



1996 Gordon Conference on Aqueous Corrosion

FINAL PROGRESS REPORT

AFOSR Grant No. F 49620-96-1-0148

The Conference was held on July 7-11, 1996 at Colby Sawyer College in New London, New Hampshire. The focus was on recent advances in understanding the fundamentals of formation and breakdown of oxide films on metals, and on other protective films and layers, of special interest to aqueous corrosion. Two special interest days were devoted to Corrosion in Electronic and Communication Systems, and Coatings and Corrosion Protection. Individual sessions were

- Oxide Film on Metals and Their Breakdown,
- Localized Breakdown of Passive Films, and
- Microscopic Techniques for Study
- Corrosion in Electronic and Communication Systems
- Coatings and Corrosion Protection
- Mechanical and Chemical Effects on Oxide Film Adhesion and Fracture

Speakers that were knowledgeable in each area were selected. The complete program is attached. Special attention was given to selection of young speakers and discussion leaders, and one third of the speakers fit this criterion. Speakers from Japan, United Kingdom, Italy, and Germany were on the program as well.

A highlight of the Conference was the poster session by 35 graduate students and postdoctoral associates. They each gave a short oral summary of the posters at the technical sessions, and this was very successful. The participation by these younger people in other parts of the Conferences was quite high as well.

The new format, i.e., Sunday evening through Thursday evening, was popular. The attendance at the last session on Thursday evening was 85, a good fraction of the total attendance of 95.

### Oxide Films on Metals

Two new techniques for investigation of oxide films were highlighted. The first was in situ grazing incidence angle x-ray scattering which can reveal the structure and orientation of thin oxide films on metal surfaces. It was found that the oxide film grown on single crystal iron was neither  $\gamma\text{-Fe}_2\text{O}_3$  nor  $\text{Fe}_3\text{O}_4$ , historically popular choices, but apparently a spinel-like  $\text{Fe}_2\text{O}_3$ . A second technique, XANES, also requiring a synchrotron light source, was used to study sputter deposited films of iron and chromium oxides. It was of interest to explore changes in structure and oxidation state upon exposure to aqueous solutions at different potentials and pH. Although easier to use, the results are more qualitative and less definitive than the x-ray scattering technique.

### Oxide Films and Breakdown

The use of in situ stress measurements on oxide films was described for iron substrates. Models for breakdown and pitting were explored for iron alloys, and contended that inclusions were required to nucleate pits, and the inclusions must be of a minimum size to propagate the pits. Microscopic techniques to explore the regions around inclusions were described in another contribution. The techniques included the classical ex-situ SEM/EDAX standard as well as scanned pH probe microscopy and confocal laser scanning microscopy with fluorescent probes.

The ability to probe single grains of a polycrystalline surface was demonstrated for titanium. 50 micrometer areas on individual grains (~200 micrometer in diameter) were defined and studied with microellipsometry, electrochemical impedance and polarization, and photoelectrochemical techniques. The techniques when used together were able to reveal the variation in oxide film properties that were generated from grain to grain on the metal surface.

Confocal laser scanning microscopy with fluorescent probes was described in a second contribution at the Conference. pH sensitive dyes in solution revealed local pH

# GORDON RESEARCH CONFERENCE

1996

## AQUEOUS CORROSION

W.H. Smyrl, Chairman

D.J. Young, Vice-Chairman

Technical Sessions

Sponsored by:

Gordon Research Conference Special Fund  
National Science Foundation  
Office of Naval Research  
Air Force Office of Scientific Research  
University of Minnesota Corrosion Research Center

## INTRODUCTION

The Gordon Research Conferences were established to foster the open sharing of new scientific findings and theories between researchers in the field. Unlike most other conferences, a full week is dedicated to presentations in one area. The talks and discussions are typically of such a duration to allow in-depth exposition and full discussion of a specific session topic. Speakers are selected by the chairman for their expertise and recent progress in areas deemed to be at the frontiers of science.

Another key aspect of the conference is accessibility. The opportunity for informal discussions outside the lecture program is unique in that attendees stay in college dormitories, have meals together and otherwise socialize in the free afternoon periods or after the evening sessions. There is also the opportunity for attendees to present their own work through poster sessions. This format is particularly helpful for graduate students and new researchers in the field to make personal contacts with established experts and international attendees.

### THE 1996 CONFERENCE ON AQUEOUS CORROSION

The conference is focused on recent advances in understanding the fundamentals of aqueous corrosion of metals, the formation and breakdown of oxide films, the behavior of coating and protective layers, and corrosion in electronic and communications systems. Individual sessions are

Oxide films on metals  
Oxide films and breakdown  
Localized breakdown of passive films and new microscopic technique  
Corrosion in electronic and communications systems  
Coatings and corrosion protection  
Microscopy and localized breakdown of passive films  
Chemical and mechanical effects on oxide film adhesion and fracture

The speakers have been selected on the basis of their unique contributions to, and their knowledge of, the subject area. Several are new speakers and five are from outside the U.S.A.

The session discussion leaders also have a wide background on corrosion and have been selected for their leadership and contributions to corrosion, and their experience with the Gordon Conference format.

### ATTENDEES

The technical sessions have been structured to allow in-depth discussion of the issues raised, with extensive participation by the attendees. We especially note the attendance and participation of graduate students and postdoctoral associates. The poster session should be an invaluable part of the Conference.

### SPONSORS

The chairman is grateful for financial support from the Gordon Research Conference Special Fund, NSF, ONR, AFOSR, and the U of MN CRC.

## SCHEDULE OF EVENTS

### Sunday, July 7

7:30 p.m. Technical Session

### Monday, July 8

9:00 a.m. Technical Session

9:30 a.m. Spouse and Guest Reception

3:00 - 4:30 p.m. Poster Session Begins

4:30 - 6:00 p.m. Chairman's Reception, Conference Center

7:30 p.m. Technical Session

### Tuesday, July 9

9:00 a.m. Technical Session

7:30 p.m. Technical Session

### Wednesday, July 10

9:00 a.m. Technical Session

7:30 p.m. Technical Session

### Thursday, July 11

9:00 a.m. Technical Session

7:30 p.m. Technical Session

10:30 p.m. Close of Conference

# GORDON RESEARCH CONFERENCE

## *Aqueous Corrosion*

July 7-11, 1996

William H. Smyrl, Chairman  
University of Minnesota

D.J. Young, Vice Chairman  
University of New South Wales

### Sunday, July 7 Evening Session *Oxide Films on Metals*

Discussion Leader: Dr. Alison Davenport

- Speakers:
- \* Dr. M.J. Toney, IBM Almaden Research Center  
"X-ray Diffraction Measurements on Anodic Oxide Films"
  - \* Dr. Patrik Schmuki, Brookhaven National Laboratory  
"in-situ XANES of Artificial Fe and Cr Oxide Passive Films"

### Monday, July 8 Morning Session: *Oxide Films and Breakdown*

Discussion Leader: Dr. Rob Kelly

- Speakers:
- \* Professor Masahiro Seo, Hokkaido University  
"Corrosion of Fe, Formation and Interfacial Properties of Oxide Films on Fe"
  - \* Professor G.T. Burstein, University of Cambridge  
"Oxide Films and Their Breakdown"

### Evening Session: *Localized Breakdown of Passive Films and New Microscopy Techniques*

Discussion Leader: Dr. Hugh Isaacs

- Speakers:
- \* Dr. Edward McCafferty, Naval Research Laboratory  
"Pitting and Its Inhibition"
  - \* Professor Richard Alkire, University of Illinois  
"Various Microscopic Techniques to Study Onset of Local Corrosion Events"

Tuesday, July 9 *Corrosion in Electronic and Communication Systems*

Discussion Leader and Organizer: Dr. Doug Sinclair, AT&T Bell Laboratories

Morning Session:

- Speakers:
- \* Dr. Robert Frankenthal, AT&T Bell Laboratories  
"Effect of AC and DC Power on the Corrosion of the Metal Shield in Coaxial Cables"
  - \* Dr. Vlasta Brusic, Cabot Corporation  
"Use of Organic Inhibiting Films in the Electronic Industry"

Evening Session:

- Speakers:
- \* Dr. Gerald Frankel, Ohio State University  
"Corrosion of Electronics - Future Problems and Challenges"
  - \* Dr. Jim Anderson, Ford Research Laboratory  
"A Systematic Experimental Approach to Processing and Performance Windows to Insure Reliability of Electronic Devices Operating under Harsh Environmental Conditions"

Panel Discussion: Frankenthal, Brusic, Frankel, Anderson

Wednesday, July 10 *Coatings and Corrosion Protection*

Discussion Leader and Organizer: Dr. Gordon Bierwagen, North Dakota State University

Morning Session:

- Speakers:
- \* Professor Pier Luigi Bonora, University of Trento  
"Corrosion Control by Coatings: Achievements and Trends"
  - \* Dr. Carol Jeffcoat, North Dakota State University  
"Effects of Thermal Transitions in Organic Coatings on Their Electrochemical and Corrosion Protection Properties"

Evening Session:

- \* Dr. Steven Tait, S.C. Johnson and Son  
"Where Are We With Predicting Coated Metal Lifetimes?"
- \* Dr. Rudy Buchheit, Sandia National Laboratory  
"Scientific Strategies Versus Technological Barriers in the Development of Environmentally Acceptable Alternatives to Corrosion Resistant Conversion Coatings for Aluminum Alloys"

Thursday, July 11 Morning Session: Microscopy and Localized Breakdown of Passive Films

Discussion Leader: Professor Florian Mansfeld

- Speakers:
- \* Professor J.W. Schultze, University of Dusseldorf  
"Microelectrochemical, Spectroscopic and AFM Investigations of Single Grains of Polycrystalline Metal Surfaces"
  - \* Dr. Patrick James, University of Minnesota  
"Microvisualization of Corrosion Events"

Evening Session: Chemical and Mechanical Effects on Oxide Film Adhesion and Fracture

Discussion Leader: Dr. Paul Natishan

- Speakers:
- \* Professor W.W. Gerberich, University of Minnesota  
"Nanomechanical Probing of Chemo-Mechanical Interactions at Surfaces"
  - \* Professor David J. Duquette, Rensselaer Polytechnic Institute  
"Electrochemistry in Chemical-Mechanical Polishing of Electronic Materials"

## SPEAKER LIST

Professor Richard C. Alkire  
Vice Chancellor for Research  
University of Illinois  
Urbana, IL 61801-3731

Phone: (217) 333-0034  
Fax: (217) 244-3716  
e-mail:

"Various Microscopic Techniques to Study Onset of Local Corrosion Events"

Dr. Jim Anderson  
MD 3083  
Ford Research Laboratory  
P.O. Box 2053  
Dearborn, MI 48121-2053

Phone: (313) 594-1187  
Fax: (313) 594-2923  
e-mail: jander17@ford.com

"Processing/Performance Windows that Insure Reliability with Respect to Environmental Effects"

Professor Pier Luigi Bonora  
Laboratory of Electrochemistry  
Department of Materials Engineering  
University of Trento  
(Trento) 38050  
Mesiano, ITALY

Phone: 39-461-882488  
Fax: 39-461-881977  
e-mail:

Corrosion Control by Coatings: Achievements and Trends"

Dr. Vlasta Brusic  
Cabot Corporation  
Aurora, IL 60504

Phone: (708) 585-9471  
Fax: (708) 585-9976  
e-mail: vbrusic%tuscola#@cabot.geis.com

"Use of Organic Inhibiting Films in the Electronic Industry"

Dr. Rudy Buchheit  
Sandia National Laboratory  
P.O. Box 5800, MS 0340  
Albuquerque, NM 87185

Phone: (505) 844-6904  
Fax: (505) 844-7910  
e-mail: rgbuchh@sandia.gov

"Scientific Strategies Versus Technological Barriers in the Development of Environmentally Acceptable Alternatives to Corrosion Resistant Conversion Coatings for Aluminum Alloys"

Professor G.T. Burstein  
University of Cambridge  
Department of Materials Science and Metallurgy  
Pembroke Street, Cambridge, CB2 3QZ  
United Kingdom

Phone: 44-122-333-4361  
Fax: 44-122-333-4567  
e-mail:

"Oxide Films and Breakdown"

Professor David J. Duquette  
Rensselaer Polytechnic Institute  
Materials Engineering  
Troy, NY 12181

Phone: (518) 276-6490  
Fax: (518) 276-6459  
e-mail: duqued@rpi.edu

"Electrochemistry in Chemical-Mechanical Polishing of Electronic Materials"

Dr. Gerald Frankel  
Department of Materials Science and Engng  
Ohio State University  
Columbus, OH 43210

Phone: (614) 688-4128  
Fax: (614) 292-1537  
e-mail: Frankel.10@osu.edu

"Corrosion of Electronics - Future Problems and Challenges"

Dr. Robert P. Frankenthal  
AT&T Bell Laboratories  
MH 1D-352  
600 Mountain Avenue  
Murray Hill, NJ 07974

Phone: (908) 582-4032  
Fax: (908) 582-3609  
e-mail:

"Effect of AC and DC Power on the Corrosion of the Metal Shield in Coaxial Cables"

Professor W.W. Gerberich  
Dept of Chem Eng and Mat Sci  
151 Amundson Hall  
University of Minnesota  
Minneapolis, MN 55455

Phone: (612) 625-8548  
Fax: (612) 626-7246  
e-mail: wgerb@maroon.tc.umn.edu

"Nanomechanical Probing of Chemo-Mechanical Interactions at Surfaces"

Dr. Pat James  
Corrosion Research Center  
221 Church St. SE  
University of Minnesota  
Minneapolis, MN 55455

Phone: (612) 624-0281  
Fax: (612) 626-7246  
e-mail: james@itasca.cems.umn.edu

"Microvisualization of Corrosion Events"

Dr. Carol Jeffcoate  
North Dakota State University  
Polymers and Coatings Department  
Fargo, ND 58105

Phone:  
Fax:  
e-mail:

"Effects of Thermal Transitions in Organic Coatings on Their Electrochemical and Corrosion Protective Properties"

Dr. Edward McCafferty  
Naval Research Laboratory  
Code 6314  
Washington, DC 20375-0001

Phone: (202) 767-2349  
Fax: (202) 404-7297  
e-mail: mccafferty@anvil.nrl.navy.mil

"Breakdown of Passivation and Its Inhibition"

Dr. Patrik Schmuki  
Institute for Microstructural Sciences  
National Research Council of Canada  
Montreal Road, Bldg. M-50, Room 190G  
Ottawa, Ontario K1A 0R6  
Canada

Phone: (613) 993-2518  
Fax: (613) 993-6337  
e-mail: schmuki@M50sci.lan.nrc.can

"in situ XANES of Artificial Fe and Cr Oxide Passive Films"

Professor J.W. Schultze  
Heinrich-Heine-University of Dusseldorf  
Institute for Physical Chemistry and  
Electrochemistry  
40225 Dusseldorf  
Germany

Phone: 49-211-81-14750  
Fax: 49-211-811-2803  
e-mail:  
joachimw.schultze@uni.duesseldorf.de

"Microelectrochemical, Spectroscopic and AFM Investigations of Single Grains of  
Polycrystalline Metal Surfaces"

Professor Masahiro Seo  
Graduate School of Engineering  
Hokkaido University  
Kita-13 Jo, Nishi-8 Chome, Kita-ku  
Sapporo 060  
Japan

Phone: 81-11-706-6735  
Fax: 81-11-706-7881  
e-mail: seo@icnet.hokudai.ac.jp

"Corrosion of Fe, Formation and Interfacial Properties of Oxide Films on Fe"

Dr. Steven Tait  
S.C. Johnson and Son  
1525 Howe  
Racine, WI 53403

Phone: (414) 260-2518  
Fax: (414) 260-4420  
e-mail: stait@sct.com

"Where Are We With Predicting Coated Metal Lifetimes?"

Dr. Michael F. Toney  
IBM Almaden Research Center  
650 Harry Road  
San Jose, CA 95120

Phone: (408) 927-1182  
Fax: (408) 927-2100  
e-mail: toney@almaden.ibm.com

"X-ray Diffraction Measurements on Anodic Oxide Films"

## DISCUSSION LEADERS

Professor Gordon Bierwagen  
North Dakota State University  
Polymers and Coatings Department  
Fargo, ND 58105

Phone: (701) 231-8294  
Fax: (701) 231-8439  
e-mail: bierwage@plains.nodak.edu

Dr. Alison Davenport  
Manchester Materials Science Centre  
University of Manchester/UMIST  
Grosvenor Street  
Manchester M1 7HS  
U.K.

Phone: 44-161-200-3560  
Fax: 44-161-200-3586  
e-mail: a.davenport@umist.ac.uk

Dr. Hugh Isaacs  
Brookhaven National Laboratory  
Bldg 480  
Upton, NY 11973

Phone: (516) 282-4516  
Fax: (516) 282-4071  
e-mail:

Dr. R.G. Kelly  
Department of Materials Science and  
Engineering  
University of Virginia  
Charlottesville, VA 22903

Phone: (804) 982-5783  
Fax: (804) 982-5799

e-mail: rgkelly@virginia.edu

Professor Florian B. Mansfeld  
Dept. of Materials Science, VHE 714  
University of Southern California  
Los Angeles, CA 90089-0241

Phone: (213) 740-4428  
Fax: (213) 740-7797  
e-mail:

Dr. Paul M. Natishan  
Naval Research Laboratory  
Code 6314  
Washington, DC 20375-0001

Phone: (202) 767-9255  
Fax: (202) 404-7297  
e-mail: natishan@anvil.nrl.navy.mil

Dr. Doug Sinclair  
AT&T Bell Labs  
1D 259  
PO Box 636  
Murray Hill, NJ

Phone: (908) 582-3345  
Fax: (908) 582-3574  
e-mail: ntcg@clockwise.att.com