

AD-A048 463

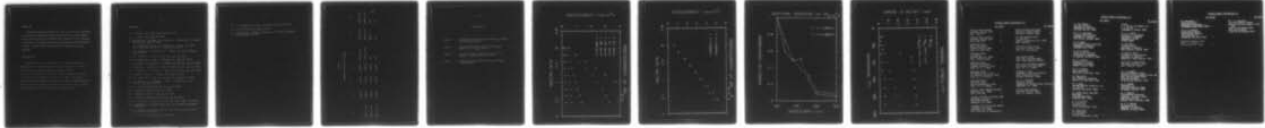
BROWN UNIV PROVIDENCE R I DEPT OF CHEMISTRY  
PREPARATION AND PHOTOELECTROLYTIC BEHAVIOR OF THE SYSTEMS WO<sub>3</sub>---ETC(U)  
NOV 77 C E DERRINGTON, W S GODEK, C A CASTRO N00014-77-C-0387

F/G 7/2

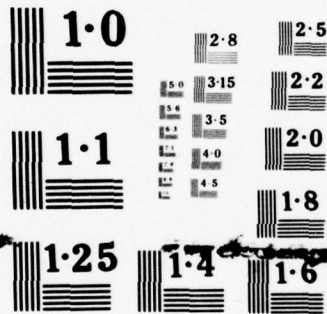
UNCLASSIFIED

NL

| OF |  
AD  
A048463



END  
DATE  
FILMED  
2- 78  
DDC



NATIONAL BUREAU OF STANDARDS  
MICROCOPY RESOLUTION TEST CHART

WO (3-x) WO (3-x) F x

4

DEC 5 1977

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD A 048463

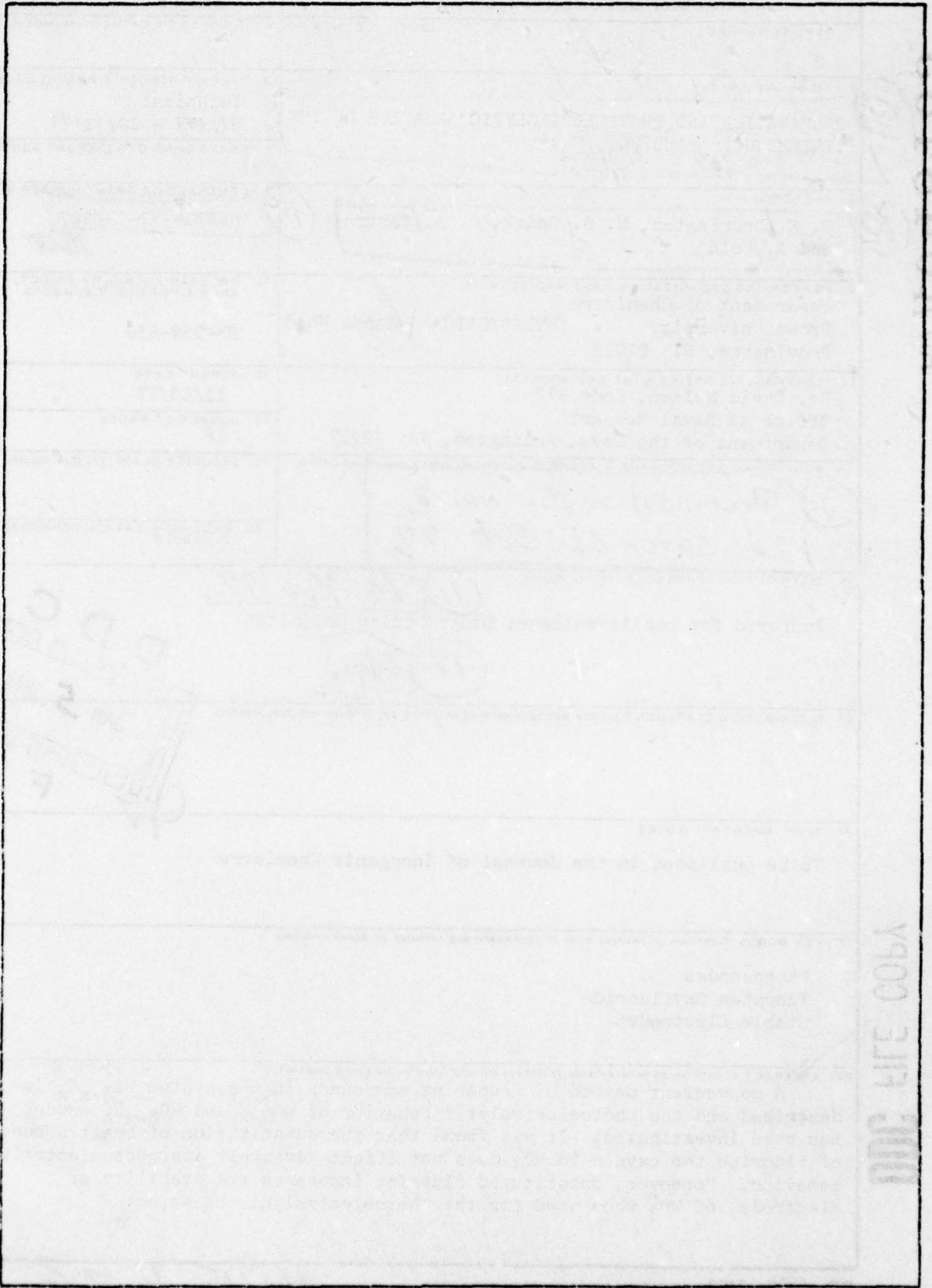
REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 2	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PREPARATION AND PHOTOELECTROLYTIC BEHAVIOR OF THE SYSTEMS $WO_{3-x}$ AND $WO_{3-x}F_x$		5. TYPE OF REPORT & PERIOD COVERED Technical 6/1/77 - 10/31/77
7. AUTHOR(s) C. E./Derrington, W. S./Godek, C. A./Castro A./Wold		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Chemistry Brown University Providence, RI 02912 INVESTIGATOR: ✓ Aaron Wold		7. CONTRACT OR GRANT NUMBER(s) N00014-77-C-0387 HOW
11. CONTROLLING OFFICE NAME AND ADDRESS Dr. David Nelson, Code 472 Office of Naval Research Department of the Navy, Arlington, VA 22217		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR-359-653
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 9) Technical rept. no. 2, 1 Jun - 31 Oct 77		12. REPORT DATE 11/10/77
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; Distribution Unlimited		13. NUMBER OF PAGES 18
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		15. SECURITY CLASS. (of this report)
18. SUPPLEMENTARY NOTES To be published in the Journal of Inorganic Chemistry		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Photoanodes Tungsten Oxyfluoride Stable Electrodes		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A convenient method of preparing compounds in the system $WO_{3-x}F_x$ is described and the photoelectrolytic behavior of $WO_{3-x}$ and $WO_{3-x}F_x$ anodes has been investigated. It was found that the substitution of small amounts of fluorine for oxygen in $WO_3$ does not affect adversely its photoelectrolytic behavior. Moreover, substituted fluorine increases the stability of electrodes of $WO_3$ when used for the photoelectrolysis of water.		

11) 10 Nov 77

12) 24p.

DDC  
JAN 5 1978  
F

AD NO. \_\_\_\_\_  
DDC FILE COPY



D.D.C.  
2  
SECRET

DDC LIFE COPY

DD FORM 1

DD FORM 1

OFFICE OF NAVAL RESEARCH

Contract No. N00014-77-C-0387

Task No. NR 359-653

TECHNICAL REPORT NO. 2

PREPARATION AND PHOTOELECTROLYTIC BEHAVIOR OF THE  
SYSTEMS  $WO_{3-x}$  AND  $WO_{3-x}F_x$

by

C. E. Derrington, W. S. Godek, C. A. Castro, and A. Wold

Prepared for Publication

in the

Journal of Inorganic Chemistry

Brown University  
Department of Chemistry  
Providence, RI 02912

November, 1977

Reproduction in whole or in part is permitted for any purpose  
of the United States Government

Approved for Public Release; Distribution Unlimited.

ACCESSION NO.	
NTIS	Section <input checked="" type="checkbox"/>
DDC	B. H. Section <input type="checkbox"/>
UNAVAIL/NO D	<input type="checkbox"/>
J S I 101 113	
BY	
DISTRIBUTION/AVAILABILITY CODES	
LIAL	
A	23 E-7

PREPARATION AND PHOTOELECTROLYTIC BEHAVIOR OF THE

SYSTEMS  $WO_{3-x}$  AND  $WO_{3-x}F_x$

C. E. Derrington, W. S. Godek, C. A. Castro, and A. Wold

Contribution from the Department of Chemistry and Division of Engineering

Brown University, Providence, Rhode Island 02912

ABSTRACT

A convenient method of preparing compounds in the system  $WO_{3-x}F_x$  is described and the photoelectrolytic behavior of  $WO_{3-x}$  and  $WO_{3-x}F_x$  anodes has been investigated. It was found that the substitution of small amounts of fluorine for oxygen in  $WO_3$  does not affect adversely its photoelectrolytic behavior. Moreover, substituted fluorine increases the stability of electrodes of  $WO_3$  when used for the photoelectrolysis of water.

## INTRODUCTION

There has been considerable interest recently in the search for stable electrode materials for use in photoelectrolysis. This process is one in which water is decomposed into hydrogen and oxygen when a suitable semiconductor, placed in an electrochemical cell, is illuminated with energy greater than the band gap, creating electron-hole pairs:<sup>1</sup> Under appropriate conditions, these electron-hole pairs can be separated and used as oxidizing and reducing species.<sup>2</sup>

The requirements of such a stable electrode material are indeed stringent. The material must be chemically inert and should have a band gap that utilizes an optimum of the solar spectrum ( $\sim 1.6$  eV). In addition, the semiconductor must be conducting and when placed in an electrolyte it should have sufficient band bending to separate the photogenerated electron-hole pairs. The position of bands relative to the electrochemical scale must be such that oxidation of  $O^{2-}/O_2$  and reduction of  $H^+/H_2$  can take place.

The degree of band bending and the position of the bands can be controlled to some degree by varying the pH of the electrolyte used in the cell and by the application of an external bias. It is known that the conductivity of such materials can be altered by chemical substitution or doping procedures. Therefore, the properties which are most difficult to control and, thus, more critical are the magnitude of the band gap and the material's chemical stability.

To date, the only materials which have been used successfully have been broad band oxides.<sup>3-6</sup> These oxides were made conductive by removing small amounts of oxygen. Since there is some question as to the long term stability of these defect structures in a highly oxidizing environment<sup>7</sup> it was of interest to compare the relative stability of defect oxides to those of oxyfluorides.



The use of  $WO_3$  as a stable electrode in photoelectrolysis has been reported by several investigators. Butler, et. al.<sup>8</sup> have indicated that  $WO_3$  is an n-type semiconductor with a band gap of 2.7 eV. Experiments performed with single crystals in a 1.0M sodium acetate solution showed spontaneous photocurrent (i.e. no applied bias) with no decay in photocurrent or visible deterioration of the electrode surface even after passage of approximately 75 coulombs/cm<sup>2</sup>. They indicated that an appreciable applied bias was necessary before photodecomposition of water was observed. Hodes, et. al.<sup>9</sup> found similar results with polycrystalline films of  $WO_3$  prepared by either the oxidation of tungsten metal films or the decomposition of ammonium tungstate. Hardee and Bard<sup>10</sup> have prepared  $WO_3$  films by three different methods. Unlike Hodes, et. al, they found that the films prepared by the oxidation of the metal were not stable on repeated cycling of the electrode. Unfortunately, the electrode surfaces were deep blue rather than yellow-green. This color difference is indicative of either reduced  $WO_3$  or hydrogen bronzes of the type  $H_xWO_3$ .

It was therefore desirable to examine more closely the photoelectrolytic behavior of  $WO_{3-x}$  for various amounts of x. It was also of interest to determine the effect on stability of substituting fluorine for oxygen in  $WO_3$ , rather than creating defects.

#### EXPERIMENTAL

Tungsten oxide was prepared by heating high purity (99.99%) tungsten foil (0.010") under flowing oxygen for 24 hours at 1000°C. Defect tungsten oxide films were made by heating the  $WO_3$  samples in evacuated sealed silica tubes in the presence of freshly ground titanium at temperatures of 100°C to 800°C for

2 to 24 hours.<sup>11</sup>

A convenient method for substituting fluorine has been used to synthesize members of the system  $WO_{3-x}F_x$ . In this process the freshly oxidized  $WO_3$  was placed on a pure tungsten foil which sits in a tungsten boat. The boat was then placed in one zone of a two zone furnace. It was determined that the optimum temperature of this reaction zone should be 650°C. Potassium bifluoride was placed in a nickel boat and inserted in the second zone of the furnace. This zone was maintained at 400°C which was sufficient to allow for a slow thermal decomposition of the  $KHF_2$ . Variation in the fluorine content was achieved by varying the temperature of the reaction zone. The entire reaction chamber consisted of a nickel tube with stainless steel Swagelok fittings welded to both ends.

The reaction tube was purged initially with argon at room temperature. After 30 minutes the gas flow was stopped and the temperature of the two zones was raised to operating conditions. It was found that uniform samples were made under these static conditions. After 4 hours the reaction tube was removed from the furnace and flushed again with argon until room temperature was achieved. During the purging procedures the argon was bubbled through a 9M NaOH solution. All reactions were carried out in a well ventilated hood.

The crystal structures of all of the samples were determined from powder x-ray diffraction spectra using either MgO or CaO as an internal standard. The scans were taken with a Philips Norelco Diffractometer, using  $CuK\alpha$  radiation ( $1.5405\text{\AA}$ ) at a rate of  $1/4^\circ 20 \text{ min}^{-1}$ .

Resistivity measurements were made by ultrasonically soldering indium leads on the polycrystalline samples and using the standard four-probe van der Pauw technique.<sup>12</sup> Optical band gap measurements were made by making KBr windows

which contained finely ground oxide or oxyfluoride intimately mixed and the absorption spectra were taken on a Cary 14 spectrophotometer.

Photoelectrolytic measurements were made by first soldering an oxide or oxyfluoride sample to a Pt wire which was sealed in a pyrex tube. All but the face of the film was then coated with an electrically insulating resin (Microstop, Michigan Chrome and Chem. Co.). The electrode was then placed in a silica cell which was filled with 0.2M sodium acetate. A platinized Pt foil with approximately 5 times the geometrical surface area of the oxide and oxyfluoride films was used as the counter electrode. The electrodes were illuminated by either the full output of a 150-W Xenon lamp or the output of a Model 7155 monochromator (Oriel Corporation). Absolute light intensity measurements were made using a Pyroelectric Radiometer (Model RK 3440, Laser Precision Corp.). The current vs wavelength curves were corrected for intensity variations by normalizing the spectral output of the lamp-monochromator system to 440 nm and using the resulting values to correct the measured photocurrents. All measurements were made with the electrolyte in equilibrium with air.

Stability against reoxidation was determined by heating the films in a stream of flowing oxygen at a rate of 100°C/hr to 1000°C and the weight change monitored with a Cahn Electrobalance.

Analysis for fluorine in the  $WO_{3-x}F_x$  samples was made by dissolving approximately 0.2g of the samples in 9 M NaOH, adjusting the pH to 5.5 with a sodium acetate/acetic acid buffer and measuring the fluoride ion concentration using a fluorine specific electrode (Model 94-09, Orion Research, Inc.). By the use of a specific electrode,  $F^-$  ion concentrations of 24  $\mu\text{g./liter}$  could be determined with a reproducibility of  $\pm 2\%$ . From the weight of the samples analyzed, the value of  $x$  in the  $WO_{3-x}F_x$  samples can be reported with an accuracy equivalent to  $\pm 0.0002$ .

## RESULTS AND DISCUSSION

### 1. Crystallography

There have been conflicting reports concerning the structure of pure  $WO_3$ .<sup>13-16</sup> It was found that  $WO_3$  prepared by oxidizing completely tungsten foil could best be indexed on a triclinic system similar to the one reported by Roth and Waring.<sup>16</sup> It transforms to a monoclinic phase upon the removal of small amounts of oxygen<sup>17</sup> or the addition of small amounts of hydrogen or sodium.<sup>18</sup>

Whereas the system  $WO_{3-x}$  ( $0 < x \leq 1$ ) is monoclinic throughout the entire range,<sup>17</sup> the system  $WO_{3-x}F_x$  ( $0 < x \leq 1$ ) undergoes the following transitions: triclinic  $\rightarrow$  monoclinic  $\rightarrow$  orthorhombic  $\rightarrow$  tetragonal  $\rightarrow$  cubic.<sup>19,20</sup> The structural properties of the  $WO_{3-x}F_x$  prepared in this study are summarized in Table I. It can be seen that the structure remains triclinic for very small ( $x=0.0079$ ) amounts of substituted fluorine in the system  $WO_{3-x}F_x$ . When the amount of substituted fluorine is  $x=0.0177$  the structure has undergone the transition to the monoclinic phase and when  $x=0.0663$  the resulting phase is orthorhombic. These are consistent with results of previous investigators.

### 2. Resistivity and Optical Properties

The resistivity of the pure  $WO_3$  samples were between  $10^6$  and  $10^8$   $\Omega$ -cm. The resistivities of the  $WO_{3-x}$  samples ranged between  $1.2 \times 10^4$   $\Omega$ -cm -  $7 \times 10^{-1}$   $\Omega$ -cm and the resistivities of the  $WO_{3-x}F_x$  samples ranged between 100  $\Omega$ -cm - 5  $\Omega$ -cm. Absorption measurements indicated that the band gap of  $WO_3$  and all  $WO_{3-x}F_x$  samples was  $2.65 \pm 0.10$  eV. This is consistent with previous investigations.<sup>8,9,21,22</sup>

### 3. Photoelectrolytic Properties

In Figure 1 are plotted the photocurrents vs applied voltage (SCE reference) for several  $WO_{3-x}$  samples. Measurements were made with the electrolyte in equilibrium with air. As can be seen the largest photocurrent is reached for the  $WO_{3-x}$  sample having the lowest resistance, with the photocurrents of the remaining samples decreasing as the resistance increases. These results are consistent with the only effect being a change in the overall cell resistance.

The photocurrents for two triclinic samples of  $WO_{3-x}F_x$  are shown vs. applied bias in Figure 2, the measurements being made with the electrolyte in equilibrium with air. Although photocurrents were observed for all of the tungsten oxyfluorides studied, the monoclinic and orthorhombic compositions ( $x \geq 0.0177$ ) show more complex behavior.

The spectral response of the  $WO_{3-x}F_x$  samples shown in Figure 3 were obtained with an applied bias of 0.5V. The photocurrents plotted here were normalized for clarity by taking the ratio of the photocurrent at a given wavelength to the maximum photocurrent obtained (i.e. at 400 nm). The actual photocurrents at 400 nm are for  $x = 0.0079$   $I = 16.06 \mu A/cm^2$  and for  $x = 0.0083$   $I = 6.07 \mu A/cm^2$ . The colors of the materials varied from a light green for the  $x = 0.0079$  sample to darker green for the  $x = 0.0083$  sample.

### 4. Stability

Stability of the  $WO_{3-x}$  and  $WO_{3-x}F_x$  samples was investigated by three procedures: Stability against reoxidation, stability against hydrolysis or dissolution, and stability in a working cell arrangement.

Figure 4 shows the results of the reoxidation experiments. It can be seen that while  $WO_{3-x}$  readily reoxidizes at 250-300°C, the  $WO_{3-x}F_x$  sample was stable to 600°C, implying an increased stability to reoxidation.

It is also clear that the thermal gravimetric data shown in Figure 4 indicates that the composition of the oxyfluoride samples prepared in this study can be represented by the formula  $WO_{3-x}F_x$ . If the composition of the samples was of the stoichiometry  $WO_{3-x}F_y$ , then there would have been a gain in weight recorded equivalent to the value of  $x-y$ . It can be seen from Figure 4 that the sensitivity of this method is such that values of  $x$  (representing an oxygen deficiency) in the system  $WO_{3-x}$  can be determined where values of  $x$  are less than 0.01.

Hydrolysis and dissolution experiments were made by placing samples of  $WO_{3-x}$  and  $WO_{3-x}F_x$  in 0.2M  $H_2SO_4$  and leaving these at 90°C for 350 hours. Neither sample showed any hydrolysis or dissolution.

Stability in a working cell, with the electrolyte in equilibrium with air, was determined by biasing the electrode at 0.5 volts with respect to the platinum cathode, illuminating then with the full output of a 150 watt Xenon lamp and monitoring the changes in photocurrent with time. It was found that while the slightly reduced  $WO_{3-x}$  films gave stable photocurrents, the more reduced samples were less stable. The most reduced sample ( $x \approx 0.03$ ) was very unstable with the photocurrent decreasing by 30% over a period of 2 hours. This is consistent with the results found by Hardee and Bard.<sup>10</sup> On the other hand, the triclinic samples of  $WO_{3-x}F_x$  gave stable photocurrents of  $2ma/cm^2$  for periods up to 46 hours ( $\approx 700$  coulombs). In addition, there was no significant weight loss and no visible change on the surface of the electrodes.

#### CONCLUSIONS

The photoelectrolytic behavior of  $WO_{3-x}$  and  $WO_{3-x}F_x$  has been investigated. It was found that substituting fluorine for oxygen in  $WO_3$ , in small amounts, does not affect adversely the photoelectrolytic behavior of  $WO_3$  but increases the stability of the compound when used as an electrode for photoelectrolysis of water. A safe and easily controlled method of preparing  $WO_{3-x}F_x$  was described.

#### ACKNOWLEDGEMENT

Acknowledgment is made to the Donors of The Petroleum Research Fund, administered by the American Chemical Society, for support of C. A. Castro. The Office of Naval Research, Arlington, Virginia supported the work of C. Derrington, and the National Science Foundation, Washington, D.C. (Grant No. 37104) supported the work of W. S. Godek. The authors would also like to acknowledge the support of the Materials Research Laboratory Program at Brown University and the helpful advice of Dr. A. Nozik of Allied Chemical Corporation and Dr. Kirby Dwight of Brown University.

REFERENCES

1. A. Fujishima and K. Honda, *Nature*, 238, 37 (1972).
2. A. J. Nozik, *Nature*, 267, 383 (1975).
3. For example J. G. Mavroides, D. I. Tcherneu, J. A. Kafalas and D. F. Kolesar *Mat. Res. Bull.*, 10, 1023 (1975).  
M. S. Wrighton, S. Grinley, P. T. Wolczanski, A. B. Ellis, D. L. Morse and A. Linz, *Proc. Nat. Acad. Sci.*, 72, (a), 1518 (1975).
4. J. G. Mavroides, J. A. Kafalas and D. F. Kolesar, *Appl. Phys. Letters* 29 (5), 241 (1976).
5. R. D. Nasby and R. K. Quinn, *Mat. Res. Bull.*, 11, 985 (1976).
6. K. L. Hardee and A. J. Bard, *J. Electrochem. Soc.*, 123, 1024 (1976).  
R. K. Quinn, R. D. Nasby and R. L. Baughman, *Mat. Res. Bull.*, 11, 1011 (1976).
7. H. Yoneyama, H. Sakamoto and H. Tamura, *Electrochimica Acta.*, 20, 341 (1975).
8. M. A. Butler, R. D. Nasby and R. K. Quinn, *Solid State Comm.*, 19, 1011 (1976).
9. G. Hodes, D. Cahen and J. Manassen, *Nature*, 26, 312 (1976).
10. K. L. Hardee and A. J. Bard, *J. Electrochem. Soc.*, 124 (2), 215 (1977).
11. D. M. Schleich, C. E. Derrington, W. Godek, D. Weisberg and A. Wold, *Mat. Res. Bull.*, 12, 331 (1977).
12. L. J. van der Pauw, *Phillips Tech. Rev.*, 20, 220 (1958).
13. G. Anderson, *Acta Chem. Scand.*, 7, 154 (1953).
14. S. Tanisaki, *J. Phys. Soc. Jap.*, 15, 566 (1960).
15. P. Gado and A. Magnéli, *Acta Chem. Scand.*, 19, 1514 (1965).
16. R. S. Roth and J. L. Waring, *J. Res. Nat. Bur. Stands.*, 70A, 4, 231 (1966).
17. E. Gebert and R. J. Ackermann, *Inorg. Chem.*, 5, 136 (1966) and references cited therein.
18. A. S. Ribnick, B. Post and E. Banks, *Adv. in Chem. Series*, 39, 246 (1963) and references cited therein.
19. A. W. Sleight, *Inorg. Chem.*, 8 (8), 1764 (1969).



20. T. G. Reynolds and A. Wold, J. Solid State Chem., 6, 565 (1973).
21. S. K. Deb, Philos. Mag., 27, 801 (1973).
22. W. Gissler and R. Memming, J. Electrochem. Soc. Virginia Conference, Airlie, Virginia, May, 1977.

TABLE 1

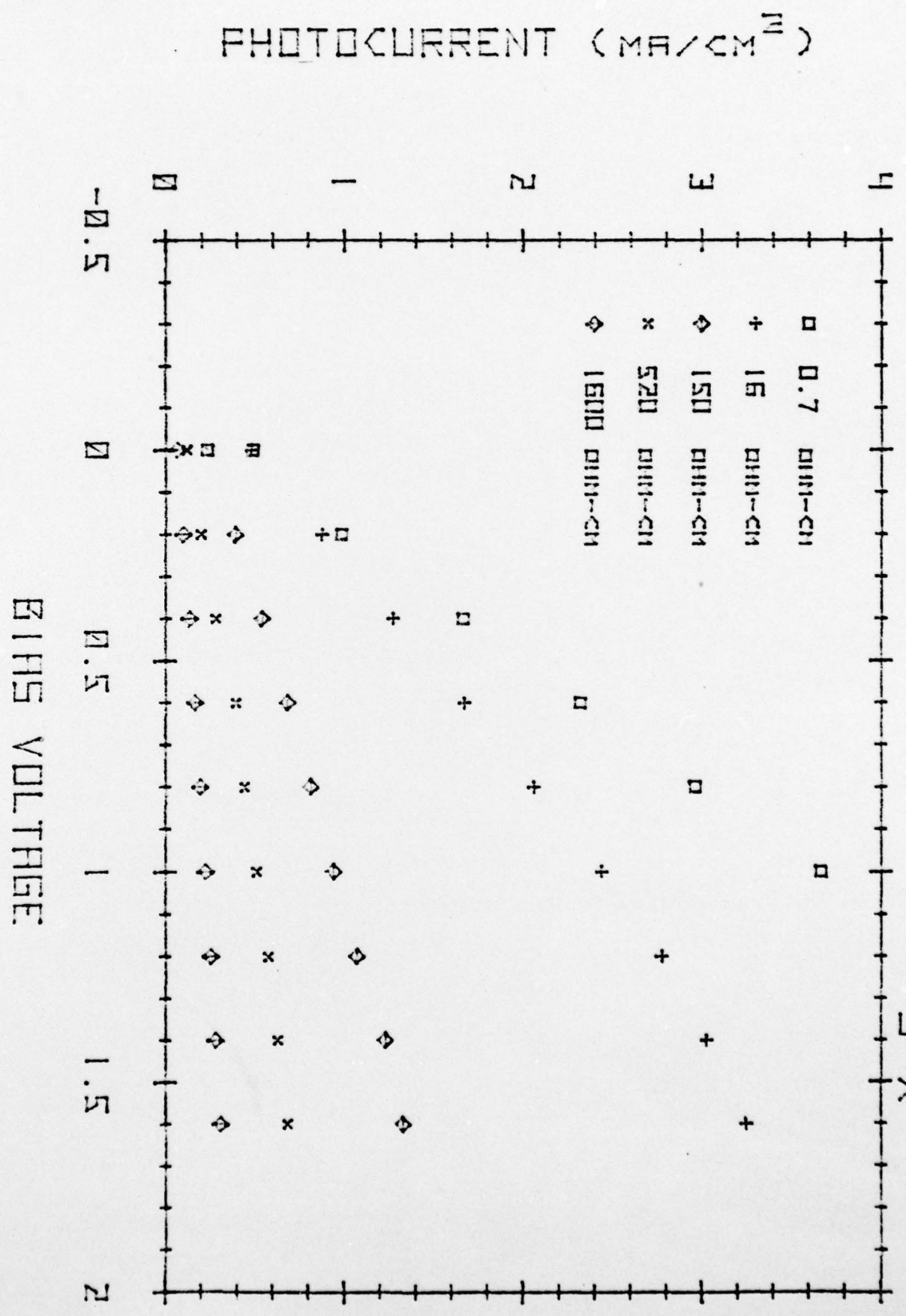
Structural Properties of  $WO_{3-x}F_x$ 

x	a	b	c	$\alpha$	$\beta$	$\delta$
0	7.306(1)	7.527(1)	3.854(1)	$88^{\circ}43' \pm 02'$	$90^{\circ}17' \pm 02'$	$90^{\circ}39' \pm 02'$
$0.0079 \pm 0.0005$	7.301(1)	7.527(1)	3.856(1)	$88^{\circ}48' \pm 0^{\circ}02'$	$90^{\circ}17' \pm 02'$	$90^{\circ}35' \pm 02'$
$0.0177 \pm 0.001$	7.311(1)	7.545(1)	3.851(1)	$90^{\circ}$	$90^{\circ}51'$	$90^{\circ}$
$0.0663 \pm 0.005$	7.369(1)	7.482(1)	3.848(1)	$90^{\circ}$	$90^{\circ}$	$90^{\circ}$

FIGURE CAPTIONS

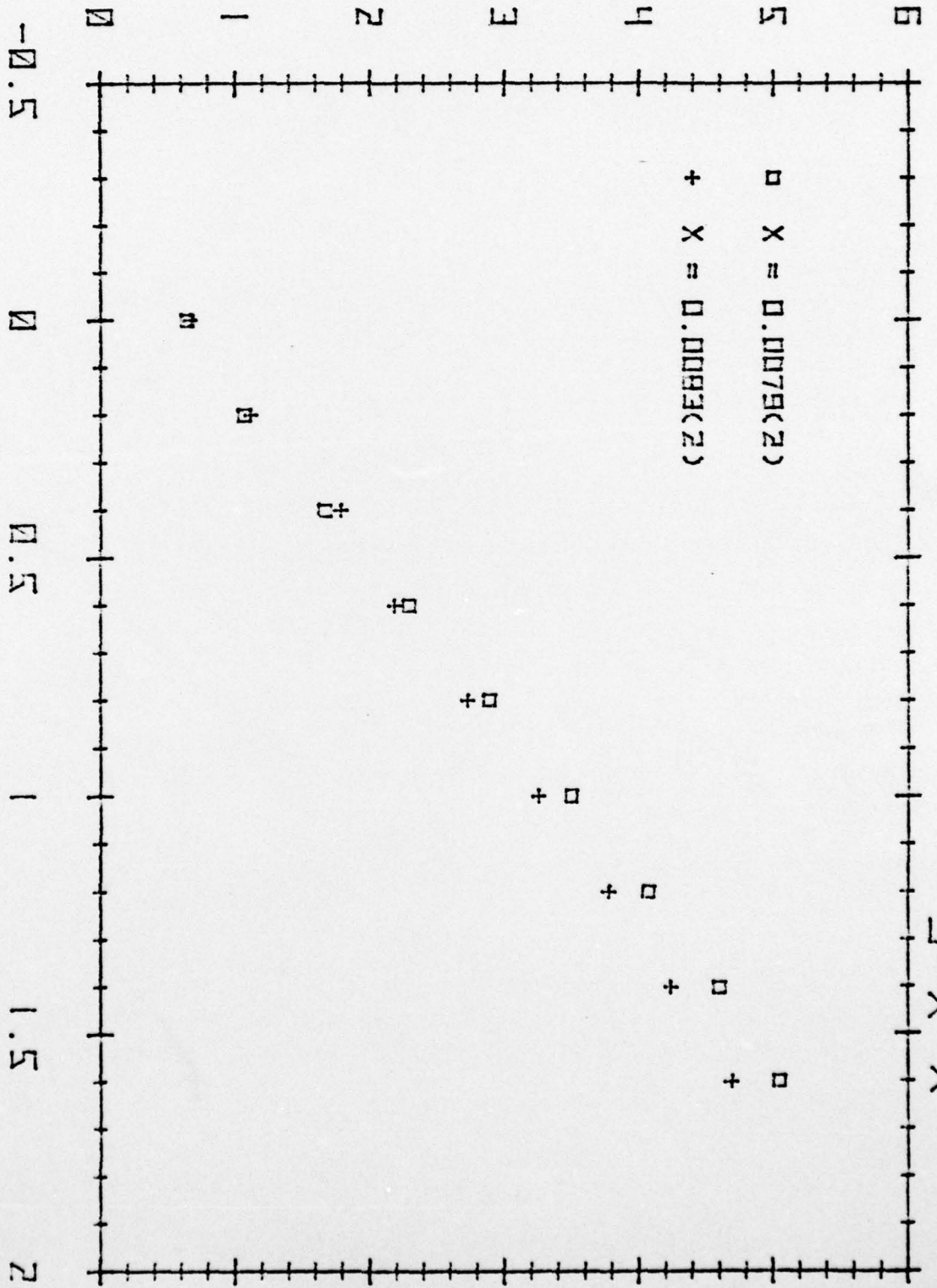
- Figure 1 - Photocurrent vs applied bias for several  $\text{WO}_{3-x}$  samples in 0.2M  $\text{NaC}_2\text{H}_3\text{O}_2$  (pH=7.8).
- Figure 2 - Photocurrent vs applied bias for several  $\text{WO}_{3-x}\text{F}_x$  samples in 0.2M  $\text{NaC}_2\text{H}_3\text{O}_2$  (pH=7.8).
- Figure 3 - Normalized Spectral Response of  $\text{WO}_{3-x}\text{F}_x$  in 0.2M  $\text{NaC}_2\text{H}_3\text{O}_2$ .  $E_g$ =optical band gap (2.7 eV).
- Figure 4 - Stability against reoxidation for  $\text{WO}_{3-x}$  and  $\text{WO}_{3-x}\text{F}_x$  in flowing oxygen.

# PHOTOCURRENT OF $\text{WO}_3\text{-X}$



# PHOTOCURRENT OF $\text{WO}_3\text{-X}_2\text{F}_x$

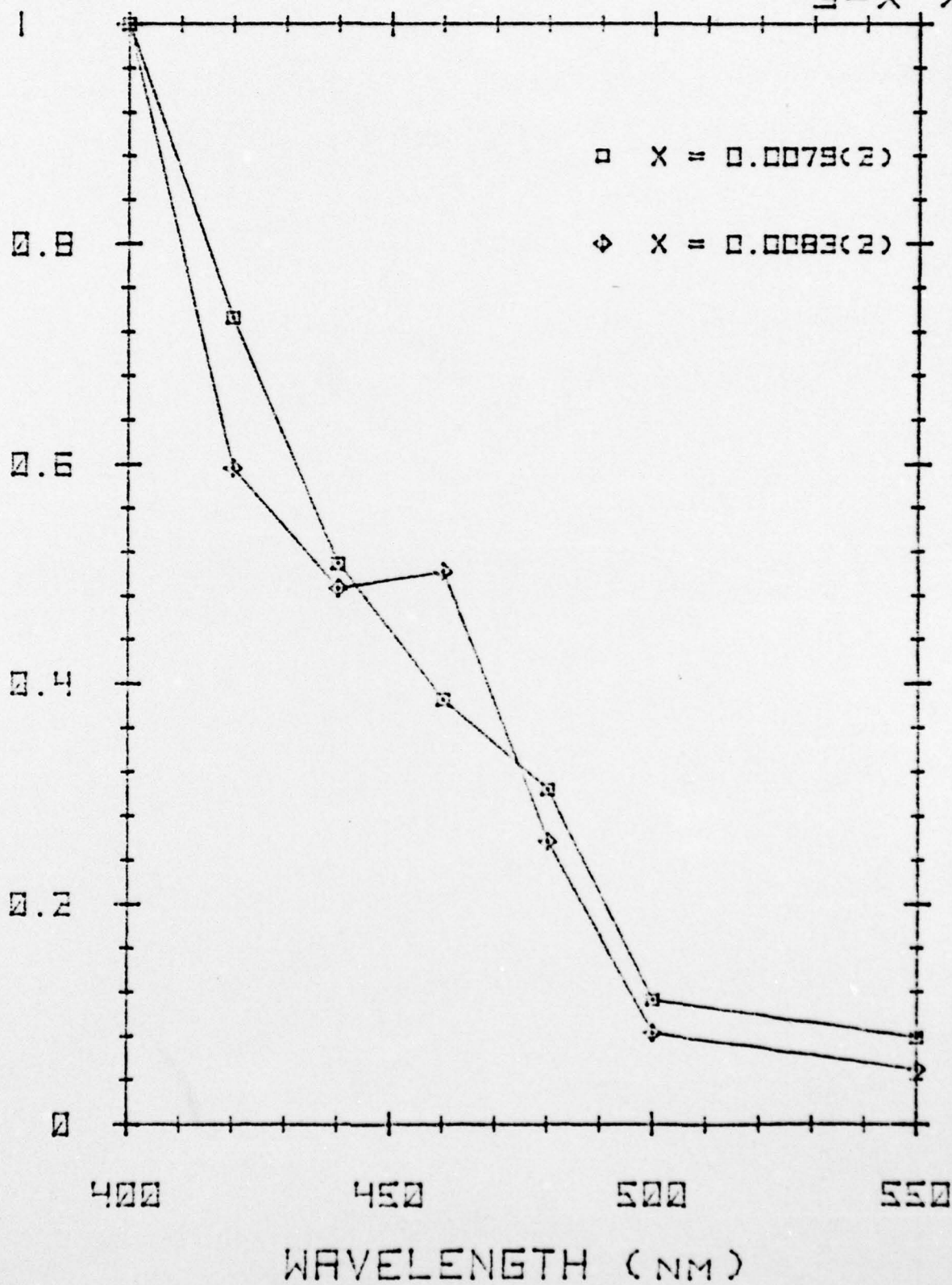
PHOTOCURRENT (MA/ $\text{CM}^2$ )



BIAS VOLTAGE

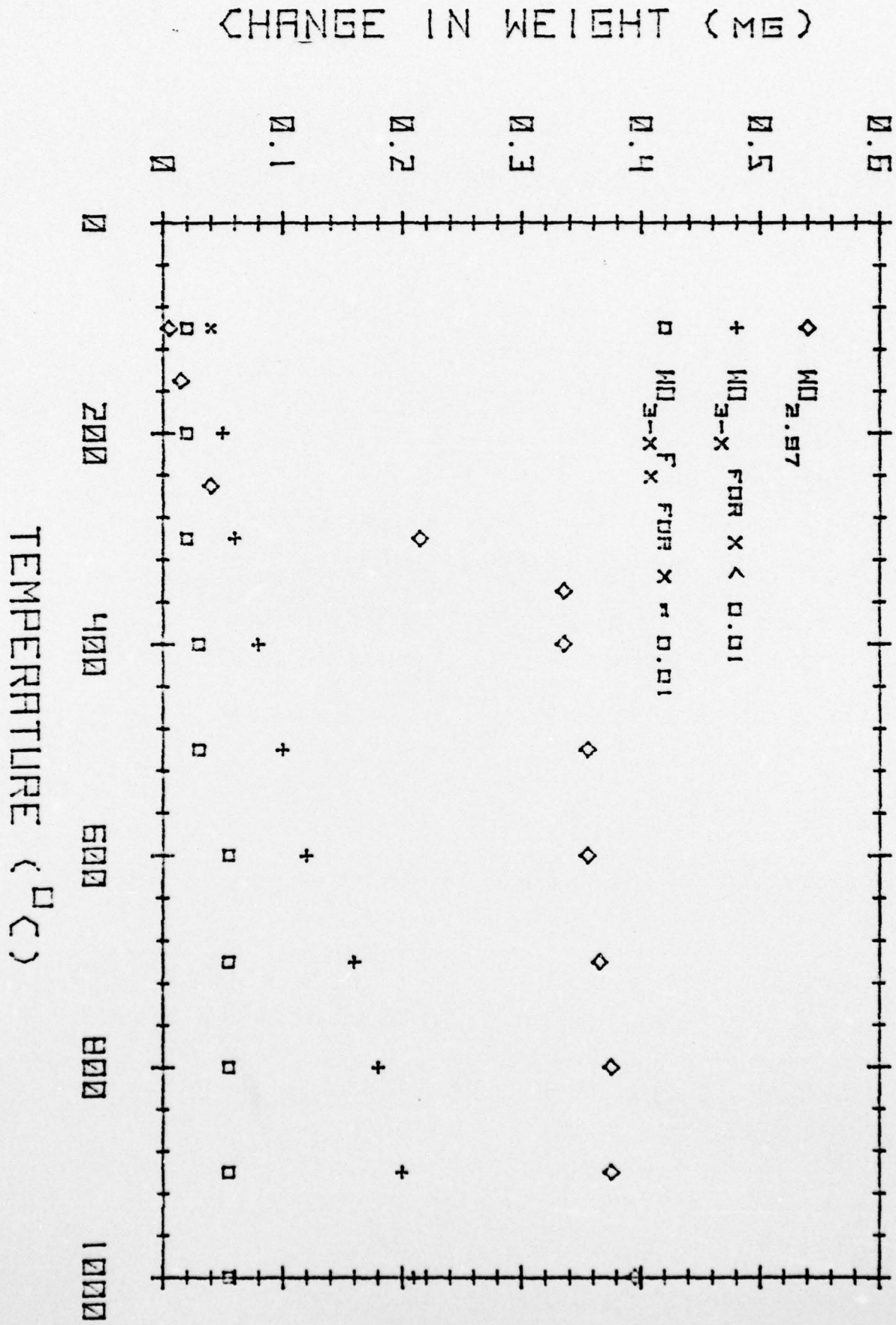
SPECTRAL RESPONSE OF  $\text{WO}_3-x\text{F}_x$ 

NORMALIZED PHOTOCURRENT



WAVELENGTH (NM)

# THERMAL STABILITY



TECHNICAL REPORT DISTRIBUTION LIST

<u>No. Copies</u>		<u>No. Copies</u>
2	Office of Naval Research Arlington, Virginia 22217 Attn: Code 472	Defense Documentation Center Building 5, Cameron Station Alexandria, Virginia 22314 12
6	Office of Naval Research Arlington, Virginia 22217 Attn: Code 102IP 1	U.S. Army Research Office P.O. Box 12211 Research Triangle Park, N.C. 27709 Attn: CRD-AA-IP 1
1	ONR Branch Office 536 S. Clark Street Chicago, Illinois 60605 Attn: Dr. Jerry Smith	Naval Ocean Systems Center San Diego, California 92152 Attn: Mr. Joe McCartney 1
1	ONR Branch Office 715 Broadway New York, New York 10003 Attn: Scientific Dept.	Naval Weapons Center China Lake, California 93555 Attn: Head, Chemistry Division 1
1	ONR Branch Office 1030 East Green Street Pasadena, California 91106 Attn: Dr. R. J. Marcus	Naval Civil Engineering Laboratory Port Hueneme, California 93041 Attn: Mr. W. S. Haynes 1
1	ONR Branch Office 760 Market Street, Rm. 447 San Francisco, California 94102 Attn: Dr. P. A. Miller	Professor O. Heinz Department of Physics & Chemistry Naval Postgraduate School Monterey, California 93940 1
1	ONR Branch Office 495 Summer Street Boston, Massachusetts 02210 Attn: Dr. L. H. Peebles	Dr. A. L. Slafkosky Scientific Advisor Commandant of the Marine Corps (Code RD-1) Washington, D.C. 20380 1
1	Director, Naval Research Laboratory Washington, D.C. 20390 Attn: Code 6100	Office of Naval Research Arlington, Virginia 22217 Attn: Dr. Richard S. Miller 1
1	The Asst. Secretary of the Navy (R&D) Department of the Navy Room 4E736, Pentagon Washington, D.C. 20350	
1	Commander, Naval Air Systems Command Department of the Navy Washington, D.C. 20360 Attn: Code 310C (H. Rosenwasser)	



TECHNICAL REPORT DISTRIBUTION LIST

<u>No. Copies</u>			<u>No. Copies</u>	
	Dr. Paul Delahay New York University Department of Chemistry New York, New York 10003	1	Library P. R. Mallory and Company, Inc. P. O. Box 706 Indianapolis, Indiana 46206	1
	Br. R. A. Osteryoung Colorado State University Department of Chemistry Fort Collins, Colorado 80521	1	Dr. P. J. Hendra University of Southampton Department of Chemistry Southampton SO9 5NH United Kingdom	1
	Dr. B. Yeager Case Western Reserve University Department of Chemistry Cleveland, Ohio 41106		Dr. Sam Perone Purdue University Department of Chemistry West Lafayette, Indiana 47907	1
	Dr. D. N. Bennion University of California Energy Kinetics Department Los Angeles, California 90024	1	Dr. Royce W. Murray University of North Carolina Department of Chemistry Chapel Hill, North Carolina 27514	1
	Dr. R. A. Marcus University of Illinois Department of Chemistry Urbana, Illinois 61801	1	Naval Ocean Systems Center San Diego, California 92152 Attn: Technical Library	1
	Dr. J. J. Auburn Bell Laboratories Murray Hill, New Jersey 07974	1	Dr. J. H. Ambrus The Electrochemistry Branch Materials Division, Research & Tech. Dep Naval Surface Weapons Center White Oak Laboratory Silver Spring, Maryland 20910	1
	Dr. Adam Heller Bell Telephone Laboratories Murray Hill, New Jersey 07974	1	Dr. G. Goodman Globe-Union Inc. 5757 North Green Bay Avenue Milwaukee, Wisconsin 53201	1
	Dr. T. Katan Lockheed Missiles & Space Co., Inc. P.O. Box 504 Sunnyvale, California 94088	1	Dr. J. Boechler Electrochimica Corporation Attention: Technical Library 2485 Charleston Road Mountain View, California 94040	1
	Dr. Joseph Singer, Code 302-1 NASA-Lewis 21000 Brookpark Road Cleveland, Ohio 44135	1	Dr. P. P. Schmidt Oakland University Department of Chemistry Rochester, Michigan 48063	1
	Dr. S. B. Brummer EIC Corporation 55 Chapel Street Newton, Massachusetts 02158	1		
	Mr. Frank Murphy 3TE Laboratories 40 Sylvan Road Waltham, Massachusetts 02154	1		

TECHNICAL REPORT DISTRIBUTION LIST

	<u>No. Copies</u>		<u>No. Copies</u>
<del>Dr. Aaron Wold</del>		Mr. D. L. Warburton	
<del>Brown University</del>		The Electrochemistry Branch	
<del>Department of Chemistry</del>		Materials Division, Research & Tech.	
<del>Providence, Rhode Island 02912</del>	1	Dept.	
Dr. R. C. Chudacek		Naval Surface Weapons Center	
McGraw-Edison Company		White Oak Laboratory	
Edison Battery Division		Silver Spring, Maryland 20910	1
Post Office Box 28			
Bloomfield, New Jersey 07003	1		
Reliability Analysis Center			
ATTN: I. L. Krulac			
Griffiss AFB, N.Y. 13441	1		