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Final Technical Report

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PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
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The Aqueous Electrochemistry of Polyacetylene, (CH)<sub>x</sub>, and Polyparaphenylene (unclassified)

Alan G. MacDiarmid

Final

FROM 5/1/83 TO 9/30/86

88/4/30

19

synthesis, doping, electrochemistry, magnetic and electronic properties, epitaxial polymerization, biphenyl (TES)

Polyacetylene, (CH)<sub>x</sub>, and polyaniline, two completely different types of conducting polymers, i.e., organic polymers which upon doping exhibit the electrical, electronic, and magnetic properties of metals while retaining the mechanical and related properties characteristic of conventional polymers, have been investigated. Studies include the synthesis, doping, electrochemistry and selected physical properties of these materials. It has been found that the polyacetylene chains in trans-(CH)<sub>x</sub> lie parallel to the fibril axis and that the electrical and optical properties are consistent with the principal pi electrical transport occurring along the (CH)<sub>x</sub> chains. Polyacetylene can be epitaxially polymerized from the gas phase on to single crystal faces of biphenyl which have been coated with a very thin layer of catalyst. The electrochemistry of polyacetylene in both aqueous and non-aqueous electrolytes has been investigated with the objective of evaluating its use as electrode-active material in rechargeable batteries. It serves as a reasonably good cathode in an aqueous electrolyte in a rechargeable battery configuration. Polyacetylene can be p-doped by oxygen in an aqueous acid electrolyte to ~ 3 S/cm and is

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Block 18, continued

rechargeable batteries, fuel cells, oxygen-doping, emeraldine, protonic acid doping, aqueous and non-aqueous electrolytes, polyacetylene, polyaniline

Block 19, continued

shown to have potential as a reversible oxygen-electrode in a fuel cell configuration. It is shown that the chemical and electrochemical p- and n-doping of polyacetylene can be simply explained on the basis of the redox potentials of the doping agents and polyacetylene.

The base form of the emeraldine oxidation state of polyaniline can be doped to the metallic conducting regime by aqueous protonic acids such as HCl. This non-redox doping phenomenon introduces a completely new concept to the conducting polymer field. A study of the electrochemistry of polyaniline in propylene carbonate shows that it acts as an excellent cathode-active material in rechargeable batteries employing a lithium metal anode.

OFFICE OF NAVAL RESEARCH

FINAL TECHNICAL REPORT

FOR

Contract N00014-83-K-0209

Task No. NR-356-842

May 1, 1983 to April 30, 1986

(No-cost extension to September 30, 1986)

"The Aqueous Electrochemistry of Polyacetylene,  $(CH)_x$ , and

Polyparaphenylene"

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## 1. SUMMARY OF WORK PERFORMED

This investigation has been concerned with the synthesis, doping, electrochemistry and selected physical studies of two completely different kinds of conducting polymers i.e. organic polymers which exhibit the electrical, magnetic and electronic properties of metals while retaining the mechanical and related properties characteristic of conventional polymers.

The 26 papers and/or chapters in established scientific journals or monographs, and two issued patents, published on work performed during this three year period and supported in whole or in part as noted in the listing of each article given in Section 2 of this report by this contract have been concerned with

- (a) polyacetylene
- and (b) polyaniline

The principal findings are summarized below (together with the corresponding paper number as given in Section 2) for each of the above polymers.

### A. Polyacetylene, (CH)<sub>x</sub>

We have shown in a very important study (#1) that the (CH)<sub>x</sub> chains in trans-(CH)<sub>x</sub> lie parallel to the fibril axis and that the electrical and optical properties are consistent with the principal pi electrical transport occurring along the (CH)<sub>x</sub> chains.

It was found that (CH)<sub>x</sub> could be epitaxially polymerized from the gas phase on to single crystal faces of biphenyl which had been coated with a very thin layer of Et<sub>3</sub>Al/Ti(OBu)<sub>4</sub> catalyst (#3). This was the first example of

epitaxial polymerization of  $C_2H_2$  to form  $(CH)_x$ . The partial alignment of the films so produced could be clearly observed by optical reflectance studies.

A particularly strong effort was made in understanding the electrochemistry of  $(CH)_x$  both in aqueous (#2, #5, #7, #11, #21, #22) and non-aqueous electrolytes (#16, #20, #24) with the objective of evaluating the use of this polymer as an electroactive material in rechargeable batteries. Our studies prior to this contract had evaluated  $(CH)_x$  as a novel cathode-active material in rechargeable batteries using non-aqueous electrolytes (#24). Work carried out under the present contract showed, surprisingly, that  $(CH)_x$  could also act as a reasonably good cathode in rechargeable batteries in aqueous electrolytes (#2, #5, #7, #11, #21, #22). This observation was completely unexpected since it had previously been believed that p-doped  $(CH)_x$  was rapidly hydrolyzed by aqueous media. However the above studies showed that in moderately acid solution, hydrolysis was greatly reduced.

One of the most unexpected observations was that  $(CH)_x$  could be p-doped by  $O_2$  (or air) in aqueous acid electrolyte to a moderately high conductivity (3 S/cm), (#9, #22). Previously it had been believed that  $O_2$  would rapidly destroy p-doped  $(CH)_x$  with complete loss of conductivity. The  $(CH)_x$  p-doped by  $O_2$  could be electrochemically reduced to reform the original undoped  $(CH)_x$ , thus proving that  $(CH)_x$  could act as a reversible  $O_2$  - electrode suggesting its possible potential application in fuel cells involving the use of air for the electrode involving the oxidation step (#9, #22).

The surprising results summarized above, including the stability of p-doped  $(CH)_x$  when immersed in aqueous media and the p-doping by  $O_2$  in aqueous media, together with our and others studies of the doping of  $(CH)_x$ , lead to a basic understanding of the whole phenomenon of p- and n-doping of  $(CH)_x$

which was summarized in several articles (#4, #10, #23). It was shown that all known chemical and electrochemical doping phenomenon involving  $(CH)_x$  could be correlated and explained in a simple manner on the basis of the known redox potentials of the doping agents and the redox potentials of  $(CH)_x$  which we had determined previously. It has subsequently become apparent that the p- and n-doping of all other conducting polymers (with the exception of polyaniline discussed in the following section) can probably be explained in a similar manner.

### B. Polyaniline

Our studies of the polyanilines, a large class of organic polymers, have shown that the emeraldine oxidation state of this class of polymer introduces a *completely new concept* into the field of conducting polymers in that it can be doped from the insulating through the semiconducting to the metallic regime by a simple protonic acid/base reaction (#7, #12, #13, #14, #15, #17, #18, #19, #25, #26). This doping process neither increases nor decreases the number of electrons on the polymer and hence differs from the doping of all other conducting polymers. Doping of all other conducting polymers occurs by an oxidation or reduction process i.e., by a process which either decreases or increases the number of electrons, respectively, in the polymer. Experimental and theoretical physicists both in the U.S.A. and abroad are currently working on this phenomenon.

We have also studied the electrochemistry of polyaniline (#16) and have two issued patents covering its use in rechargeable batteries in non-aqueous electrolytes. Batteries of this type are now being manufactured commercially in Japan.

As can be seen from the above brief summary and from the list of publications provided, this contract has proven to be most productive and has not only made very significant advances in the rapidly expanding field of conducting polymers but has also materially contributed to their technological use.

## 2. PUBLICATIONS AND PATENTS

### A. Papers

1. C. R. Fincher, D. Moses, A. J. Heeger and A. G. MacDiarmid, "Structure, Morphology and Electronic Properties of Trans-(CH)<sub>x</sub>", Synth. Met., 6, 243 (1983). (Supported by ONR and N.S.F.-M.R.L. Grant No. DMR-79-23647).
2. A. G. MacDiarmid, R. J. Mammone, S. J. Porter and N. L. D. Somasiri, "Polyacetylene, (CH)<sub>x</sub>, Electrodes in Batteries and Fuel Cells Using Aqueous Electrolytes", Extended Abstracts, Electrochemical Soc. Meeting 83-2, 145 (1983). (Supported by ONR, N.S.F.-M.R.L. Grant No. DMR-79-23647, and the Science and Engineering Research Council of the United Kingdom).
3. T. Woerner, A. G. MacDiarmid, A. Feldblum and A. J. Heeger, "Optical Anisotropy of Partially Aligned Polyacetylene Film Polymerized Directly from Gaseous Acetylene", J. Polym. Sci., Polym. Lett. Ed., 22, 119 (1984). (Supported by ONR and N.S.F. Grant No. DMR-80-22870).
4. A. G. MacDiarmid, R. J. Mammone, J. R. Krawczyk and S. J. Porter, "Reduction Potentials: Key to Doping Phenomena in Polyacetylene, (CH)<sub>x</sub>", Mol. Cryst. Liq. Cryst., 105, 89 (1984). (Supported by ONR, N.S.F.-M.R.L. Grant No. DMR-79-23647 and the Science and Engineering Research Council of The United Kingdom).
5. R. J. Mammone and A. G. MacDiarmid, "The Aqueous Chemistry and Electrochemistry of Polyacetylene, (CH)<sub>x</sub>", Synth. Met., 9, 143 (1984). (Supported by ONR and N.S.F.-M.R.L. Grant No. DMR-79-23647).

6. T. C. Chung, Y. Schlesinger, S. Etemad, A. G. MacDiarmid and A. J. Heeger, "Optical Studies of Pyrolyzed Polyacrylonitrile", *J. Polym. Sci.*, 22 1239 (1984). (Supported by ONR).
7. A. G. MacDiarmid, J. C. Chiang, M. Halpern, W. S. Huang, J. R. Krawczyk, R. J. Mammone, S. L. Mu, N. L. D. Somasiri and W. Wu, "Aqueous Chemistry and Electrochemistry of Polyacetylene and 'Polyaniline': Application to Rechargeable Batteries", *Polymer Preprints*, 25, 248 (1984). (Supported by ONR, N.S.F. Grant No. DMR-80-22870, N.S.F.-M.R.L. Grant No. DMR-79-23647 and D.O.E. Grant No. DE-ACO2-81-ER-10832).
8. S. I. Yaniger, M. J. Kletter and A. G. MacDiarmid, "Dependence of Physical and Electronic Properties of Polyacetylene,  $(CH)_x$ , on Conjugation Length", *Polymer Preprints*, 25, 264 (1984). (Supported by ONR and N.S.F., Grant No. DMR-80-22870).
9. R. J. Mammone and A. G. MacDiarmid, "p-Doping of  $(CH)_x$  to the Metallic Regime with Gaseous Oxygen: Application to Oxygen Fuel Cell Type Electrodes", *J. Chem. Soc., Faraday Trans. I*, 81, 105 (1985). (Supported by ONR).
10. A. G. MacDiarmid, R. J. Mammone, R. B. Kaner and S. J. Porter, "The Concept of 'Doping' of Conducting Polymers: The Role of Reduction Potentials", *Phil. Trans. R. Soc. Lond.* A314, 3 (1985). (Supported by ONR, N.S.F. Grant No. DMR-80-22870, N.S.F.-M.R.L. Grant No. DMR-79-23647 and the Science and Engineering Research Council of the United Kingdom).
11. W. Wanqun, R. J. Mammone and A. G. MacDiarmid, "Stability and Electrochemistry of Polyacetylene in Aqueous Media", *Synth. Met.*,

- 10, 235 (1985). (Supported by ONR, D.O.E. contract No. DE-ACO2-81-ER-10832 and the Government of the People's Republic of China).
12. A. G. MacDiarmid, J. C. Chiang, M. Halpern, W. S. Huang, S. L. Mu, N. L. D. Somasiri, W. Wu and S. I. Yaniger, " 'Polyaniline': Inter-conversion of Metallic and Insulating Forms", *Mol. Cryst. Liq. Cryst.* 121, 173 (1985). (Supported by ONR, N.S.F. Grant No. DMR-80-22870, N.S.F.-M.R.L. Grant No. DMR-82-16718, D.O.E. Grant No. DE-ACO2-81-ER-10832 and the Government of the People's Republic of China).
13. A. G. MacDiarmid, J. C. Chiang, W. S. Huang, B. D. Humphrey and N. L. D. Somasiri, "Polyaniline: Protonic Acid Doping to the Metallic Regime," *Mol. Cryst. Liq. Cryst.* 125, 309 (1985). (Supported by ONR, N.S.F. Grant No. DMR-80-22870 and N.S.F.-M.R.L. Grant No. DMR-82-16718).
14. W. S. Huang, B. D. Humphrey and A. G. MacDiarmid, "Polyaniline, A Novel Conducting Polymer: Morphology and Chemistry of its Oxidation and Reduction in Aqueous Electrolytes", *J. Chem. Soc. Faraday Trans.*, 1, 82, 2385 (1986). (Supported by ONR and N.S.F.-M.R.L. Grant No. DMR-82-16718).
15. A. G. MacDiarmid, J. C. Chiang, A. F. Richter and A. J. Epstein, "Polyaniline: A New Concept in Conducting Polymers", *Synth. Met.* 18, 285 (1987). (Supported by ONR and N.S.F.-M.R.L. Grant No. DMR-82-16718).
16. A. G. MacDiarmid, L. S. Yang, W. S. Huang and B. D. Humphrey, "Polyaniline: Electrochemistry and Application to Rechargeable Batteries," *Synth. Met.* 18, 393 (1987). (Supported by ONR and N.S.F.

Grant No. DMR-80-22870 and N.S.F.-M.R.L. Grant No. DMR 82-16718, and the Government of the Peoples' Republic of China).

17. A. J. Epstein, J. M. Ginder, R. W. Bigelow, H. S. Woo, D. B. Tanner, A. F. Richter, W. S. Huang and A. G. MacDiarmid, "Insulator-to-Metal Transition in Polyaniline", *Synth. Met.*, 18, 303 (1987). (Supported by ONR and N.S.F. Grant No. DMR-84-16511 and N.S.F.-M.R.L. Grant No. DMR-82-16718).
18. A. J. Epstein, J. M. Ginder, F. Zuo, H.S. Woo, D. B. Tanner, A. F. Richter, M. Angelopolous, W. S. Huang and A. G. MacDiarmid, "Insulator to Metal Transition in Polyaniline: Effect of Protonation in Emeraldine," *Synth. Met.* 21, 63 (1987). (Supported by ONR and N.S.F. Grant No. DMR-84-16511 and N.S.F.-M.R.L. Grant No. DMR-82-16718).
19. J. M. Ginder, A. F. Richter, A. G. MacDiarmid and A. J. Epstein, "Insulator-to-Metal Transition in Polyaniline," *Solid State Commun.* 63, 97 (1987). (Supported by ONR).

B. Chapters (or Sections) in Books

20. A. G. MacDiarmid, "Polyacetylene Batteries", Progress in Batteries and Solar Cells, H. Shimotake, Ed., Japanese Electrochem. Soc. Tokyo, p. 31 (1984). (Supported by ONR, N.S.F.-M.R.L. Grant No. DMR-79-23647 and D.O.E. contract No. DE-ACO2-81-ER-10832).
21. R. B. Kaner, A. G. MacDiarmid and R. J. Mammone, "Polyacetylene, (CH)<sub>x</sub>: An Electrode-Active Material in Aqueous and Nonaqueous Electrolytes", A.C.S. Symposium Series, Polymers in Electronics, 242, T. Davidson, Ed., A.C.S., Washington, D.C. p. 575 (1984). (Supported by ONR, and D.O.E. contract No. DE-ACO2-81-ER-10832).

22. A. G. MacDiarmid, R. J. Mammone, N. L. D. Somasiri and J. R. Krawczyk, "Fuel Cells and Batteries Employing Polyacetylene Electrodes in Aqueous Electrolytes", Energy Technology XI, R. F. Hill, Ed., Government Institutes, Inc., Washington, D.C., p. 577 (1984). (Supported by ONR and N.S.F.-M.R.L. Grant No. DMR-79-23647).
23. A. G. MacDiarmid and S. J. Porter, "Conducting Polymers: The Concept of p- and n-Doping", Conducting Polymer Materials, H. Sasabe, Ed., CMC Publishing Co., Tokyo, p. 204 (1984). (Supported by ONR, N.S.F.-M.R.L. Grant No. DMR-79-23647 and the Science and Engineering Research Council of The United Kingdom).
24. A. G. MacDiarmid and R. B. Kaner, "Electrochemistry of Polyacetylene,  $(CH)_x$ : Application to Rechargeable Batteries", Handbook on Conjugated Conducting Polymers, T. Skotheim, Ed., Marcel Dekker Inc., New York, 1, p. 689 (1986). (Supported by ONR, Department of Energy Contract No. DE-ACO2-81-ER-1083, N.S.F. Grant No. DMR-80-22870, and N.S.F.-M.R.L. Grant No. DMR-82-16718).
25. W. R. Salaneck, I. Lundstrom, B. Liedberg, M.A. Hasan, R. Erlandsson, P. Konradsson, A. G. MacDiarmid and N. L. D. Somasiri, "Spectroscopic Characterization of Some Polyanilines", Electronic Properties of Polymers and Related Compounds, H. Kuzmany, M. Mehring, S. Roth, Eds., Springer-Verlag, New York, p. 218 (1985). (Supported by ONR, NSF-M.R.L. Grant No. DMR-82-16718, and the Swedish Board for Technical Development and the Swedish Natural Science Research Council).
26. A. G. MacDiarmid, J.C. Chiang, A. F. Richter, N. L. D. Somasiri and A. J. Epstein, "Polyaniline: Synthesis and Characterization of the Emeraldine

Oxidation State by Elemental Analysis." Conducting Polymers, Luis Alcácer, Ed., Reidel Pub., Dordrecht, Holland, p. 105, (1987). (Supported by ONR and N.S.F.-M.R.L. Grant No. DMR-82-16718).

C. Patents Issued

1. U.S. Patent #4,442,187, filed December 1980, Issued April 10, 1984, A. G. MacDiarmid, A. J. Heeger and P. J. Nigrey, "Batteries Having Conjugated Polymer Electrodes". (Supported in part by ONR and N.S.F. Grant No. DMR-80-22870).
  
2. U.S. Patent # 4,728,589, filed August 1985, Issued March 1, 1988, A. G. MacDiarmid, A. J. Heeger, and P. J. Nigrey, "Reversible Electrochemical Doping of Conjugated Polymers and Secondary Batteries Based Thereon". (Supported in part by ONR and N.S.F. Grant No. DMR-80-22870).

3. HONORS, AWARDS, PRIZES

1. Alan G. MacDiarmid, Honorary Doctorate of Science, awarded by Elizabethtown College, Elizabethtown, PA, May 14, 1983.
2. Alan G. MacDiarmid, "1984 Chemical Pioneer" awarded by the American Institute of Chemists, June 3, 1984.
3. Alan G. MacDiarmid, 1985 "Top 100" Innovation Award, Science Digest.

4. PRESENTATIONS AT TOPICAL OR SCIENTIFIC/TECHNICAL SOCIETY CONFERENCES

May 1, 1983 - September 30, 1986

(All lectures given summarized work supported in part by ONR, N.S.F. Grant No. DMR-80-22870, N.S.F.-M.R.L. Grant Nos. DMR-79-23647, DMR-82-16718, and D.O.E. Grant No. DE-AC02-81-ER-10832).

1. 5/9-11/83 - Electrochemical Society Meeting session on Conducting Organic Polymers in Energy Conversion and Storage, San Francisco, CA, invited lecture: "The Electrochemistry of Polyacetylene: Application in High Power Density Rechargeable Batteries."
2. 5/23 - 26/83 - International Symposium on Structure and Bonding in Noncrystalline Solids, Reston, VA, invited lecture: "Polyacetylene,  $(CH)_x$ , the Prototype Conducting Polymer" (Conference sponsored in part by ONR).
3. 5/28-6/4/83 - ASEA Centennial Conference, Stockholm, Sweden, invited lecture: "Polyacetylene,  $(CH)_x$ , the Prototype Conducting Polymer."
4. 6/15-17/83 - Allied Course on Conducting Polymers, Institute in Science and Technology, State University of New York, New Paltz, NY, invited lecture: "Polyacetylene: Synthesis, Properties and Chemistry of the Doping Process."
5. 7/11, 12/83 - Materials Research Council, Workshop on Electrochemical Energy Sources, La Jolla, CA, lecture: "Polyacetylene, A Material for Batteries" (Conference sponsored by DARPA).
6. 8/20 - 23/83 - Synthetic Metals II, Los Alamos, NM, invited lecture: "The Aqueous Chemistry and Electrochemistry of Polyacetylene."
7. 8/25 - 26/83 - Symposium on Order in Polymeric Materials, GTE, Waltham, MA, invited lecture: "The Aqueous Chemistry and Electrochemistry of Polyacetylene."
8. 8/29 - 31/83 - American Chemical Society, Washington, DC, Symposium on Advanced Batteries, invited lecture: "A Review of Conductive Polymer Batteries."

9. 10/6/83 - Case Western Reserve University, Frontiers in Chemistry Lecture Series, invited lecture: "Polyacetylene,  $(\text{CH})_x$ , The Prototype Conducting Polymer."
10. 10/10 - 11/83 - Electrochemical Society, Washington, DC, Symposium on Advances in Battery Materials and Processes, lecture: "Polyacetylene,  $(\text{CH})_x$ , Electrodes in Batteries and Fuel Cells Using Aqueous Electrolytes."
11. 11/1/83 - Dow Corning, Midland, Michigan, invited lecture: "Polyacetylene,  $(\text{CH})_x$ , The Prototype Conducting Polymer."
12. 11/20 - 22/83 - The American Physical Society, San Francisco, CA, talk: "p-Doping of  $(\text{CH})_x$  to the Metallic Regime with Gaseous Oxygen: Potential Application to  $\text{O}_2$  - Fuel-Cell Type Electrodes."
13. 12/2-3/83 - University of Minnesota, Minneapolis, Minnesota, Symposium on Organic Chemistry and Microelectronics, invited lecture: "Polyacetylene,  $(\text{CH})_x$ , The Prototype Conducting Polymer."
14. 12/12 - 15/83 - Army Research Office, Charleston, SC, Working Group meeting on Principles and Applications of Electrochemistry, invited lecture: "Conducting Polymer Batteries."
15. 2/7/84 - Auburn University, Auburn, Alabama, Winter Quarter Chemistry Colloquium, invited lecture: "Polyacetylene,  $(\text{CH})_x$ : The Prototype Conducting Polymer."
16. 2/23/84 - U.S. Patent Office, Washington, DC, invited lecture: "Polyacetylene,  $(\text{CH})_x$ , the Prototype Conducting Polymer: Synthesis, Structure and Applications to Batteries, Fuel Cells and Photovoltaic Devices."
17. 3/19-21/84 - 11th Energy Technology Conference and Exposition, Washington, DC, lecture: "Fuel Cells and Batteries Employing Polyacetylene Electrodes in Aqueous Electrolytes."
18. 4/8-13/84 - American Chemical Society, St. Louis, Missouri, Symposium on the Interface Between Polymer Chemistry and Inorganic Chemistry, invited lecture: "Aqueous Chemistry and Electrochemistry of Polyacetylene,  $(\text{CH})_x$ ."

19. 4/23-26/84 - American Physical Society, Washington, DC, talk: "New Concepts in Doping Polyacetylene: Use of Protonic Acids and Gaseous Oxygen."
20. 4/26/84 - University of Alabama, Tuscaloosa, AL, Ramsay Lecture: "From Organic Metals to Organic Batteries."
21. 5/9 - 10/84 - Conference on High Performance Polymers, London, England. invited lectures: "Current Developments in Polymer Technology in United States" and "Conducting Polymers—Their Scope and Applications."
22. 5/15/84 - North Carolina University, Raleigh, NC, Conference on Industrial Science and Technological Innovation, invited lecture: "Conducting Polymers."
23. 5/21/84 - Johnson Wax, Racine, Wisconsin, Johnson Rondelle Seminar Series, invited lecture: "Polyacetylene,  $(CH)_x$ : the Prototype Conducting Polymer."
24. 5/31-6/1/84 - The Royal Society, London, England, Discussion meeting on Electrical and Magnetic Properties of Low-dimensional Solids, invited lecture: "The Concept of Doping of Conducting Polymers: The Role of Reduction Potentials."
25. 6/3-6/84 - American Institute of Chemists, Montreal, Quebec, Canada, Chemical Pioneer Award Lecture: "Polyacetylene,  $(CH)_x$ : the Prototype Conducting Polymer."
26. 6/4-8/84 - Oakland University, Rochester, Michigan, Meadowbrook Conference on Conducting Polymers, invited lecture: on "Aqueous Chemistry and Electrochemistry of Polyacetylene: Application to Rechargeable Batteries," (Conference sponsored by ONR).
27. 6/17-22/84 - International Conference on the Physics and Chemistry of Low-Dimensional Synthetic Metals, Abano Terme, Italy, invited lecture: "Synthesis and Properties of a form of 'Polyaniline' Conducting in the Metallic Regime;" and poster: "Applications of Polyacetylene and 'Polyaniline' to Batteries and Fuel Cells Employing Aqueous Electrolytes."
28. 6/26/84 - Queen Mary College, London, England, Conference on Electrical Conduction in Polymers II, invited lecture: "Oxygen Doping of Polyacetylene,  $(CH)_x$ , to the Metallic Regime: Application to Fuel Cell-type Electrodes."

29. 7/24/84 - Princeton University, Princeton, NJ, Woodrow Wilson Dreyfus Summer Institute, invited lecture: "Organic Metals."
30. 7/30-8/3/84 - Gordon Research Conference on Dielectric Phenomena, Plymouth, NH, invited lecture: "Polyacetylene,  $(CH)_x$ : the Prototype Conducting Polymer."
31. 8/27-31/84 - American Chemical Society, Philadelphia, PA, Breakthrough Lecture: "Synthetic Metals: A New Role for Organic Polymers;" and poster: "Aqueous Chemistry and Electrochemistry of Polyacetylene and 'Polyaniline': Application to Rechargeable Batteries."
32. 9/25/84 - Cornell University, Ithaca, NY, invited lecture: "Polyacetylene,  $(CH)_x$ : the Prototype Conducting Polymer."
33. 10/25/84 - American Chemical Society, Symposium on Advances in Chemistry for Electronics, Rochester, NY, invited lecture: "Synthetic Metals: A New Role for Organic Polymers."
34. 10/31-11/2/84 - American Chemical Society, Midwest Regional Meeting, Springfield, Missouri, invited lecture: "Synthesis and Properties of a form of 'Polyaniline' Conducting in the Metallic Regime."
35. 12/16-22/84 - International Chemical Congress of Pacific Basin Societies, Honolulu, Hawaii, Symposium on Spectroscopic Techniques in Inorganic Chemistry, invited lecture: "Application of Electrochemical Voltage Spectroscopy and Related Techniques in the Study of Conducting Polymers;" and Symposium on Horizons in the Chemistry and Properties of Low-Dimensional Solids, poster: "Synthesis and Properties of an Air and Water Stable form of 'Polyaniline' Conducting in the Metallic Regime."
36. 3/25-29/85 - American Physical Society, Baltimore, MD, talks: "Protonic Acid Doping: A New Approach for Converting Organic Polymers to the Metallic State" (by A. G. MacDiarmid); "Characteristics of Polyaniline Cathodes and Anodes in Aqueous Electrolytes" (by N.L.D. Somasiri); "Electrochemical and Electronic Properties of Polyaniline" (by B. D. Humphrey); and "Relationship Between Physical and Electronic Properties of Polyacetylene and Conjugation Length" (by G. A. Arbuckle).

37. 4/9-12/85 - Synthetic Metals III, Los Alamos, NM, invited lecture: "Protonic Acid Doping: A New Method for Converting Organic Polymers to the Metallic State."
38. 4/28-5/3/85 - American Chemical Society, Miami, FL, invited lecture: "Protonic Acid Doping: A New Approach for Converting Organic Polymers to the Metallic State."
39. 5/12-17/85 - The Electrochemical Society, Toronto, Ontario, Canada, invited lecture: "Polyaniline: Application as an Anode and Cathode Material in Rechargeable Batteries Employing Aqueous Electrolytes."
40. 5/21-22/85 - Oak Ridge National Laboratory and University of Tennessee, Knoxville, TN, invited lecture: "Synthetic Metals: A New Role for Organic Polymers."
41. 9/8-13/85 - American Chemical Society, Chicago, IL, Symposium on Materials in Emerging Technologies, invited lecture: "Synthetic Metals: A New Role for Organic Polymers."
42. 10/7-9/85 - Brookhaven National Laboratory, Upton, NY, Workshop on Conducting Polymers, invited lecture: "Polyaniline: A New Concept in Conducting Polymers."
43. 10/16-18/85 - Short Course on Conducting Polymers: Polymeric Organic Metals and Semiconductors, State University of New York, New Paltz, NY, invited lecture: "Applications of Conducting Polymers to Rechargeable Batteries and Fuel Cells."
44. 1/20-24/86 - Gordon Conference on Electrochemistry, Santa Barbara, CA, invited lecture: "Electrochemistry of Polyaniline: Applications to Rechargeable Batteries."
45. 3/2-6/86 - TMS Conference on Electrical Properties of Organic Materials, New Orleans, LA, invited lecture: "Polyaniline: An Inexpensive Environmentally Stable Conducting Polymer."
46. 7/28-31/86 - Workshop on Conducting Polymers, U.S. Army Research, Development and Standardization Group, Sintra, Portugal, invited lecture: "Polyaniline: A New Concept in Conducting Polymers."

47. 9/7-12/86 - American Chemical Society, Anaheim, CA, Symposium on Chemistry, Electrochemistry and Electronic Properties of Conducting Polymers, invited lecture: "Cycling Studies of the Reduced Polyacetylene Electrode" (by R. B. Kaner).

48. 9/15-17/86 - Case Western Reserve University, Cleveland, OH, Symposium on Electrochemistry as an Emerging High Tech Area, invited lecture: "Conducting Polymers."

5. PERSONNEL WHO RECEIVED FULL OR PARTIAL SUPPORT ON  
ONR CONTRACT #N00014-83-K-0209

	<u>Period of Support</u>	<u>Degree Awarded</u>	<u>Subsequent Employment</u>
<u>Principal Investigator:</u>			
Alan G. MacDiarmid	2 summer months each year		
<u>Co-Investigator</u>			
Alan J. Heeger	5/83 - 6/83, 1 mon. summer		Physics Dept., Univ. of Calif., Santa Barbara
<u>Graduate Students</u>			
Robert J. Mammone	5/83 - 3/85	Ph.D.	Army ERADCOM
WuSong Huang	5/85 - 2/86	Ph.D.	Post-Doc, IBM
Alan J. Richter	5/85 - 9/86		Continuing on ONR/URI Contract
<u>Post Doctoral Fellows</u>			
Stuart I. Yaniger	8/84 - 7/85		Nicolet Instrument Co.
Brian D. Humphrey	8/85 - 7/86		Professor, Montclair State College
Robert Demitras	9/84 - 5/85		Deceased
Mei Xiang Wan*	9/85 - 8/86		Professor, Beijing Univ., China
<u>Undergraduate</u>			
John Krawczyk	7/83 - 8/85		Graduate school, Univ. of Florida

\*Partial support