

AD-A147 414

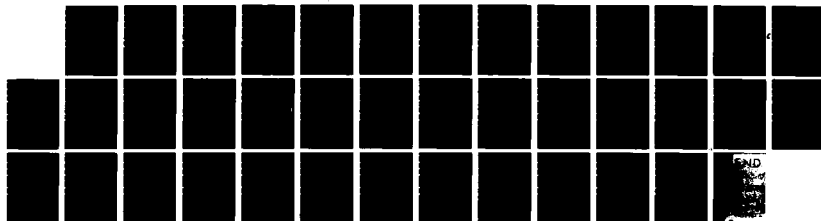
ELECTROCHEMICAL INTERFACES AND ELECTRODE PROCESSES(U)
CASE-WESTERN RESERVE UNIV CLEVELAND OH E B YEAGER
15 AUG 84 N00014-75-C-0953

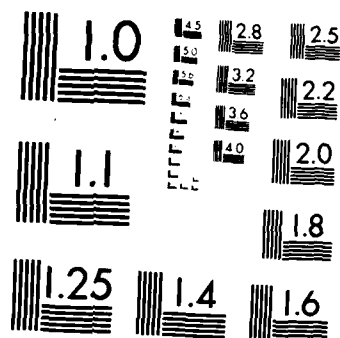
1/1

UNCLASSIFIED

F/G 7/4

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

12

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD-A147 414

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Electrochemical Interfaces and Electrode Processes		5. TYPE OF REPORT & PERIOD COVERED Final Report 1 Jan 1976 - 31 March 1983
AUTHOR(s) Ernest B. Yeager		6. PERFORMING ORG. REPORT NUMBER
PERFORMING ORGANIZATION NAME AND ADDRESS Case Center for Electrochemical Sciences and The Chemistry Dept., Case Western Reserve Univ., Cleveland, Ohio 44106		8. CONTRACT OR GRANT NUMBER(s) N00014-75-C-0953
CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Chemistry Program - Chemistry Code 472 Arlington, VA 22217		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 359-451
MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE 15 August 1984
		13. NUMBER OF PAGES 28
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) CONFIDENTIAL		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Electrochemical interfaces; electrosorption; spectroscopic surface techniques		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report summarizes ONR research on the development and use of spectroscopic techniques for the study of electrochemical interfaces and electrode processes occurring at such interfaces. A number of <u>in-situ</u> techniques have been used including ultraviolet-visible reflectance spectroscopy and ellipsometry, infrared attenuated total reflectance spectroscopy, surface enhanced and resonant Raman spectroscopy, and Mössbauer spectroscopy. These <u>in-situ</u> techniques have provided important insight into the electronics and the		

DTIC FILE COPY

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

84 11 07 003

20. ABSTRACT, cont'd

properties of adsorbed molecules, ions and atoms at electrochemical interfaces. They have also been used to examine the adsorption isotherms and kinetics of adsorption-desorption.

The in-situ techniques, however, are insufficient to establish the type of adsorption sites or compositional questions. For this reason substantial use has also been made of ex-situ surface physics techniques including LEED, AES, XPS and secondary ion mass spectroscopy. Special hardware and techniques have been developed as part of the ONR contract research to facilitate the transfer of electrodes between the electrochemical and ultrahigh vacuum environments and vice versa with the possibility for restructuring and contamination at a minimum. The report describes the application of these techniques to adsorption on single crystal electrodes.

FINAL REPORT

submitted to the

OFFICE OF NAVAL RESEARCH

for research on

ELECTROCHEMICAL INTERFACES AND ELECTRODE PROCESSES

Contractor: Case Western Reserve University, Cleveland, Ohio 44106

Department: Case Center for Electrochemical Sciences and
the Chemistry Department

Contract No.: N00014-75-C-0953

Project No.: NR 359-451

Initiation Date: 1 January 1976

Termination Date: 31 March 1983

Project Director: Ernest Yeager, Hovorka Professor of Chemistry

Date of Submission of Final Report: 15 August 1984

Accession For

NRIS	STARI	X
DOIS	TR	
USIA	TR	
DOIS	TR	

7-1

A-1

I. RESEARCH OBJECTIVES AND OVERVIEW

The objectives of the ONR sponsored research are two-fold:

1. the understanding of the factors controlling electrosorption of various species on metal and semiconductor electrodes;
2. the relationship of the kinetics of various electrode processes to the electrode properties and adsorption on electrodes.

While electrochemical methods have high sensitivity to adsorption on electrodes (down to a small fraction of a monolayer), they lack sufficient atomic level specificity to identify uniquely the type of sites, the molecular configuration of the adsorbate, the nature of the bonding to the surface, the interaction between adsorbed species and the competitive aspects with respect to solvent adsorption. Consequently much of the emphasis on this ONR sponsored research has been in the use of complementary techniques to study adsorption on electrodes. The in situ techniques which have been used for this purpose as part of the ONR research and the systems which have been studied have included

1. ultraviolet-visible reflectance spectroscopy - automatic ellipsometry
2. infrared attenuated reflectance spectroscopy
3. surface enhanced and resonant Raman
4. Mossbauer spectroscopy

These measurements have yielded critically needed information concerning the electronic and vibrational properties of electrosorbed species and anodic films as well as the adsorption isotherms and the kinetics of the adsorption-desorption and surface rearrangements. They are insufficient by themselves to pin down the type of adsorption sites or compositional questions. For this reason, we have also made substantial use of ex situ

techniques to complement the electrochemical and in situ spectroscopic measurements. These have included

1. LEED
2. Auger electron spectroscopy
3. X-ray photoelectron spectroscopy
4. secondary ion mass spectroscopy

Special apparatus and techniques have been developed as part of the ONR contract research to facilitate the transfer between the electrochemical and ultrahigh vacuum interface and vice versa with the possibility of restructuring minimized. The types and distribution of adsorption sites is dependent on the surface topography and particularly the crystallographic plane. LEED and ultrahigh vacuum techniques have proved essential for the preparation of single crystal surfaces and their characterization before and after the electrochemical measurements. While many groups are carrying out electrochemical measurements on single crystals, their work is in general not indicative of surfaces with known zone axes. To prepare a clean surface corresponding to a given surface plane requires in general vacuum-LEED techniques and very special transfer procedures. Furthermore, the surfaces usually reconstruct during the electrochemical measurements and post-electrochemical LEED examination is essential. The effort to carry out such "ultra" electrochemical experiments, however, is very demanding and time-consuming.

The electrochemical systems to which such in situ and ex situ methods have been applied in this ONR sponsored research have included

1. underpotential deposited metals on gold: UV-visible, ellipsometry, LEED, AES (1-4,26)

2. electrosorbed hydrogen on platinum: LEED, AES, XPS (5-8,26).
3. adsorbed halogen ions on Au: UV-visible reflectance (including kinetics - electroreflectance admittance) (9).
4. adsorbed transition metal macrocyclic complexes on Ag, Au, Pt, basal plane of graphite, high area carbon: UV-visible reflectance Raman, Mossbauer (Fe, Co⁵⁷) (10-14,22,27).
5. adsorbed probe molecules on Ag, Pt, carbon, semiconductors: Raman (15-18)
6. anodic films and passivation layers on Pt, Au, Fe^{*}, Fe-Cr^{*}, Ni, Ag: UV-visible reflectance, ellipsometry, infrared, Raman, Mossbauer, XPS, AES, SIMS (19-25,27,28).

This research for the most part is summarized in various technical reports and publications. More recent developments over the past year are summarized in the following sections of this report.

II. RECENT DEVELOPMENTS IN CONTRACT RESEARCH

A. Upgrading of the thin-layer-electrochemical-cell-LEED-Auger-XPS system

The thin-layer-electrochemical cell-LEED system was designed and constructed in the latter 1970's as part of the ONR contract research. This system permits single crystal electrode surfaces to be prepared and characterized with LEED in ultra-high vacuum and then transferred into a thin layer electrochemical cell without removing the electrode from the vacuum chamber. The electrochemical measurements are carried out in the presence of ultra-pure argon as a supporting gas. Following the electrochemical measurements, the electrode surface is again returned to the ultra-high vacuum and re-examined with LEED and AES. Most of the recent studies have been carried out with dilute aqueous HF since this electrolyte is not specifically adsorbed over a substantial range with single crystal surfaces such as gold

* Some of the more recent measurements on iron and the iron-chromium alloys have been carried out as part of the ONR/SRO project at Case on the passivation of iron and ferrous alloys from Sept. 1979 - August 1982.

and platinum. The system was used to examine the electrosorption of hydrogen on single crystal platinum and underpotential deposition of lead on single crystal gold. The results have shown that each of the low index planes of these face-centered cubic single crystal metals have quite different adsorption characteristics. On the basis of these measurements it is clear that fundamental studies must be carried out on single crystal surfaces to be meaningful. On the other hand, the post-electrochemical LEED examination indicates that the surfaces often reconstruct in the electrochemical environment either giving new LEED patterns or becoming sufficiently disorganized so as not to give a pattern at low electron beam voltages where the diffraction arises principally from the surface layer. Only over relatively narrow potential ranges and then only on some crystal planes is it possible to maintain the original surface configuration. Furthermore, the AES measurements indicate that the surfaces are very easily contaminated and that even only a small fractional surface coverage can produce gross changes in the electrochemical properties.

On the basis of these earlier studies during 1978-81, the conclusion was reached that the study of electrochemical adsorption is only meaningful on single crystals for solid electrodes and that such electrochemical studies must be carried out with pre- and post-electrochemical LEED measurements with the most effective transfer possible. Consequently we have directed further effort to refining and upgrading this electrochemical-LEED-AES system. The changes made during the past one and a half years have included the following:

1. XPS-AES capability

The original system had only the limited capability afforded by the Varian RFD grid LEED-AES system. A Vacuum Generators hemispherical electron analyzer (CLAM-100) has been added together with

a dual target X-ray source (Al,Mg) and an electron gun. The available funds were insufficient to secure the signal processing computer system from Vacuum Generators. A surprisingly effective system, however, has been developed by our group using a Commodore Pet microprocessor together with a Nicolet signal average (1170) and associated peripheral equipment. This system now provides us a high performance XPS-AES capability. A diagram of the overall system as it now stands is shown in Fig. 1.

2. Increased pumping speed

The vacuum system consists of two principal vacuum chambers:

Chamber A: This chamber contains the LEED-AES-XPS system plus a sputtering gun and electron beam heater. The vacuum is usually in the 10^{-11} Torr range.

Chamber B: This chamber houses the thin layer electrochemical cell plus a quadrupole mass spectrometer. Ultra-pure argon is used in this chamber at ca. 0.3 atm when the thin-layer cell is formed. This chamber has heretofore been only pumped with a triode ion pump and after sufficient time reached the 10^{-10} Torr range. This chamber is connected to Chamber A with an isolation valve between the two chambers and a magnetically operated transfer wand to convey the single crystal electrode between the two chambers.

After the electrochemical measurements it is important to purge out the support gas (argon) and volatilize the electrolyte (0.1M HF) as rapidly as possible. To accomplish such, a turbomolecular pump has been connected to Chamber B, which pulls the pressure down to 10^{-8} Torr in 90 - 120 s following the completion of the electrochemical experiments. The sample is then transferred into Chamber A through the low conduction connection between the two chambers. In 3 to 5 minutes, the sample is again in position for LEED or AES-XPS examination at a pressure of 10^{-10} Torr. This has greatly reduced the possibility of post-electrochemical contamination of single crystal surfaces such as Pt with CO and other materials released from the

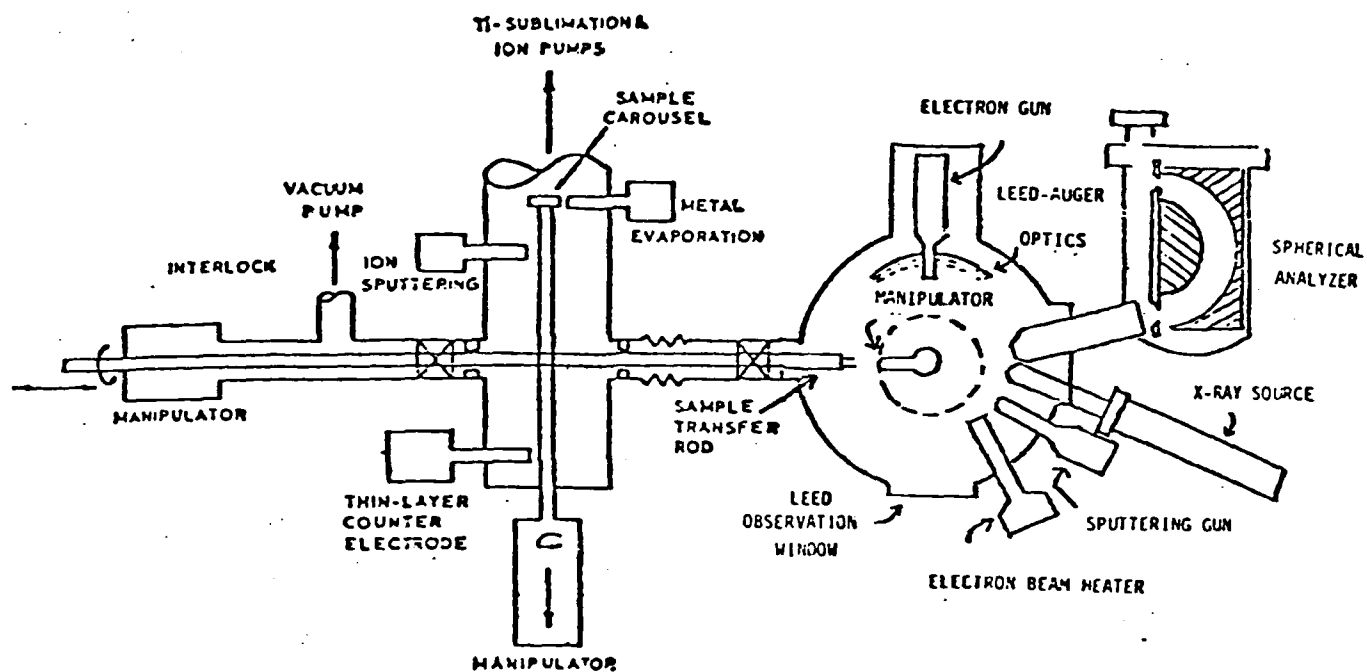


Fig. 1. LEED-Auger-ESCA-thin layer electrochemical cell system

walls of the chamber or present in the argon or released from the triode pump while pumping out the large amount of argon in Chamber B. With this system it has been possible to reduce the carbon level on Pt single crystal surfaces in the post-electrochemical AES measurements to 5 to 10% of a monolayer. Even so, we are still seeking to lower the carbon surface contamination in the post-electrochemical measurements to a much lower level $\leq 2\%$.

3. Electrolyte handling system

The electrolyte handling system has been completely rebuilt to provide better control of the purity of the electrolytic solutions such as 0.1M HF and better control of the volume delivered for the electrochemical measurements. The delivery system only exposes the electrolyte to Teflon. The portions of the Teflon delivery system outside the vacuum chamber are surrounded by an argon atmosphere to eliminate the possibility of O_2 diffusing through the walls into the solution.

4. Thin-layer electrochemical cell

Heretofore the thin-layer cell has consisted of the single crystal working electrode and a combined counter-reference electrode of α -Pd-H. This counter-reference electrode, however, can prove erratic under some circumstances. Consequently a three-electrode system has also been developed in which a Teflon-surrounded α -Pd-H electrode with only the end exposed is used as a separate reference, placed between the working and counter electrodes. This arrangement is currently being tested and should result in a larger number of successful runs as well as more accurate voltammetry results.

The system for cleaning, charging and pretesting the α -Pd-H counter electrode has also been greatly upgraded, using a third small vacuum chamber

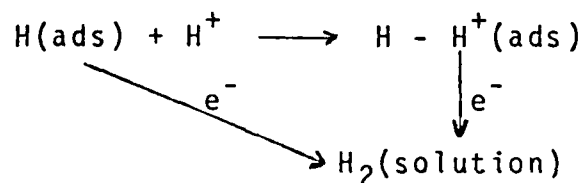
with its own ion pump.

B. Studies of the electrosorption of hydrogen on single crystal platinum surfaces.

In 1977-79, hydrogen adsorption and desorption were examined on the low index planes of Pt in H_2SO_4 solutions using the earlier version of the thin-layer cell-LEED-Auger system. When the potential was cycled only in the 0.0 to 0.55 V vs. α -Pd-H, the voltammetry curves on the (111) and (110) planes each showed only one major adsorption-desorption peak corresponding to weakly bound hydrogen and with a total charge only a small fraction of that expected for a monolayer. The (100) surface also showed only one predominant adsorption-desorption peak at more anodic potentials corresponding to more strongly bound hydrogen also with the charge corresponding to a small fraction of a monolayer. Cycling the potential into the anodic film region (1.45 V) resulted in the growth of these peaks on each of the surfaces. This could be explained in two ways: (1) the surfaces restructured at more anodic potentials and (2) carbon or other contamination was oxidized off the surface by cycling out to the anodic potentials, thus freeing up the surface for H adsorption. Both probably occurred. The use of sulfuric acid as the electrolyte, however, interfered with the post-electrochemical LEED and AES examination since this electrolyte is difficult to volatilize and becomes highly oxidizing as water is preferentially lost.

Consequently, the decision was made to repeat the measurements with 0.1M HF as the electrolyte using the partially upgraded system. More emphasis was placed on the purity of the low index surfaces before introduction into the electrochemical environment and the question of carbon

monoxide contamination during the pump down following the electrochemical measurements. The voltammetry results on the Pt 111 and 110 (2 x 1) surfaces were rather similar. Cycling into the anodic range resulted in the growth of the principal hydrogen peak. The subsequent LEED patterns for electrodes not cycled into the anodic film region indicated the patterns to be similar to those initially obtained although the background was increased. Carbon levels for the initial surfaces were usually below detection and in the post-electrochemical AES measurements were less than 10% monolayer level. When the electrode was cycled into the anodic film region (1.45 V), the hydrogen peaks again grew but the LEED showed major restructuring with loss of most of the pattern at low electron beam voltages. The voltammetry results on the Pt 100 (5 x 20) in HF, however, were quite different (see Fig. 2). With potential sweeps in the hydrogen adsorption and so-called anion region, the cathodic peak appeared in the anodic sweep.* This cathodic spike is attributed to the irreversible adsorption of hydrogen attending a structural rearrangement of the surface. The hydrogen can be desorbed very irreversibly at 0.8 V. Furthermore, potential window opening experiments indicate that this hydrogen can be cathodically desorbed at potentials less than 0.15 V. The process is proposed to be



* Dr. P. Ross has just reported that F. Wagner and himself at Lawrence Berkeley have now also observed such a cathodic spike in the anodic sweep for Pt(100).

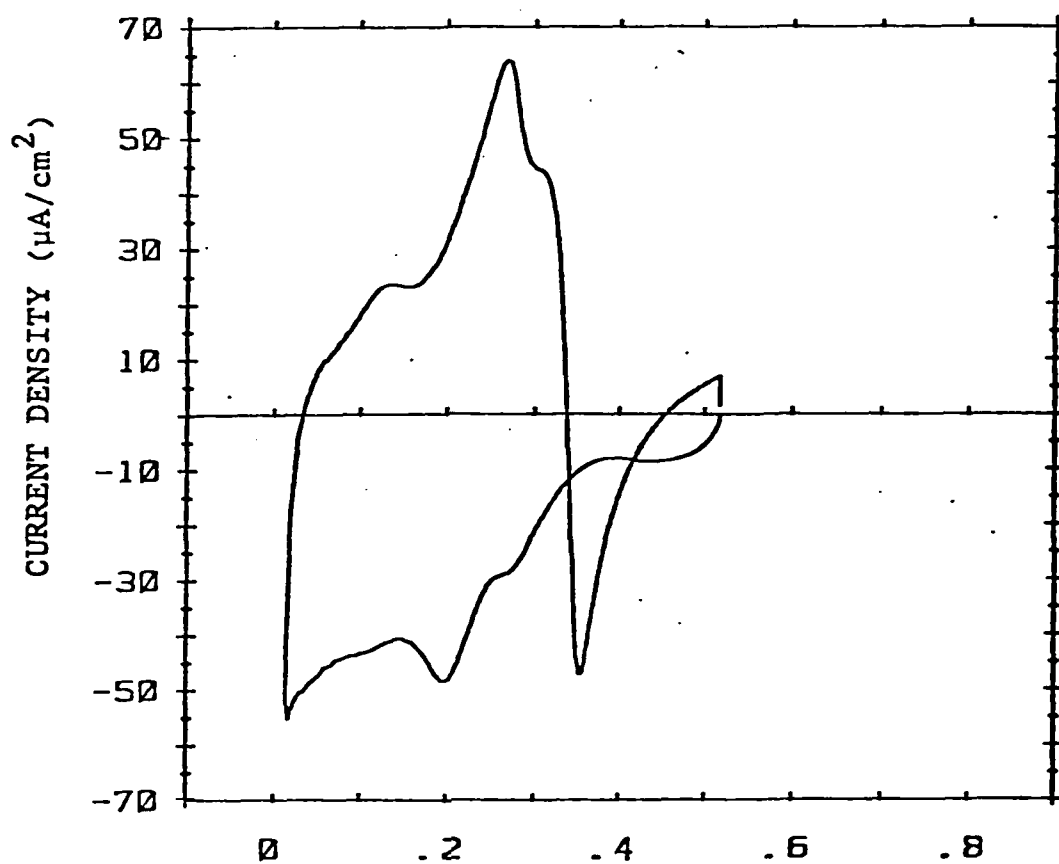


Fig. 2. linear sweep voltammetry Pt (100) - 5 x 20 in
0.1M HF. Sweep rate = 50 mV/s.

which may occur in one or two steps. These correspond to the Heyrovsky and Horiuti mechanisms for H_2 generation.

Highly irreversible structural rearrangements attending the adsorption of hydrogen on the Pt(100 - 5 x 20) surface from the gas phase have been reported by Norton et al. (28). The hydrogen is adsorbed at 120°K with the loss of the 5 x 20 overlayer and cannot be desorbed until 350-500°V. The cathodic peak in the anodic sweep at ca. 0.40 V in Fig. 2 is analogous to the low temperature adsorption from the gas phase and the desorption at the much more positive potential of 0.80 analogous to the high temperature desorption.

With multiple sweeps into the anodic film region (1.4 V) the cathodic spike is depressed and the voltammetry curve in the hydrogen region becomes similar to that found for 0.05M H_2SO_4 . Post-electrochemical LEED examination of the Pt (100) surface indicates loss of the 5 x 20 overlayer even if the potential is swept only in the limited range 0 - 0.5 V. With sweeps well into the anodic film region, the spot pattern becomes difficult to discern with a large amount of background diffuse scattering. With higher electron beam voltages the LEED pattern again exhibits well-defined spots. The surface after exposure to quite positive potentials has undergone substantial rearrangement.

These studies of hydrogen electrosorption on Pt in 0.1M HF were carried out before the installation of the Vacuum Generators Clam 100 hemispherical analyzer and the dual target x-ray source for XPS measurements. We are presently in the process of repeating a few of the measurements in 0.1M HF with post-electrochemical studies of the surfaces with XPS and AES to check more carefully on the presence of trace surface impurities.

C. Studies of underpotential deposition on single crystal metals

During the period 1976 - 79, the LEED-AES thin layer electrochemical cell system was used to study the underpotential deposition of lead on various gold single crystal surfaces. This work is summarized in published papers [15 and a technical report (51)]. During the last year of this contract, research has been initiated on a thorough LEED study of underpotential deposited layers on single crystal surfaces using this apparatus after the upgrading described earlier in this report. Underpotential deposition of lead on the low index surfaces of silver has been chosen for this study. The work has been continued under a follow on ONR contract. Research also has been initiated on the simultaneous underpotential deposition of two species, for example lead and copper on gold. The initial work is on polycrystalline gold but research under the continuation of this project will involve single crystal gold substrates.

D. Studies of anodic film formation on platinum single crystal surfaces

When the platinum single crystal surfaces are exposed to potentials in the anodic film region and withdrawn at potentials cathodic to this region, the LEED patterns indicate major surface changes. Work has been initiated to pin down the nature of these changes from the LEED patterns as functions of electron beam voltage. The platinum surfaces are also being withdrawn from the electrochemical cell at different potentials in the anodic film region to investigate the nature of the film with LEED and to check on the state of the platinum and adsorbed oxygen with XPS. In preliminary experiments with electrodes withdrawn in the anodic film region we have found fluorine in the XPS but not if the electrode is withdrawn at less positive potentials. This warrants careful investigation. This work is on-going and promises much needed information to understand the electrocatalytic properties of platinum for such reactions as O_2 electroreduction

E. Adsorbed transition metal macrocyclic complexes on electrode surfaces

Various transition metal macrocyclic complexes adsorbed on electrode surfaces exhibit high catalytic activity for various electrode reactions. The reduction of O_2 on such surfaces has been of special interest. Some of these complexes such as the iron tetrasulfonated phthalocyanines (TSPc) have high activity for the overall 4-electron reduction of O_2 to OH^- or H_2O while others such as the CoTSPc promote two-electron reduction of O_2 to peroxide (5,29,30). The former process is much preferred for such applications as fuel cells, metal-air batteries and certain industrial electrolytic processes.

The state of these adsorbed complexes on electrode surfaces and their interactions with O_2 and reactive intermediates such as O_2^- and HO_2^- are not well understood. As part of the research sponsored by both DOE and ONR, the Raman and visible reflectance spectroscopy of adsorbed layers of Co and Fe-TSPc as well as transition metal-free H_2 TSPc have been examined in acid, neutral and alkaline electrolytes (10-13). The Raman measurements have been carried out on silver electrodes roughened by cycling the potential. The reflectance of the adsorbed Co and Fe-TSPc species were examined on the basal plane of stress-annealed graphite, platinum and gold (10,13). The Raman and UV-visible spectra of the solution phase Co- and Fe-TSPc were also examined with and without O_2 present in acid, neutral and alkaline electrolytes. Unfortunately fluorescence interfered with obtaining the Raman spectra of the H_2 -TSPcNa₄, although the fluorescence was not pronounced for this species adsorbed on the electrode surface, probably because of quenching of the fluorescence by energy exchange with the metal (13).

The visible reflectance spectra of the adsorbed Co- and Fe-TSPc are similar to those of the solution and solid phase species. An easily detectable change occurs in the reflectance spectra with exposure of the

system to O_2 at constant electrode potential. The Raman spectra for the adsorbed species have essentially the same frequencies as the solution phase and solid phase species. The relative intensities, however, are quite different and furthermore are strongly dependent on the electrode potential as well as laser excitation frequency. The peak heights fall into two distinct types of potential dependence. This suggests that the macrocyclic may be present on the surface in two orientations or configurations with the amount in each configuration dependent on potential. Unfortunately, the selection rules for molecules exhibiting both surface enhancement and intrinsic resonance or pre-resonance enhancement are not well identified and hence identification of the configuration on the surface is uncertain. The Raman also is not sensitive to the axial ligand using visible laser excitation (488.0, 514.5 or 632.8 nm) and it is necessary to carry out the Raman studies in the ultraviolet to pin down whether di-oxygen is bound in the axial position and if so in a superoxide or peroxide state. Further work is planned using ultraviolet Raman.

Some of the possible configurations for the Co- and Fe-TSPc adsorbed species are shown in Fig. 3. In view of the strong adsorption and similarity of the spectra to that of the solids, we favor configurations b and d.

Mossbauer effect spectroscopy provides a means for examining the Fe and Co macrocyclics including the Fe- and Co-Pc in high area carbon electrodes in porous carbon electrolyte structures (14,22,27). We have been successful in examining the Fe phthalocyanine and Co tetramethoxyphenyl porphyrin in situ in alkaline and acid electrolytes as well as ex situ. This is an exciting development since it is possible to gain fundamental insight into the behavior of the complexes within high area electrodes. These studies are in an early state but already quite useful information has been obtained. For the Fe

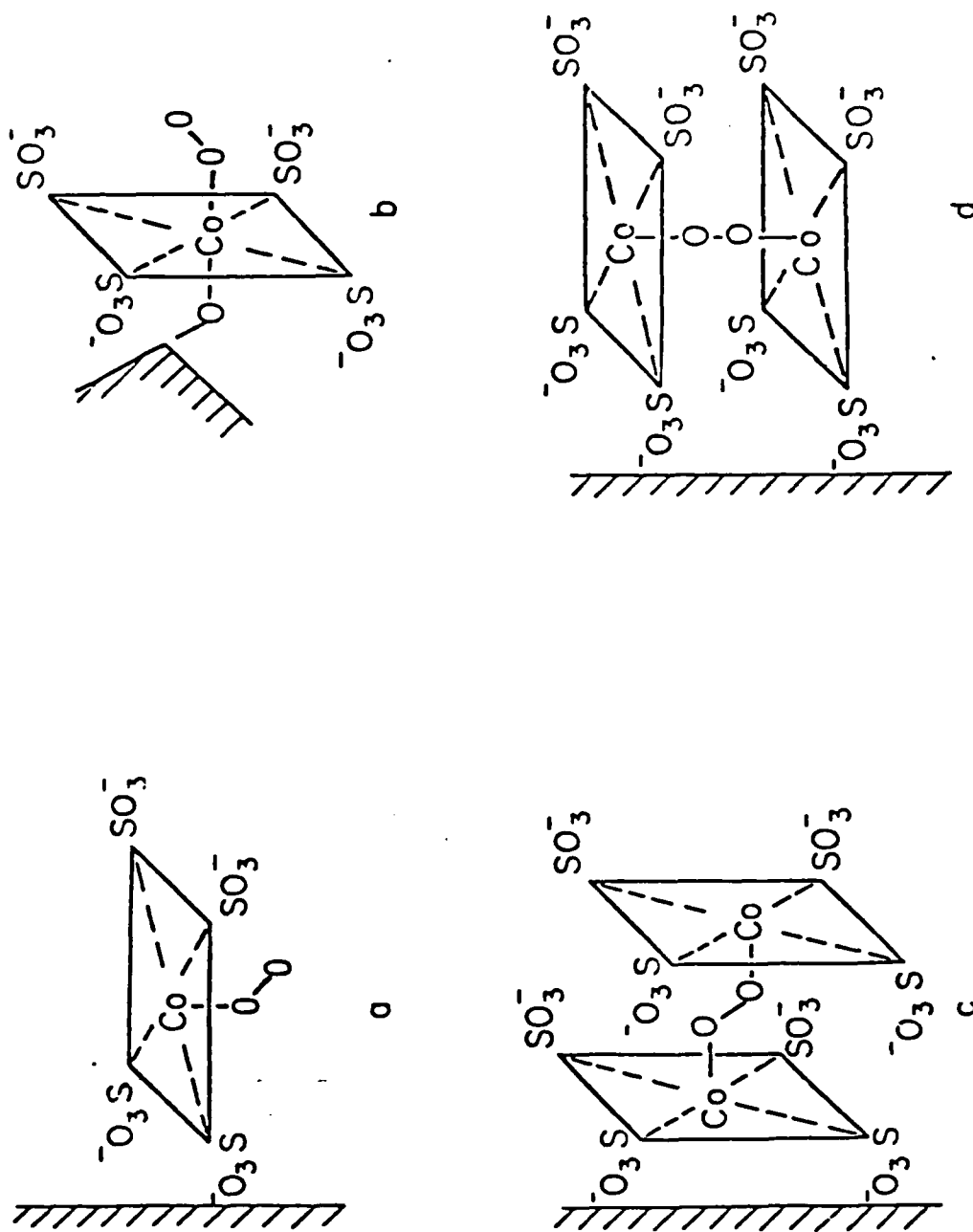


Fig. 3. Possible configurations for CoTSPc adsorbed on an electrode surface.
[Kötz and Yeager (11)]

phthalocyanines, the concentration of the naturally present ^{57}Fe is sufficient with the FePc catalyzed electrode used as the absorber for the γ -rays from a ^{57}Co source. For the Co complexes, the species have been synthesized with ^{57}Co and the electrodes loaded with this species used as the γ -ray emitter. The relaxational properties of the intermediate ^{57}Fe produced from the ^{57}Co are such that the system behaves similarly to Fe.

For the FePc in a moderately high area Teflon bonded carbon electrode, two sets of doublets are observed: one associated with the bulk solid and the other with the adsorbed species. The quadrupole splitting for the adsorbed species (0.88 mm/s) is low and provides evidence that the adsorbed species is probably bound through an axial O ligand to the electrode surface. This would be compatible with configuration b in Fig. 3.

The Mossbauer effect spectroscopy has also provided some interesting information on the effects of the electrode treatment on the state of the FePc in the electrode (27). For example, with FePc on carbon treated at $\sim 400^\circ\text{C}$ in H_2 before electrochemical examination, the Mossbauer measurements revealed the six doublets of metallic iron in a dispersed form. In helium under the same preparative conditions, there was no evidence of instability from the Mossbauer measurements. The Mossbauer measurements have also indicated that the amount of the macrocyclic complex in the adsorbed and bulk states in the electrode is quite sensitive to the preparative procedure.

References to Sections I and II

1. R. Adzic, E. Yeager and B. D. Cahan, J. Electrochem. Soc. 121 (1974) 474.
2. J. Horkans, B. D. Cahan and E. Yeager, ibid. 122 (1975) 1585.
3. P. Hagans, A. Homa, W. O'Grady and E. Yeager, LEED-Auger-Thin Layer Electrochemical Cell Studies of the Underpotential Deposition of Lead on Gold Single Crystals. Technical Report 51, ONR Contract N00014-75-C-0853, 15 December 1979.
4. E. Yeager, Surface Sci. 101 (1980) 831.
5. E. Yeager, J. Electrochem. Soc. 128 (1981) 160C.
6. W. O'Grady, M. Woo, P. Hagans and E. Yeager, in Electrode Materials and Processes for Energy Conversion and Storage, eds. J. McIntyre, S. Srinivasan, and F. Will, The Electrochemical Society, Princeton, NJ, 1977, p. 172.
7. W. E. O'Grady, M. Woo, P. Hagans and E. Yeager, J. Vac. Sci. Technol. 14 (1977) 421.
8. A. Homa, E. Yeager and B. Cahan, LEED-AES-Thin Layer Electrochemical Studies of Hydrogen Adsorption on Platinum Single Crystals, J. Electroanal. Chem. submitted (Technical Report No. 53).
9. R. Adzic, E. Yeager and B. Cahan, J. Electroanal. Chem. 85 (1977) 267.
10. B. Nikolic, R. Adzic and E. Yeager, J. Electroanal. Chem. 103 (1979) 281.
11. R. Kötzt and E. Yeager, J. Electroanal. Chem. 113 (1980) 113.
12. R. Kötzt and E. Yeager, ibid. 123 (1981) 335.
13. B. Simic-Glavaski, S. Zecevic and E. Yeager, ibid. submitted.
14. D. Scherson, S. Yao, E. Yeager, J. Eldridge, M. Kordesch and R. Hoffman, ibid. submitted.
15. G. Hagan, B. Simic-Glavaski and E. Yeager, ibid. 88 (1978) 269.
16. J. F. Brazdil and E. Yeager, J. Phys. Chem. 85 (1981) 995.
17. J. F. Brazdil and E. Yeager, ibid. 85 (1981) 1005.
18. J. F. Brazdil and E. Yeager, ibid. 85 (1981) 2194.
19. D. J. Wheeler, B. D. Cahan, C. T. Chen and E. Yeager, in Passivity of Metals, eds. R. P. Frankenthal and J. Kruger, The Electrochemical Society, Princeton, NJ, 1978, p. 546-563.

20. C. Chen, B. D. Cahan and E. Yeager, Passivation Studies of Iron, Nickel and Their Alloys by In-Situ Ellipsometry and Ex-Situ ESCA Techniques, Technical Report 48, ONR Contract N00014-75-C-0953, Case Western Reserve University, February 1979.
21. B. D. Cahan, C. T. Chen, D. J. Wheeler and E. Yeager, "Optical-Electrochemical Studies of the Passivation of Iron," Proc. Fourth Symposium on Fluid-Solid Surface Interactions, Office of Naval Research-Bureau of Standards, 1979.
22. D. Scherson, S. Yao, E. Yeager, J. Eldridge, M. Kordesch and R. Hoffman, Appl. Surface Sci. 10 (1982) 325.
23. S. C. Tjong and E. Yeager, J. Electrochem. Soc. 128 (1981) 2251.
24. S. C. Tjong and E. Yeager, ibid 129 (1982) 1276.
25. S. C. Tjong, J. Eldridge, R. Hoffman, R. Hehemann and E. Yeager, Proc. Symposium on Corrosion, R. Frankenthal and J. Kruger, eds., The Electrochemical Society, Pennington, NJ, 1982, pp. 50-58.
26. E. Yeager, A. Homa, B. Cahan and D. Scherson, J. Vac. Sci. Technol. 20 (1982) 628.
27. D. Scherson, S. Yao, E. Yeager, J. Eldridge, M. Kordesch and R. Hoffman, J. Phys. Chem., in press.
28. R. Kötzt and E. Yeager, J. Electroanal. Chem. 111 (1980) 105.
29. E. Yeager, J. Zagal, B. Nikolic and R. Adzic, Proc. Third Symposium on Electrode Processes, The Electrochemical Society, Princeton, NJ, 1980, pp. 436-456.
30. J. Zagal, P. Bindra and E. Yeager, J. Electrochem. Soc. 127 (1980) 1506.

III. TECHNICAL REPORTS, PUBLICATIONS AND PAPERS BASED ON CONTRACT RESEARCH

A. Technical Reports

43. Light Scattering from Electrochemical Interfaces, G. Blondeau and E. Yeager, 1 January 1976.
44. Mechanism of Electrochemical Reactions on Non-Metallic Surfaces, E. Yeager, 1 February 1976.
45. Specular Reflectance Studies of Bromide Adsorption on Gold, R. Adzic, E. Yeager and B. D. Cahan, 1 December 1976.
46. Recent Advances in the Understanding of Electrocatalysis and the Relation to Surface Chemistry, E. Yeager, 15 May 1977.
47. An Overview of the Electrochemical Interface and Optical Spectroscopic Studies, E. Yeager, 1 June 1977.
48. Passivation of Iron, C. Chen, B. D. Cahan, D. J. Wheeler and E. Yeager, 6 February 1979.
49. Optical and Electrochemical Studies of Adsorbed Transition Metal Complexes and Their O₂ Electrocatalytic Properties, E. Yeager, J. Zagal, B. Z. Nikolic and R. R. Adzic, 1 May 1979.
50. A Mechanistic Study of O₂ Reduction on Water Soluble Phthalocyanines Adsorbed on Graphite Electrodes, J. Zagal, P. Bindra and E. Yeager, 1 October 1979.
51. LEED-Auger-Thin Layer Electrochemical Studies of the Underpotential Deposition of Lead onto Gold Single Crystals, P. Hagans, A. Homa, W. O'Grady and E. Yeager, 15 December 1979.
52. Recent Advances in the Science of Electrocatalysis, E. Yeager, 1 November 1980.
53. LEED-AES-Thin Layer Electrochemical Studies of Hydrogen Adsorption on Platinum Single Crystals, A. Homa, E. Yeager and B. Cahan, 1 August 1982.
54. Applications of in situ Mossbauer Effect Spectroscopy to the Study of Electrode-Electrolyte Interfaces, D. Scherson, S. Yao, E. Yeager, J. Eldridge, M. Kordesch and R. Hoffman, 1 September 1982.

B. Publications

1. "Light Scattering at Electrochemical Interfaces," by G. Blondeau and E. Yeager, Progress in Solid State Chemistry 11 (1976) 153-170.
2. "Mechanisms of Electrochemical Reactions in Non-Metallic Surfaces," by E. Yeager, in Proc. NBS Workshop on Electrocatalysis on Non-Metallic Surfaces, NBS Special Publication, 1976.
3. "Oxygen Electrocatalysts for Life Support Systems," by W. E. O'Grady, C. Iwakura and E. Yeager, ASME Publication 76-EMAS-37 (1976) 1-11.
4. "Electrode Surface Studies by LEED-Augur," W. E. O'Grady, M.Y.C. Woo, P. L. Hagans and E. Yeager, J. Vac. Sci. Technol. 14 (1977) 365-367.
5. "Mechanism of the Hydrogen Electrode Reaction on Platinum in Acid Solution," F. Ludwig, R. K. Sen and E. Yeager, Elektrochim. 13 (1977) 816-820.
6. "The Electrocatalysis of O₂ Reduction," R. K. Sen, J. Zagal and E. Yeager, Inorg. Chem. 16 (1977) 3379.
7. "Oxygen Reduction by Co(II) Tetrasulfonated Phthalocyanine Adsorbed on a Stress Annealed Pyrolytic Graphite Electrode Surface," by J. Zagal, R. K. Sen, and E. Yeager, J. Electroanal. Chem. 83 (1977) 207-213.
8. "Electrochemical Hydrogen Adsorption on Pt (111) and (100) Surfaces," W. E. O'Grady, M.Y.C. Woo, P. L. Hagans and E. Yeager, Proc. of the Symposium on Electrode Materials and Processes for Energy Conversion
9. "Recent Advances in the Understanding of Electrocatalysis and its Interrelation to Surface Chemistry," E. Yeager, ibid., pp. 149-171.
10. "Application of Electrode Kinetics Principles to Energy Conservation," E. Yeager, Proc. Workshop on Energy Conservation in Industrial Electrochemical Processes, Argonne Natl. Laboratory, August 10-12, 1977.
11. "An Overview of the Electrochemical Interface and Optical Spectroscopic Studies," E. Yeager, J. Physique 38 (1977) 1-17.
12. "The Kinetics of the Oxygen Reduction Reaction on Gold in Alkaline Solution," J. Electrochem. Soc. 125 (1978) 1103-1109.
13. "Hydrogen Adsorption on Single Crystal Platinum Electrodes," W. E. O'Grady, M.Y.C. Woo and E. Yeager, J. Electrochem. Soc. 125 (1978) 345-349.
14. "The Raman Spectra of an Adsorbed Species on an Electrode Surface," G. Hagan, B. Simic-Glavaski and E. Yeager, J. Electroanal. Chem. 88 (1978) 269-275.
15. "Optical Studies of the Passivation of Iron," D. J. Wheeler, B. D. Cahan, C. T. Chen and E. Yeager, Proc. 4th International Symposium on Passivity, R. Frankenthal and J. Kruger, eds, The Electrochemical Society, Princeton, NJ. 1978, pp. 546-563.

16. "Optical Electrochemical Studies of the Passivation of Iron," B. D. Cahan, C. T. Chen, D. J. Wheeler and E. Yeager, Proc. Fourth Symposium on Fluid-Solid Surface Interactions, Office of Naval Research - National Bureau of Standards, 1979.
17. "Oxygen Electrodes for Electrochemical Energy Storage," E. Yeager in Energy Storage, J. Silverman, ed., Pergamon Press, New York, NY, 1979, pp. 201-211.
18. "Reflectance Spectra of Monolayers of Tetrasulfonated Transition Metal Phthalocyanines Adsorbed on Electrode Surfaces," B. Z. Nikolic, R. R. Adzic, and E. Yeager, J. Electroanal. Chem. 103 (1979) 281-287.
19. "Optical and Electrochemical Studies of Adsorbed Transition Metal Complexes and Their O₂ Electrocatalytic Properties," E. Yeager, J. Zagal, B. Z. Nikolic and R. R. Adzic, Proceedings of the Third Symposium on Electrode Processes, National Meeting of the Electrochemical Society, Boston, May 1979, S. Bruckenstein, J.D.E. McIntyre, B. Miller and E. Yeager, eds., The Electrochemical Society, Princeton, NJ, 1980, pp. 436-456.
20. "A Mechanistic Study of O₂ Reduction on Water Soluble Phthalocyanines Adsorbed on Graphite Electrodes," J. Zagal, P. Bindra and E. Yeager, J. Electrochem. Soc. 127 (1980) 1506-1517.
21. "Non-traditional Approaches to the Study of Solid-Electrolyte Interfaces: Problem Overview," E. Yeager, Surface Sci. 101 (1980) 1-22.
22. "Recent Developments in the Science of Electrocatalysts," E. Yeager, J. Electrochem. Soc. 128 (1981) 160C-171C.
23. "Resonance Raman Spectra of Adsorbed Species at Solid-Gas Interfaces: 3. Analysis of the Raman Excitation Profiles for Molecules Adsorbed on Semiconductor Oxide Surfaces, J. Brazdil and E. Yeager, J. Phys. Chem. 85 (1981) 2194-2199
24. "Theory for C-N⁻ and Ag-C Vibrational Frequency Dependence on Potential: Cyanide on a Silver Electrode," A. Anderson, R. Kötz and E. Yeager, Chem. Phys. Letters 82 (1981) 130-134.
25. "Offsetting Impurities in O₂ Electroreduction on Platinum with Adsorbed Metal Ions, R. Amadelli, J. Molla and E. Yeager, J. Electroanal. Chem. 126(1981) 265-271
26. "Spectroscopic Techniques for the Study of Solid-Liquid Interfaces," E. Yeager, A. Homa, B. Cahan, and D. Scherson, J. Vac. Sci. Technol. 20 (1982) 628-633.
27. "Oxygen Electrodes for Industrial Electrolysis and Electrochemical Power Generation," by Ernest Yeager, Proceedings of the Case Centennial Symposium on Electrochemistry in Industry: New Directions, Cleveland, Ohio, October 1980, E. Yeager, U. Landau, and D. Kortan, eds., Plenum Publ. Co., NYC, 1982, pp. 29-58.

28. "Applications of In Situ Mossbauer Effect Spectroscopy to the Study of Electrode-Electrolyte Interfaces," by D. A. Scherson, S.B. Yao, E. B. Yeager, J. Eldridge, M. E. Kordesch and R. W. Hoffman, *J. Electroanal. Chem.*, 150, 535-543 (1983).
29. "In Situ and Ex Situ Mossbauer Spectroscopy Studies of Iron Phthalocyanine Adsorbed on High Surface Area Carbon," by D. A. Scherson, S. B. Yao, E. B. Yeager, J. Eldridge, M. E. Kordesch, and R. W. Hoffman, *J. Phys. Chem.*, 87, 932 (1983).
30. "LEED-AES Thin-Layer Electrochemical Studies of Hydrogen Adsorption on Platinum Single Crystals," by Arthur S. Homa, E. Yeager and B. D. Cahan, *J. Electroanal. Chem.*, 150, 181-192 (1983).
31. "Cobalt Tetramethoxyphenyl Porphyrin--Emission Mossbauer Spectroscopy and O₂ Reduction Electrochemical Studies," by D. A. Scherson, S. L. Gupta, C. Fierro, E. B. Yeager, M. E. Kordesch, J. Eldridge, R. W. Hoffman and J. Blue, *Electrochim. Acta* 28, 1205 (1983).
32. "Oxygen Cathodes: Present Status and Problem Areas," by Ernest Yeager, Workshop on Renewable Fuels and Advanced Power Sources for Transportation, Boulder, CO, June 17 and 18, 1982, pp. 27-54.
33. "Study of Phthalocyanines in Aqueous Solutions and Adsorbed on Electrode Surfaces," by B. Simic-Glavaski, S. Zecevic, and E. Yeager, *J. Electroanal. Chem.*, 150, 469-479 (1983).

C. Papers Presented at Conferences and Meetings

1. "LEED-Auger Studies of Electrode Surfaces," by W. O'Grady, M. Woo, P. Hagans and E. Yeager, The Electrochemical Society Natl. Meeting, Washington, May 1976.
2. "Ellipsometric Studies of the Dynamics of Iron Passivation," by B.D. Cahan, T. Grcev, C.T. Chen, and E. Yeager, *ibid.*
3. "Oxygen Electrocatalysts for Life Support Systems," by W. O'Grady, C. Iwakura and E. Yeager, Intersociety Conference on Environmental Systems, San Diego, Calif., July 1976.
4. "Structural Studies of Electrode Surfaces," by W. O'Grady, M. Woo, P. Hagans, and E. Yeager, International Society of Electrochemistry, International Meeting, Zurich, September 1976.
5. "Studies of the Dynamics of Passivation Using Automatic Ellipsometry," by B.D. Cahan, T. Grcev, C.T. Chen and E. Yeager, *ibid.*
6. "Electrode Surface Studies by LEED-Auger," by W. O'Grady, M. Woo, P. Hagans and E. Yeager, American Vacuum Society, National Symposium, Chicago, September 1976.

7. "Gas Fed Porous Electrodes," by E. Yeager and B. Cahan, The Electrochemical Society, National Meeting, Las Vegas, October 1976.
8. "Application of Electrode Kinetics Principles to Energy Conservation Problems," by E. Yeager, Workshop on Energy Conservation in Industrial Electrochemical Processes, Argonne National Laboratory, August 10-12, 1976.
9. "Electrochemical Hydrogen Adsorption on the Pt (111) and (100) Surfaces," by H. E. O'Grady, M.Y.C. Moo, P.L. Hagans and E. Yeager, The Electrochemical Society, National Meeting, Philadelphia, May 8-13, 1977.
10. "Recent Advances in the Understanding of Electrocatalysis and its Interrelation to Surface Chemistry," E. Yeager, ibid.
11. "An Overview of the Electrochemical Interface and Optical Spectroscopic Studies," E. Yeager, Colloquium on Optical Properties of Solid-Liquid Interfaces, sponsored by the CNRS, La Colle sur Loup, France, May 23-28, 1977.
12. "Electrochemical Properties of Electrode Surfaces in Relation to Materials Research," E. Yeager and H.E. O'Grady, Symposium on Materials from a Chemical Viewpoint, American Chemical Society, National Meeting, New Orleans, March 20-25, 1977.
13. "The Optimization of Oxygen Cathodes and Anodes for Various Applications," E. Yeager, Gordon Research Conference on Electrochemistry, Santa Barbara, Calif., January 17-21, 1977.
14. "Transient Ellipsometric Studies of the Growth and Reduction of Passive Films on Iron," C.T. Chen, B.D. Cahan, and E. Yeager, National Meeting, The Electrochemical Society, Seattle, May 21-26, 1978. (Extended Abstract 61).
15. "Raman Spectra of Molecules Adsorbed on Electrodes," G. Hagan, B. Simic-Glavaski, and E. Yeager, ibid. (Extended Abstract 535).
16. "Ellipsometric Spectroscopy of the Passive Film on Iron," B.D. Cahan, C.T. Chen and E. Yeager, International Meeting of the International Society of Electrochemists, Budapest, 26 August - 2 September, 1978, (Extended Abstract 426-427.)
17. "The Raman Spectroscopy of Adsorbed Species on Electrode Surfaces," G. Hagan, B. Simic-Glavaski, and E. Yeager, ibid. (Extended Abstract 441-3).
18. "Optical and Electrochemical Studies of the Passivation of Iron," by B.D. Cahan, C.T. Chen, D.J. Wheeler and E. Yeager, ONR Symposium on Interfaces (in conjunction with the West German-U.S. Navy Scientific Data Exchange Agreement), National Bureau of Standards, Gaithersburg, MD, 18-20 October 1978.

19. "Surface Properties of Electrodes and their Relation to Electrochemical Reaction Rates," E. Yeager, Gordon Research Conference on Electrochemistry, Santa Barbara, Calif. 3-12 January 1979.
20. "Sample Transfer Techniques for Analysis of Electrode Surfaces by LEED-Auger Electron Spectroscopy," P. Hagans, A. Homa, and E. Yeager, Pittsburgh Analytical Meeting, Cleveland, 1-6 March 1979. (Abstract 448).
21. "LEED-Auger-Thin Layer Electrochemical Studies of the Underpotential Deposition of Pb on Au Single Crystals," P. Hagans, A. Homa, and E. Yeager, Third Symposium on Electrode Processes, National Meeting, The Electrochemical Society, Boston, 6-11 May 1979.
22. "Optical and Electrochemical Studies of Adsorbed Transition Metal Complexes and Their O_2 Electrocatalytic Properties," E. Yeager, J. Zagal, B.Z. Nikolic, and R.R. Adzic, invited lecture, *ibid.*
23. "Electrocatalysis and Its Application in Electrochemical Energy Conversion," E. Yeager, Case Western Reserve University Chemistry Department Frontiers Lecture Series, April 26, 1979.
24. "Oxygen Electrodes for Electrochemical Energy Storage Systems," by E. Yeager, First International Assembly on Energy Storage, National Academy of Sciences (USA) and Council of Academies of Science (Yugoslavia), Dubrovnik, 27 May - 1 June 1979.
25. "Non-traditional Approaches to the Study of Solid-Electrolyte Interfaces: An Overview," E. Yeager, invited opening lecture, International Symposium on Non-Traditional Approaches in Electrochemistry, Snowmass, Colorado, September 23-27, 1979.
26. " O_2 Electrolysis and its Application to Energy Conservation," E. Yeager, meeting of the Capitol Section of The Electrochemical Society, Washington, DC, March 6, 1980.
27. "Fundamental Aspects of O_2 Electrochemistry", E. Yeager, University of Osaka, Japan, April 1980.
28. "Underpotential Electrodeposition", E. Yeager, at Amanashi University, Japan, April 1980.
29. "Fundamental Aspects of O_2 Electrocatalysis," E. Yeager, at Institute of Catalyst Research, Hokkaido University, Japan, April 1980.
30. "Adsorbed Transition Metal Macrocyclic Complexes on Graphite and Metal Surfaces: Optical and Electrocatalytic Properties," E. Yeager, U.S.-France Joint Seminar on Adsorptive Attachment and Chemical Bonding to Electrode Surfaces to Catalyze Electrochemical Reactions, N.S.F.-C.N.R.S., Isle of Bendor, France, June 22-26, 1980.

31. "The Chemi-Conductor: A New Model for the Passive Film on Iron," by B.D. Cahan, 31st International Meeting of the International Society of Electrochemistry, Venice, September 22-26, 1980.
32. "Underpotential Deposition of Lead on Single Crystal Gold: LEED-Auger Thin Layer Cell Electrochemical Studies," by P. Hagans, A. Homa, U. O'Grady and E. Yeager, ibid.
33. "Optical Reflectance Spectroscopy and Electrochemical Properties of Adsorbed Monolayers of Phthalocyanines," by B.Z. Nikolic, R.R. Adzic, J. Zagal and E. Yeager, ibid.
34. "Oxygen Electrodes for Industrial Electrolysis and Electrochemical Power Generation," E. Yeager, Case Centennial Symposium on Electrochemistry in Industry--New Directions, Cleveland, October 20-22, 1980.
35. "Recent Advances in the Science of Electrocatalysis," E. Yeager, address on receiving the Edward Goodrich Lohman Medal, The Electrochemical Society Fall Meeting, Hollywood, Florida, October 7, 1980.
36. "Raman Studies of the Vibrational Properties of Adsorbed Species and Films at Electrochemical Interfaces," E. Yeager, R. Kotz and G. Nazri, The Electrochemical Society Spring National Meeting, Minneapolis, May 10-15, 1981.
37. "Electrocatalysis: Fundamental Aspects and Recent Developments," E. Yeager and D. Scherson, ibid.
38. "Auger and SIMS Studies of the Passivation of Iron-Chromium Alloys," S. Tjong, J. Eldridge, R. Hoffman, R. Hehemann, and E. Yeager, The Electrochemical Society Fall National Meeting, Denver, Oct. 11-16, 1981.
39. "UHV-LEED-AES Techniques Applied to Single Crystal Electrochemical Interfaces," A. Homa, B. D. Cahan and E. Yeager, ibid.
40. "Spectroelectrochemical Methods," E. Yeager, Lecture at Whiteshell Nuclear Research Establishment, Pinawa, Canada, July 16, 1982.
41. "Surface Chemistry of Electrochemical Interfaces," E. Yeager, Langmuir Lecture, American Chemical Society National Meeting, Kansas City, Sept. 12-16, 1982.
42. "LEED-AES-Thin Layer Electrochemical Studies of Hydrogen Adsorbed on Platinum Single Crystals," A. Homa, E. Yeager and B. Cahan, International Conference on Electronic and Molecular Structure of Electrode-Electrolyte Interfaces, Logan, Utah, July 25-30, 1982.
43. "Study of Phthalocyanines in Aqueous Solutions and Adsorbed on Electrode Surfaces," B. Simic, S. Zecevic and E. Yeager, ibid.
44. "Applications of in situ Mossbauer Effect Spectroscopy to the Study of Electrode-Electrolyte Interfaces," D. Scherson, S. Yao, E. Yeager, J. Eldridge, M. Kordesch and R. Hoffman, ibid.

45. "Mechanistic Aspects of O_2 Electrocatalysis," by E. Yeager, D. Scherson and B. Simic-Glavaski, The Electrochemical Society National Meeting, San Francisco, May 1983. Extended Abstr. 83-1, 706 (submitted for publication in Proceedings of the Symposium on Electrocatalysis).
46. "Oxygen Reduction Electrocatalysis: Fundamental Aspects," by E. Yeager, The Electrochemical Society, National Meeting, Washington, D.C. October 1983. Extended Abstr. 83-2, 387.
47. "Oxygen Interaction with Adsorbed Tetrakisulfonated Phthalocyanines," by S. Zecevic, B. Simic-Glavaski and E. Yeager, loc. cit. Extended Abstr. 83-2, 482.

IV. CONTRACT PERSONNEL

A. Senior Personnel

1. Ernest Yeager, Hovorka Professor of Chemistry and Director, Case Center for Electrochemical Sciences: Project Director (1976-83)
2. B. D. Cahan, Professor of Chemistry: Co-principal investigator (1976-83)

B. Graduate Students (Ph.D theses based on ONR centered research)

1. C. Chen (1977-78) Ph.D 1979
2. Arthur Homa (1978-82) Ph.D 1982
3. Michael Hanson (1980-84) Ph.D thesis completion Oct. 1984
4. R. Allen Wilkinson (1981-84) Ph.D thesis completion, spring 1985
5. G. McDougall (1982-84) Ph.D thesis completion, late 1985

C. Postdoctoral appointments

1. R. K. Sen (1976)
2. W. O'Grady (1976)
3. B. Nikolic (1978)
4. B. Simic-Glavaski (1977)

DL/413/83/01
GEN/413-2

TECHNICAL REPORT DISTRIBUTION LIST, GEN

	<u>No. Copies</u>		<u>No. Copies</u>
Office of Naval Research Attn: Code 413 800 N. Quincy Street Arlington, Virginia 22217	2	Naval Ocean Systems Center Attn: Technical Library San Diego, California 92152	
ONR Pasadena Detachment Attn: Dr. R. J. Marcus 1030 East Green Street Pasadena, California 91106	1	Naval Weapons Center Attn: Dr. A. B. Amster Chemistry Division China Lake, California 93555	
Commander, Naval Air Systems Command Attn: Code 310C (H. Rosenwasser) Washington, D.C. 20360	1	Scientific Advisor Commandant of the Marine Corps Code RD-1 Washington, D.C. 20380	
Naval Civil Engineering Laboratory Attn: Dr. R. W. Drisko Port Hueneme, California 93401	1	Dean William Tolles Naval Postgraduate School Monterey, California 93940	
Superintendent Chemistry Division, Code 6100 Naval Research Laboratory Washington, D.C. 20375	1	U.S. Army Research Office Attn: CRD-AA-IP P.O. Box 12211 Research Triangle Park, NC 27709	
Defense Technical Information Center Building 5, Cameron Station Alexandria, Virginia 22314	12	Mr. Vincent Schaper DTNSRDC Code 2830 Annapolis, Maryland 21402	
DTNSRDC Attn: Dr. G. Bosmajian Applied Chemistry Division Annapolis, Maryland 21401	1	Mr. John Boyle Materials Branch Naval Ship Engineering Center Philadelphia, Pennsylvania 19112	
Naval Ocean Systems Center Attn: Dr. S. Yamamoto Marine Sciences Division San Diego, California 91232	1	Mr. A. M. Anzalone Administrative Librarian PLASTEC/ARRADCOM Bldg 3401 Dover, New Jersey 07801	

DL/413/83/01
056/413-2

TECHNICAL REPORT DISTRIBUTION LIST, 056

Dr. G. A. Somorjai
Department of Chemistry
University of California
Berkeley, California 94720

Dr. J. Murday
Naval Research Laboratory
Surface Chemistry Division (6170)
455 Overlook Avenue, S.W.
Washington, D.C. 20375

Dr. J. B. Hudson
Materials Division
Rensselaer Polytechnic Institute
Troy, New York 12181

Dr. Theodore E. Madey
Surface Chemistry Section
Department of Commerce
National Bureau of Standards
Washington, D.C. 20234

Dr. Chia-wei Woo
Department of Physics
Northwestern University
Evanston, Illinois 60201

Dr. Robert M. Hexter
Department of Chemistry
University of Minnesota
Minneapolis, Minnesota

Dr. J. E. Demuth
IBM Corporation
Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, New York 10598

Dr. M. G. Lagally
Department of Metallurgical
and Mining Engineering
University of Wisconsin
Madison, Wisconsin 53706

Dr. Adolph B. Amster
Chemistry Division
Naval Weapons Center
China Lake, California 93555

Dr. W. Kohn
Department of Physics
University of California, San Diego
La Jolla, California 92037

Dr. R. L. Park
Director, Center of Materials
Research
University of Maryland
College Park, Maryland 20742

Dr. W. T. Peria
Electrical Engineering Department
University of Minnesota
Minneapolis, Minnesota 55455

Dr. Keith H. Johnson
Department of Metallurgy and
Materials Science
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Dr. J. M. White
Department of Chemistry
University of Texas
Austin, Texas 78712

Dr. R. P. Van Duyne
Chemistry Department
Northwestern University
Evanston, Illinois 60201

Dr. S. Sibener
Department of Chemistry
James Franck Institute
5640 Ellis Avenue
Chicago, Illinois 60637

Dr. Arold Green
Quantum Surface Dynamics Branch
Code 3817
Naval Weapons Center
China Lake, California 93555

Dr. S. L. Bernasek
Princeton University
Department of Chemistry
Princeton, New Jersey 08544

DL/413/83/01
056/413-2

TECHNICAL REPORT DISTRIBUTION LIST, 056

Dr. F. Carter
Code 6132
Naval Research Laboratory
Washington, D.C. 20375

Dr. Richard Colton
Code 6112
Naval Research Laboratory
Washington, D.C. 20375

Dr. Dan Pierce
National Bureau of Standards
Optical Physics Division
Washington, D.C. 20234

Professor R. Stanley Williams
Department of Chemistry
University of California
Los Angeles, California 90024

Dr. R. P. Messmer
Materials Characterization Lab.
General Electric Company
Schenectady, New York 22217

Dr. Robert Gomer
Department of Chemistry
James Franck Institute
5640 Ellis Avenue
Chicago, Illinois 60637

Dr. Ronald Lee
R301
Naval Surface Weapons Center
White Oak
Silver Spring, Maryland 20910

Dr. Paul Schoen
Code 5570
Naval Research Laboratory
Washington, D.C. 20375

Dr. John T. Yates
Department of Chemistry
University of Pittsburgh
Pittsburgh, Pennsylvania 15260

Dr. Richard Greene
Code 5230
Naval Research Laboratory
Washington, D.C. 20375

Dr. L. Kesmodel
Department of Physics
Indiana University
Bloomington, Indiana 47403

Dr. K. C. Janda
California Institute of Technology
Division of Chemistry and Chemical
Engineering
Pasadena, California 91125

Professor E. A. Irene
Department of Chemistry
University of North Carolina
Chapel Hill, North Carolina 27514

Dr. Adam Heller
Bell Laboratories
Murray Hill, New Jersey 07974

Dr. Martin Fleischmann
Department of Chemistry
Southampton University
Southampton SO9 5NH
Hampshire, England

Dr. John W. Wilkins
Cornell University
Laboratory of Atomic and
Solid State Physics
Ithaca, New York 14853

Dr. Richard Smardzewski
Code 6130
Naval Research Laboratory
Washington, D.C. 20375

DL/413/83/01
056/413-2

TECHNICAL REPORT DISTRIBUTION LIST, 056

Dr. R. G. Wallis
Department of Physics
University of California
Irvine, California 92664

Dr. D. Ramaker
Chemistry Department
George Washington University
Washington, D.C. 20052

Dr. P. Hansma
Physics Department
University of California
Santa Barbara, California 93106

Dr. J. C. Hemminger
Chemistry Department
University of California
Irvine, California 92717

Professor T. F. George
Chemistry Department
University of Rochester
Rochester, New York 14627

Dr. G. Rubloff
IBM
Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, New York 10598

Professor Horia Metiu
Chemistry Department
University of California
Santa Barbara, California 93106

Captain Lee Myers
AFOSR/NC
Bolling AFB
Washington, D.C. 20332

Professor Roald Hoffmann
Department of Chemistry
Cornell University
Ithaca, New York 14853

Dr. R. W. Plummer
Department of Physics
University of Pennsylvania
Philadelphia, Pennsylvania 19104

Dr. E. Yeager
Department of ~~Chemistry~~
Case Western Reserve University
Cleveland, Ohio 44106

Professor D. Hercules
University Pittsburgh
Chemistry Department
Pittsburgh, Pennsylvania 15260

Professor M. Winograd
Department of Chemistry
Pennsylvania State University
University Park, Pennsylvania 16802

Dr. G. D. Stein
Mechanical Engineering Department
Northwestern University
Evanston, Illinois 60201

Professor A. Steckl
Department of Electrical and
Systems Engineering
Rensselaer Polytechnic Institute
Troy, New York 12181

Professor G. H. Morrison
Department of Chemistry
Cornell University
Ithaca, New York 14853

Dr. David Souire
Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709

DL/413/83/01
359/413-2

TECHNICAL REPORT DISTRIBUTION LIST, 359

Dr. Paul Delahay
Department of Chemistry
New York University
New York, New York 10003

Dr. P. J. Hendra
Department of Chemistry
University of Southampton
Southampton SO9 5NH
United Kingdom

Dr. T. Katan
Lockheed Missiles and
Space Co., Inc.
P.O. Box 504
Sunnyvale, California 94088

Dr. D. N. Bennion
Department of Chemical Engineering
Brighma Young University
Provo, Utah 84602

Dr. R. A. Marcus
Department of Chemistry
California Institute of Technology
Pasadena, California 91125

Mr. Joseph McCartney
Code 7121
Naval Ocean Systems Center
San Diego, California 92152

Dr. J. J. Auburn
Bell Laboratories
Murray Hill, New Jersey 07974

Dr. Joseph Singer, Code 302-1
NASA-Lewis
21000 Brookpark Road
Cleveland, Ohio 44135

Dr. P. P. Schmidt
Department of Chemistry
Oakland University
Rochester, Michigan 48063

Dr. H. Richtol
Chemistry Department
Pennselaer Polytechnic Institute
Troy, New York 12181

Dr. E. Yeager
Department of Chemistry
Case Western Reserve University
Cleveland, Ohio 44106

Dr. C. E. Mueller
The Electrochemistry Branch
Naval Surface Weapons Center
White Oak Laboratory
Silver Spring, Maryland 20910

Dr. Sam Perone
Chemistry & Materials
Science Department
Lawrence Livermore National Lab.
Livermore, California 94550

Dr. Royce W. Murray
Department of Chemistry
University of North Carolina
Chapel Hill, North Carolina 27514

Dr. G. Goodman
Johnson Controls
5757 North Green Bay Avenue
Milwaukee, Wisconsin 53201

Dr. B. Brummer
EIC Incorporated
111 Chapel Street
Newton, Massachusetts 02158

Dr. Adam Heller
Bell Laboratories
Murray Hill, New Jersey 07974

Electrochimica Corporation
Attn: Technical Library
2485 Charleston Road
Mountain View, California 94040

Library
Duracell, Inc.
Burlington, Massachusetts 01803

Dr. A. B. Ellis
Chemistry Department
University of Wisconsin
Madison, Wisconsin 53706

DL/413/83/01
359/413-2

TECHNICAL REPORT DISTRIBUTION LIST, 359

Dr. M. Wrighton
Chemistry Department
Massachusetts Institute
of Technology
Cambridge, Massachusetts 02139

Dr. B. Stanley Pons
Department of Chemistry
University of Utah
Salt Lake City, Utah 84112

Donald E. Mains
Naval Weapons Support Center
Electrochemical Power Sources Division
Crane, Indiana 47522

S. Ruby
DOE (STOR)
M.S. 68025 Forrestal Bldg.
Washington, D.C. 20595

Dr. A. J. Bard
Department of Chemistry
University of Texas
Austin, Texas 78712

Dr. Janet Osteryoung
Department of Chemistry
State University of New York
Buffalo, New York 14214

Dr. Donald W. Ernst
Naval Surface Weapons Center
Code R-33
White Oak Laboratory
Silver Spring, Maryland 20910

Mr. James R. Moden
Naval Underwater Systems Center
Code 3632
Newport, Rhode Island 02840

Dr. Bernard Spielvogel
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709

Dr. William Ayers
ECD Inc.
P.O. Box 5357
North Branch, New Jersey 08876

Dr. M. M. Nicholson
Electronics Research Center
Rockwell International
3370 Miraloma Avenue
Anaheim, California

Dr. Michael J. Weaver
Department of Chemistry
Purdue University
West Lafayette, Indiana 47907

Dr. R. David Rauh
EIC Corporation
111 Chapel Street
Newton, Massachusetts 02158

Dr. Aaron Wold
Department of Chemistry
Brown University
Providence, Rhode Island 02192

Dr. Martin Fleischmann
Department of Chemistry
University of Southampton
Southampton SO9 5NH ENGLAND

Dr. R. A. Osteryoung
Department of Chemistry
State University of New York
Buffalo, New York 14214

Dr. Denton Elliott
Air Force Office of Scientific
Research
Bolling AFB
Washington, D.C. 20332

Dr. R. Nowak
Naval Research Laboratory
Code 6130
Washington, D.C. 20375

Dr. D. F. Shriver
Department of Chemistry
Northwestern University
Evanston, Illinois 60201

Dr. Aaron Fletcher
Naval Weapons Center
Code 3852
China Lake, California 93555

DL/413/83/01
359/413-2

TECHNICAL REPORT DISTRIBUTION LIST, 359

Dr. David Aikens
Chemistry Department
Rensselaer Polytechnic Institute
Troy, New York 12181

Dr. A. P. B. Lever
Chemistry Department
York University
Downsview, Ontario M3J1P3

Dr. Stanislaw Szpak
Naval Ocean Systems Center
Code 6343, Bayside
San Diego, California 95152

Dr. Gregory Farrington
Department of Materials Science
and Engineering
University of Pennsylvania
Philadelphia, Pennsylvania 19104

M. L. Robertson
Manager, Electrochemical
and Power Sources Division
Naval Weapons Support Center
Crane, Indiana 47522

Dr. T. Marks
Department of Chemistry
Northwestern University
Evanston, Illinois 60201

Dr. Micha Tomkiewicz
Department of Physics
Brooklyn College
Brooklyn, New York 11210

Dr. Lesser Blum
Department of Physics
University of Puerto Rico
Rio Piedras, Puerto Rico 00931

Dr. Joseph Gordon, II
IBM Corporation
K33/281
5600 Cottle Road
San Jose, California 95193

Dr. D. H. Whitmore
Department of Materials Science
Northwestern University
Evanston, Illinois 60201

Dr. Alan Bewick
Department of Chemistry
The University of Southampton
Southampton, SO9 5NH ENGLAND

Dr. E. Anderson
NAVSEA-56Z33 NC #4
2541 Jefferson Davis Highway
Arlington, Virginia 20362

Dr. Bruce Dunn
Department of Engineering &
Applied Science
University of California
Los Angeles, California 90024

Dr. Elton Cairns
Energy & Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Dr. D. Cipris
Allied Corporation
P.O. Box 3000R
Morristown, New Jersey 07960

Dr. M. Philpott
IBM Corporation
5600 Cottle Road
San Jose, California 95193

Dr. Donald Sandstrom
Department of Physics
Washington State University
Pullman, Washington 99164

Dr. Carl Kannewurf
Department of Electrical Engineering
and Computer Science
Northwestern University
Evanston, Illinois 60201

DL/413/83/01
359/413-2

TECHNICAL REPORT DISTRIBUTION LIST, 359

Dr. Robert Somoano
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103

Dr. Johann A. Joebstl
USA Mobility Equipment R&D Command
DRDME-EC
Fort Belvoir, Virginia 22060

Dr. Judith H. Ambrus
NASA Headquarters
M.S. RTS-6
Washington, D.C. 20546

Dr. Albert R. Landgrebe
U.S. Department of Energy
M.S. 6B025 Forrestal Building
Washington, D.C. 20595

Dr. J. J. Brophy
Department of Physics
University of Utah
Salt Lake City, Utah 84112

Dr. Charles Martin
Department of Chemistry
Texas A&M University
College Station, Texas 77843

Dr. H. Tachikawa
Department of Chemistry
Jackson State University
Jackson, Mississippi 39217

Dr. Theodore Beck
Electrochemical Technology Corp.
3935 Leary Way N.W.
Seattle, Washington 98107

Dr. Farrell Lytle
Boeing Engineering and
Construction Engineers
P.O. Box 3707
Seattle, Washington 98124

Dr. Robert Gotscholl
U.S. Department of Energy
MS G-226
Washington, D.C. 20545

Dr. Edward Fletcher
Department of Mechanical Engineering
University of Minnesota
Minneapolis, Minnesota 55455

Dr. John Fontanella
Department of Physics
U.S. Naval Academy
Annapolis, Maryland 21402

Dr. Martha Greenblatt
Department of Chemistry
Rutgers University
New Brunswick, New Jersey 08903

Dr. John Wasson
Syntheco, Inc.
Rte 6 - Industrial Pike Road
Gastonia, North Carolina 28052

Dr. Walter Roth
Department of Physics
State University of New York
Albany, New York 12222

Dr. Anthony Sammells
Eltron Research Inc.
710 E. Ogden Avenue #108
Naperville, Illinois 60540

Dr. W. M. Risen
Department of Chemistry
Brown University
Providence, Rhode Island 02192

Dr. C. A. Angell
Department of Chemistry
Purdue University
West Lafayette, Indiana 47907

Dr. Thomas Davis
Polymer Science and Standards
Division
National Bureau of Standards
Washington, D.C. 20234

END

FILMED

12-84

DTIC