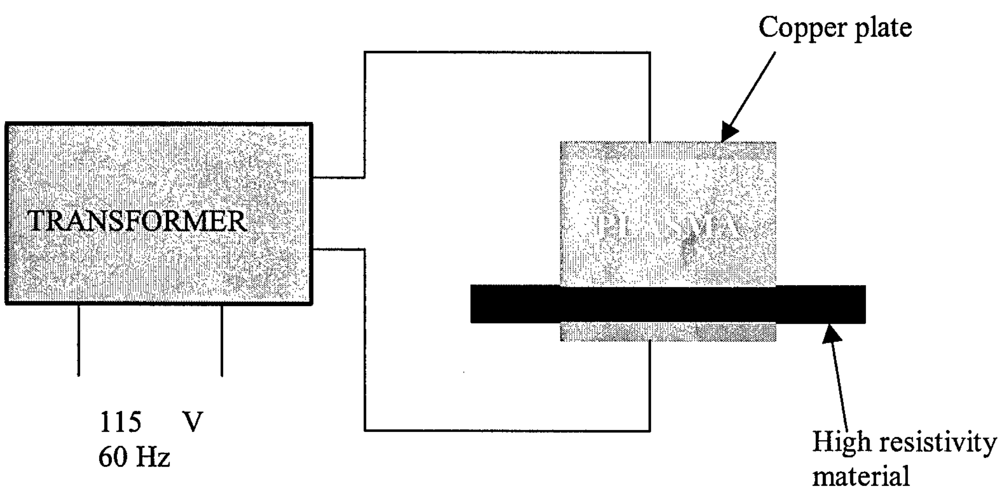


Fig. 2 Configuration of the Resistive Barrier Discharge

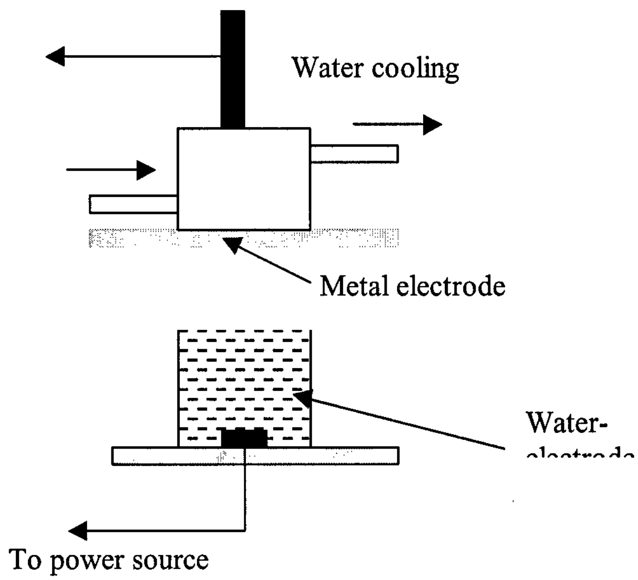


Fig. 3 Configuration of an air discharge using a water electrode

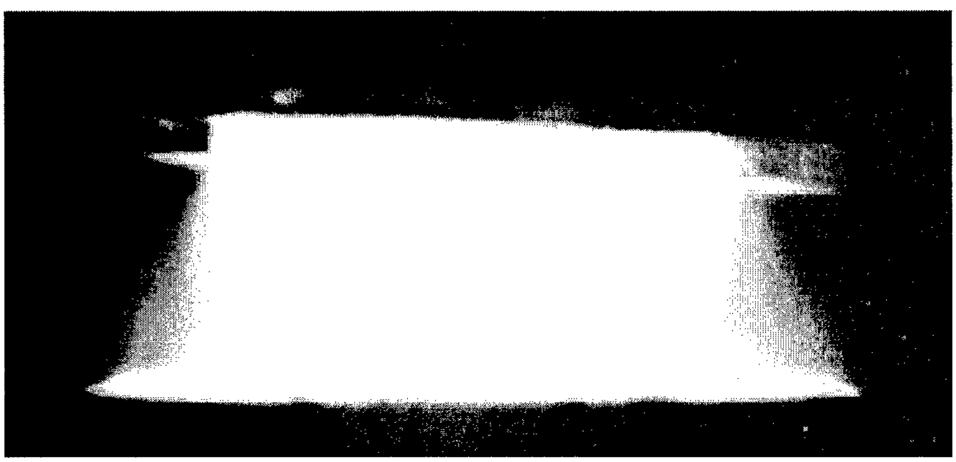


Fig.4 Photo of the Resistive Barrier Discharge (RBD)
V_{rms} = 13 kV; f = 60 Hz; Helium

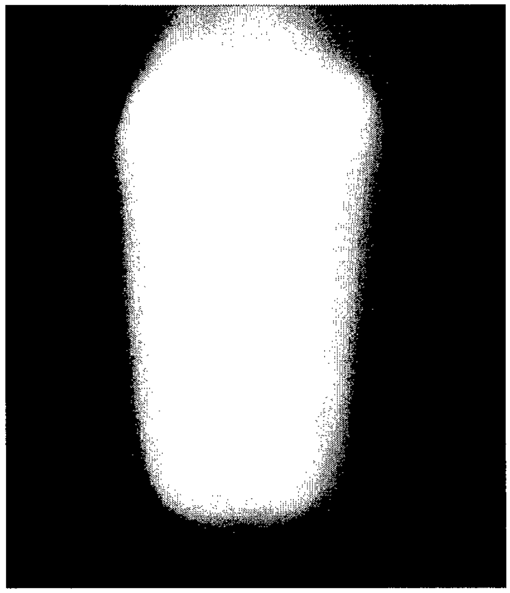


Fig 5. Photograph of an air discharge generated by the system shown in figure 3

All the plasma discharges generated by the above mentioned methods can be used to treat the surfaces of materials, decontaminate various media, and breakdown polluting gases (such as VOC's , SO_x, and NO_x). Each of these applications requires an optimum set of plasma operating parameters, such as temperature, number density, and power density. Therefore plasma diagnostics is a very crucial task to understand thoroughly the physics and chemistry of the discharge. This understanding allows us to find means to optimize the power consumption of these discharges, and to tailor the plasma for each specific application.

Impact of the purchased Instruments on our research activities

The acquired instrumentation allows us to pursue our development of cold plasma devices and to conduct both electrical and spectroscopic measurements. The electrical diagnostics are useful in the study of the stability of the discharges, and the onset of instabilities. The spectroscopic diagnostics allow us to carry out optical emission spectroscopy, which enables us to measure such key parameters such as the electron number density and gas temperature. Both the electron number density and gas temperature are important parameters in the Air Plasma Ramparts Program. Achieving a parameter range suitable to the APRP goal, with an acceptable level of applied power, is one of our research interests. Optical emission spectroscopy also allows us to analyze the light emitted by atoms, molecules, and radicals when they are excited by the field or by collisions with other particles. The wavelengths detected are characteristics of the excited species. Monitoring the discharge over a broad spectral range provides a detailed account of what active species are present in the plasma. This is important for such applications as pollution abatement, decontamination, and plasma-surface interactions, since it is the short-lived active species (such as O, OH, N, H, O_2^*) which react with the materials under test and induce the desired changes.

List of Purchased Instruments and Equipment

1. HP 8595 E Spectrum analyzer	$ 14,500
2. 85024 A High Frequency Probe	$ 2,775
3. PFM 3000 AHC RF Matching Network	$ 7,960
4. SR 844 Dual Phase Lock-in Amplifier	$ 7, 950
5. DC Power Supply (40 kV)	$ 5,820
6. DC Power Supply (2 kV)	$ 3,000
7. Sony Triton Monitor	$ 826
8. Panasonic CCD Camera	$ 849
9. Video Lens VZM 450i	$ 992
10. Two Instrument Cabinets	$ 3,013
11. Denton Vacuum Discovery14 Sputtering System	$ 60,000

Biological Applications

In collaboration with ODU's Department of Ocean Earth and Atmospheric Sciences we have been conducting experiments on the effects of the non-thermal plasma generated by the RBD on bacteria. Not only the germicidal effects of the plasma were studied, but we also investigated the effects of the discharge on the biochemical pathways of bacteria and on their cell morphology. It was discovered that non-thermal plasmas exhibit sub-lethal effects, which could induce metabolic changes. These changes can have direct impact on cell viability. Also, using electron microscopy, it was discovered that the effects of plasma on cell morphology was dependent on the type of microorganism. Apparently, when exposed to a lethal plasma dose, Gram negative bacteria undergo substantial cell damage, while Gram positive bacteria show no visible morphological changes. This work was recently published in the Applied Physics Letters (Vol. 81, No. 4, pp.772-774) under the title, " Effects of non-equilibrium atmospheric pressure plasmas on the heterotrophic pathways of bacteria and on their cell morphology".

Collaborations with Other Groups

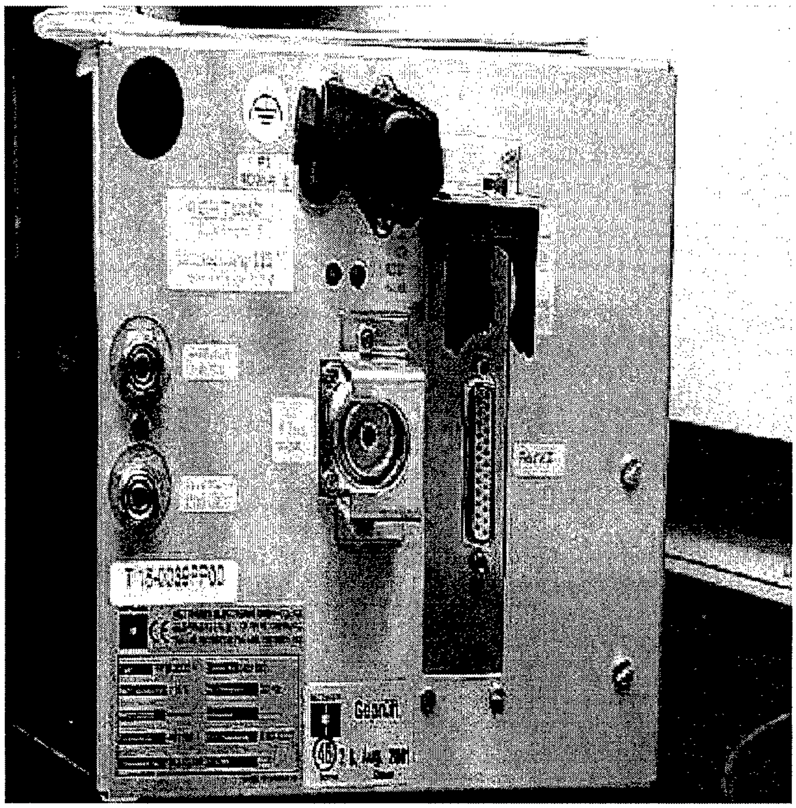
The P.I. has been involved in the research activities of the Plasma Rampart MURI Program directed by AFOSR in cooperation with DDR&E. In this context, a collaborations with Prof. K. H. Schoenbach's group at ODU and Prof. Igor Alexeff (Univ. Tennessee) have been ongoing. These collaborations are mainly on diagnostics for gas temperature and electron number density measurement. In addition, the P.I. of this project is a member of the research team at ODU, working on the AFOSR-funded Compact Pulsed Power MURI. This effort is headed by Prof. Edl Schamiloglu of the University of New Mexico.

Other Activities of the P.I.

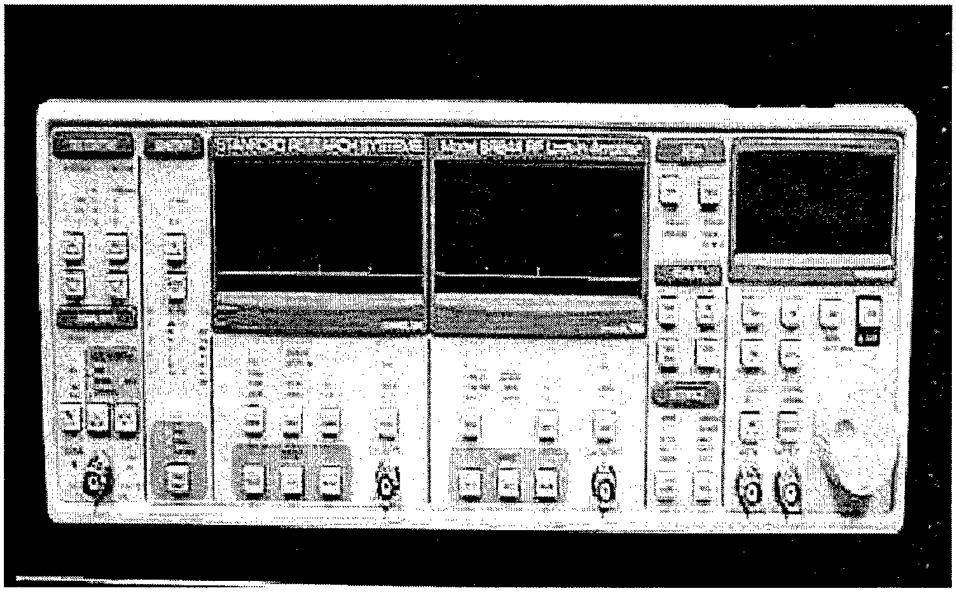
The P.I. served as a Session Chair at the Pulsed Power Plasma Conference, which was held at Las Vegas, NV, June 17-22, 2001. This session was on the Medical, Biological, and Environmental Applications of Plasmas. The P.I. also served as the organizer of the same session at the IEEE International Conference on Plasma Science, which was held in Banff, Canada, May 2002. In addition, the P.I. is presently serving as Guest Editor of the IEEE Transactions on Plasma Science Special Issue on the Non-Thermal Medical/ Biological Applications of Ionized Gases, and Electromagnetic Fields. This issue is scheduled to appear in August 2002.

APPENDIX

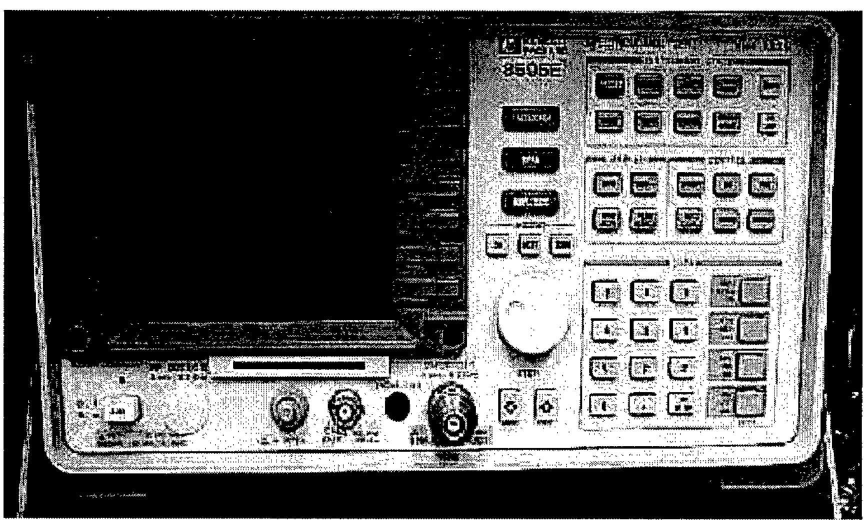
Photos of Main Instruments and Equipment



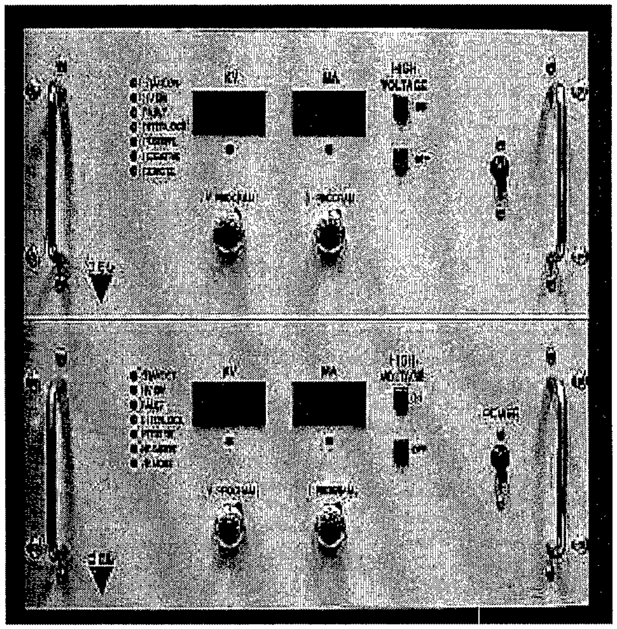
RF impedance matching network



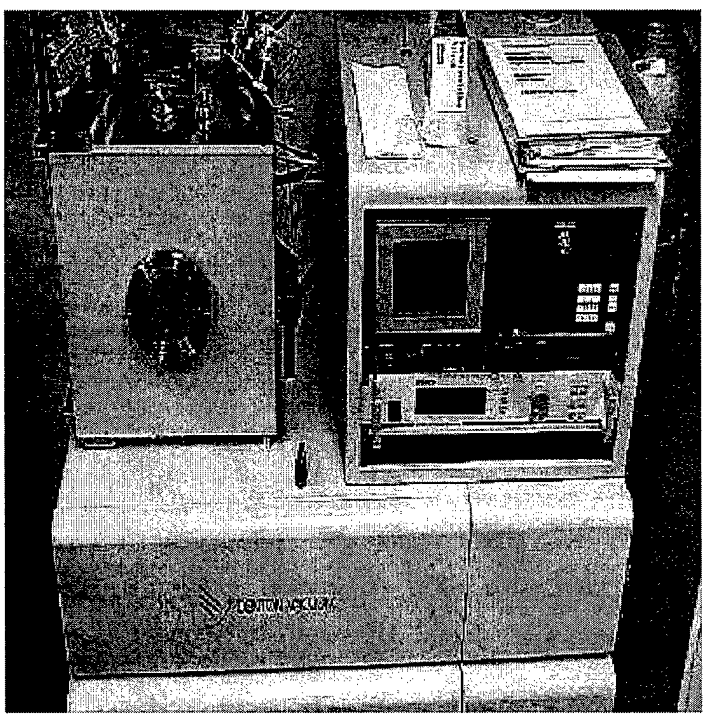
Dual lock-in amplifier



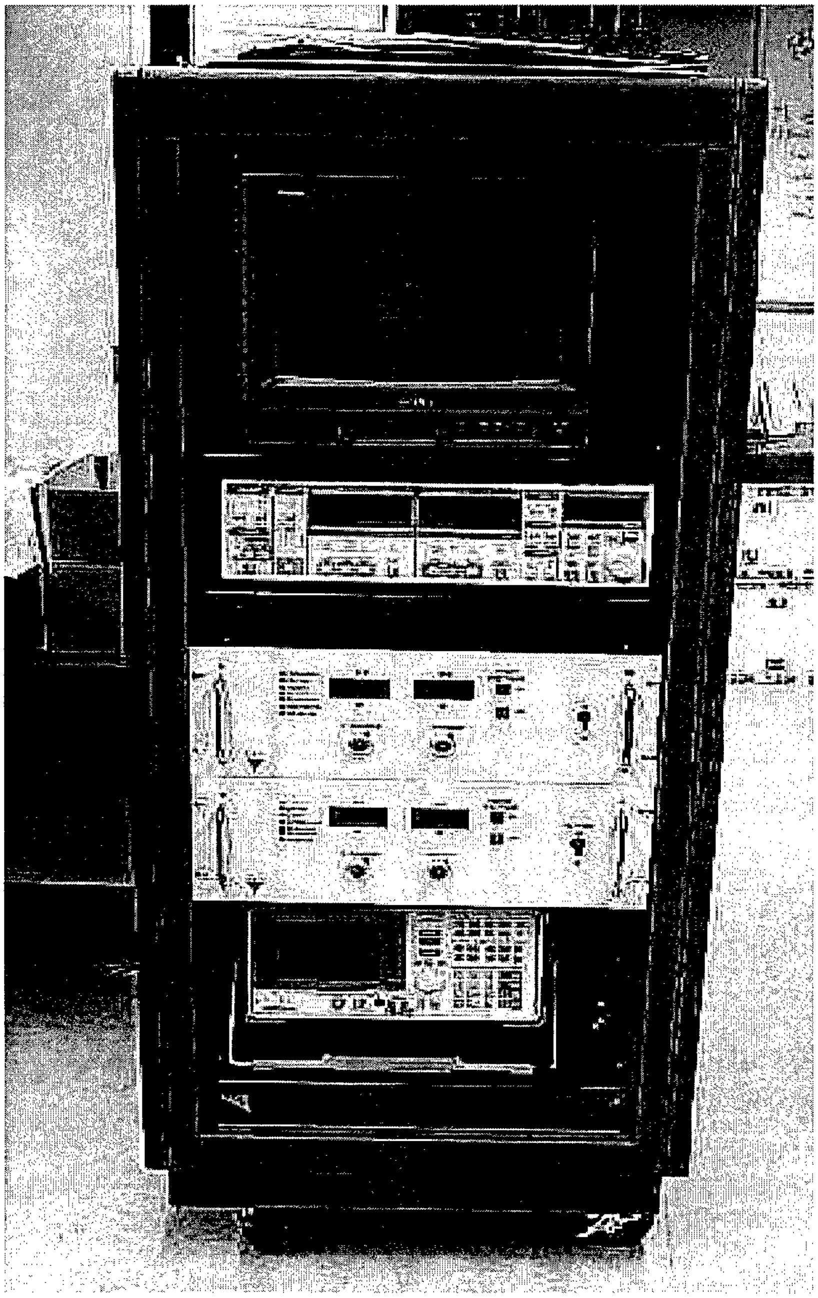
Spectrum analyzer



DC power supplies



Sputtering system



Instrumentation in cabinet