DOE/ER/45409--3

DE93 010140

Final Progress Report

for

"Photomodulation Spectroscopy of Photocarrier Dynamics, Electronic Defects and Morphology of Conducting Polymers"

by

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MAR 29 1993
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to

U.S. Department of Energy
Division of Material Science

Grant No. DE-FG02-89ER45409

~~SHOULD BE DE-FG02-89ER45409?~~

Duration: 42 months

From

October 1, 1989

To

March 31, 1993

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Table of Contents

FINAL PROGRESS REPORT
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"Photomodulation Spectroscopy of Photocarrier Dynamics, Electronic Defects and Morphology of Conducting Polymers"

I. INTRODUCTION

This is the final progress report on the activities associated with the DOE grant to the Physics Department of the University of utah, starting on October 1, 1989, on photocarrier dynamics, electronic defects and morphology of conducting polymers using the photomodulation spectroscopy. During the period covered by this grant we have achieved impressive results and have started new studies, hopefully to be completed during the grant continuation period covered by the renewal proposal. First we will introduce our two newly developed experimental techniques and then we will describe our progress made according to the material studied, since this is the best method to summarize our accomplishments. We have used a variety of techniques in our studies such as: CW photomodulation, photomodulation in the femtosecond and picosecond time ranges, CW resonant Raman scattering, transient photoinduced Raman scattering, electro-absorption, degenerate four-wave mixing and the newly technique of spin dependent photomodulation. These techniques have been used to obtain the transient electronic response of the studied conducing polymers.

II. ACCOMPLISHMENTS

(A) New Experimental Techniques

During the grant period of 89-93 we have developed two new experimental techniques and have applied them for the first time in the field of conductivity polymers. These are the absorption detected magnetic resonance (ADMR) and the transient photoinduced resonant Raman scattering (TPRRS), to be described as follow.

(1) Absorption Detected Magnetic Resonance

We have devised a novel technique, the absorption detected magnetic resonance (ADMR) to elucidate the spin quantum numbers associated with photoexcitations as observed in their optic transitions. Generally, in ADMR, changes in the strength of photoinduced optical transitions (photomodulation (PM) intensity) are measured as a function of magnetic field H applied to a sample irradiated simultaneously with both microwave photons (3-16 GHz) and photons of energy greater than the optical gap (or S_1 - S_0 transition energy). The latter produces the excited states, for example, singlet and triplet excitons, polarons, bipolarons, solitons, etc, whereas the former induce absorption between states (Δm_s) split by H (Zeeman splitting). This technique is similar to the optical detected magnetic resonance (ODMR) technique, except that changes in

PM, not photoluminescence, are recorded: ADMR is, therefore, more versatile than ODMR because it does not require radiative recombination.

The ADMR set-up consists of a pump beam (usually a laser) to excite the material and a probe beam from an incandescent light source dispersed by a monochromator (in the spectral range of 0.25 to 3.5 eV). The sample is placed in a high Q value μ wave cavity equipped with optical windows for transmission; the cavity is placed in a dewar in a superconducting magnet. The RF field of the μ waves is modulated with a frequency f and changes ΔT in the probe transmission T are recorded with a lock in amplifier referenced to f, as a function of H. When a resonant H is determined at a fixed probe wavelength, then H is fixed and a spectrum of ΔT as a function of probe photon energy is obtained. $\Delta T/T$ is proportional to the change in the steady state density of photoexcitations caused by the μ wave absorption, thus ΔT is nonzero only if some of the photoexcitations carry spins or are associated with spin-dependent generation of recombination processes.

The ADMR technique is quite general and can be applied to semiconductors, conducting polymers, defects in insulators, CDW materials, MX chains, etc. So far we have applied the ADMR technique to several conducting polymers and amorphous semiconductors. We have used the ADMR technique for studying photoexcitations by determining their energy levels in the PM spectrum as well as their spin and charge states, in trans-polyacetylene, soluble derivatives of poly(paraphenylenevinylene) and polythiophene and also in polydiacetylene single crystals. From our preliminary results we verified the photogeneration of stable charged photoexcitations, which are solitons in polyacetylne, the unique degenerate ground state conducting polymer, and polarons and bipolarons in the other, non degenerate, polymers. However, the highlight of our results is the finding of neutral photoexcitations with non-zero spins in all conducting polymers. This happens if a fast intersystem crossing occurs between the excited odd symmetry B_U state into the even symmetry $2A_g$ state; the latter cannot decay into charged excitations. We found that the neutral photoexcitations in trans-polyacetylene are spin ½ neutral solitons (S°) with an optical transition at 1.35 eV, providing a definitive explanation to the long standing puzzle associated with this spectral feature. On the other hand, in the nondegenerate conducting polymers studied, the neutral photoexcitations form triplet ($S=1$) excitons which cannot dissociate into $S^\circ\bar{S}^\circ$ pairs due to the confinement caused by their backbone structure.

(2) Transient Photoinduced Resonant Raman Scattering

The transient photoinduced Raman scattering is not an entirely new technique, like the ADMR. It was applied before in polymers, with subnanosecond time resolution. However, its picosecond version using two dye lasers for pump and probe in the spectral range of resonant absorption, is completely new. Our technique is transient photoinduced resonant Raman scattering (TPRRS) with picosecond resolution, in which the transient response of individual resonantly enhanced phonons in the system can be separately monitored with different pump-probe wavelengths.

This is a very powerful technique for mixed systems such as partially polymerized polyacetylene $(CH)_x$, where the phonons of the constituents have different resonances. Since the strongly coupled resonant vibrations in *cis* and *trans* $(CH)_x$ have different frequencies and since their intensities in resonant Raman scattering (RRS) can be influenced separately by photoexcitations in *cis* and *trans* segments, respectively, the photoexcitations dynamics in *cis* could be obtained by monitoring the TPRRS response of the *cis*- $(CH)_x$ phonons. We observed, (ref. A14) for the first time, a fast migration of photoexcitations from *cis* into *trans* segments, which is dominated by a diffusion process in the *cis* segements. This was possible to observe only by TPRRS.

Our time-resolved resonant Raman experiments use two short, pump and probe, laser pulses. In the course of photoexcitation, the sample is pumped into an excited state or undergoes a photochemical reaction. A time-delayed, weak probing pulse then monitors the instantaneous state of the medium, and initiates transient Raman spectra from the excited state of the segments. This is a variation of the well-known pump and probe technique. By adjusting the separation of the ultrashort laser pulses in time, transient Raman scattering with picosecond time resolution can be measured. By adjusting the frequencies of the pump and probe laser pulses, resonance effects can be investigated. Although transient photoinduced absorption (PA) provides information about photoexcited carrier relaxation, sometimes it also includes other contributions such as thermal effects, strain waves, and energy transfer (Ref. A3). In contrast, TPRRS can be regarded as being proportional only to the population of the excited states, and therefore, it shows real photoexcited carrier relaxation dynamics. Such a signal can provide clearer information about electronic relaxation processes than PA measurements. Moreover, transient Raman scattering contains considerably more information than transient PA because the decay of the individual vibrations in TPRRS spectra can be studied separately.

Picosecond TPRRS spectra were excited using a mode-locked Nd:YAG laser which was frequency doubled and synchronously pumped two dye lasers (pump and probe) producing pulses typically with 2-ps time durations and 0.2-nJ energies at a repetition rate of 76 MHz. The time resolution of the system, as estimated by the cross correlation of the dye laser pulses in potassium dihydrogen phosphate, was about 5 ps. The pump and probe beams were focused onto the sample through a sapphire substrate using an achromatic lens, and complete overlap was assured by maximizing the PA signal. The Raman scattering was monitored in the forward direction using a triple spectrograph with 3-cm^{-1} resolution coupled to a multichannel charge-coupled device detector. Spectra were recorded with different time delays τ between pump and probe. Collection of a single TPRRS spectrum at a fixed pump-probe delay τ required recording four data sets (1) RRS scattered intensity I_A excited by the pump beam alone; (2) I_B excited by the probe beam along; (3) I_{A+B} excited by both beams simultaneously; and (4) I_C which measured the background spectrum without laser excitation. The TPRRS signal is the change ΔI in the probe RRS intensity I_B induced by the pump beam. The ΔI spectrum is then obtained by subtracting: $\Delta I = I_{A+B} + I_C - (I_A + I_B)$. To obtain a satisfactory signal-to-noise ratio, between 4 and 10 spectra at each τ were averaged.

Under resonance conditions we usually got negative ΔI for TPRRS (Ref. A14, A21, and A22). The TPRRS sign can be readily explained by a reduction in the RRS cross section associated with real photoexcitations which block the electronic transitions available in the absence of the pump beam. Similar bleaching of transitions occurs in the PA spectrum resulting in increased transmission: $\Delta T > 0$. For our sample $\Delta I/I$ ($\approx 2 \times 10^{-2}$) was larger than $\Delta T/T$ ($\approx 3 \times 10^{3}$) [A14] and this can be explained using the phase space filling (PSF) model [A22] to describe $\chi^{(3)}$, which influences both TPRRS and transient PA signals. It is proportional to the density ratio of the photoexcited excitons N_x and the excitons at saturation N_S ($\chi^{(3)} \sim N_x/N_s$). Using this form of $\chi^{(3)}$, we calculated for TPRRS $\Delta I/I = 2N_x/N_s$, whereas for PA $\Delta T/T = \alpha d N_x/N_s$, where αd is the optical density (OD) of the sample film. Consequently, $\Delta I/I = (2/OD) \times \Delta T/T$, and since for our thin films $OD < 0.2$ at 750 nm, this explains the larger $\Delta I/I$ signal for the TPRRS that we got.

(B) Photoexcitation Dynamics in Conducting Polymers

We will now mention the main accomplishments of our studies in conducting polymers by summarizing the main results obtained in each group of polymers:

(1) Polyacetylene

We have used the ADMR technique at 3 GHz to study the spin states of photoexcitations in trans $(CH)_x$ (A18) and in trans segments in partially isomerised $(CH)_x$ (B_{11}). We have verified that the charged photoexcitations are solitons ($S^{\pm}$). However, we observed, for the first time (A18), that the neutral photoexcitations in t-$(CH)_x$ are neutral solitons ($S^{\bullet}$) with spin ½. In short segments of trans in partially isomerized $(CH)_x$, two $S^{\bullet}$ are subject to ferromagnetic exchange interaction which favors the triplet configuration. Our results were sufficiently novel to publish the work in Phys. Rev. Lett. (A18). However, it opened a new problem in the photophysics saga of $(CH)_x$: Since it is known, from picosecond PA work (A4, C1), that $S^{\bullet}$ are generated within ½ ps, the way $S^{\bullet}$ are formed following photo excitation and the branching ratio of $S^{\bullet}/S^{+}$ are open questions.

We have also measured photoexcitation dynamics in the picosecond time domain in fully *trans* and partially isomerized $(CH)_x$ and $(CD)_x$ films with different *cis/trans* content ratios, using the TPRRS technique. Following the distinctively different decay kinetics of *cis* and *trans* vibrations, we observed an intersystem crossing of photoexcitations from *cis* to *trans* segments which is dominated by a diffusion process in the *cis* segments, with a time constant between 24 and 215 ps depending on the *cis/trans* ratio. Our unique results were, once again, suitable for publication in Phys. Rev. Lett. (A14) and we plan to use the novel TPRRS technique in the anti-stokes configuration to measure phonons and breathers dynamics in various conducting polymers, as will be described in our renewal proposal.

(2) Polythiophene and Soluble Derivatives:

We have measured the nonlinear optical response $\chi^{(3)}$ of this material with 60 femtoseconds resolution (Refs. A9 and A11). We discovered a very fast electronic process (200 fs) which is probably associated with free-carrier renormalization (Ref. A9). We have also studied the longer electronic relaxation (up to 3ns) and measured the transient PA spectrum for the first time (Ref. 4). We have also studied the film morphology by the picosecond ultrasonics technique (Refs. A3 and A7) and found a linear dispersion relation for the LA mode for frequencies up to 100 GHz.

Recently we have completed (A33) some elaborate studies on electrochemically polymerized polythiophene, in which we followed the evolution of the photo-excitations from femtoseconds to miliseconds, using the transient PM and the ADMR techniques. Our results showed that photogenerated exciton-polarons are formed within 300 fs. These excitons decay in the nanosecond time domain by 1D diffusion toward recombination centers. We identified the dominant excitations after about 250 ns to be charged polarons and bipolarons, which give a spin ½ ADMR signal at $g=2.003$ (C3). Our results were published in Phys. Rev. Lett. (A33), and we would like to extend the nanoseconds to miliseconds PM decay to other systems, as is described in our renewal proposal.

(3) Polydiacetylene - 4BCMU

We have studied the resonant Raman scattering (RRS) dispersion with the laser frequency ω_L in a solution cast polydiacetylene film. The data were analyzed (Refs. A2 and A8) using the amplitude model formalism. We have conjectured that the disorder in the film affects the exciton bands in the same way as it affects the excited energy levels in $(CH)_x$. We have started a thorough study of transient photoinduced RRS in 4BCMU films. Preliminary results showed a dynamic spectral hole burning in the RRS of the C=C stretching phonons (Refs. A7 and A21). We have studied the RRS dispersions and the picosecond transient response of photoexcitations in 4BCMU at high pressures, up to 80 kbars. We found that the photoinduced excitons dramatically change their dynamics at high pressure, due to fewer 3D chain defects; the results were published in Phys. Rev. Lett. (Ref. A13).

We have also studied (B6) the electronic energies and phonon frequencies of polydiacetylene 4-BCMU thin films at high pressures up to 50 kbar using Raman scattering under preresonant and resonant conditions. Pressure-induced changes in the resonant Raman scattering (RRS) include: (1) hardening of the most strongly coupled phonon frequencies, (2) dispersion of the RRS frequencies with the laser excitation ω_L which shift to lower energies in analogy with the red shift of the absorption band at high pressures, and (3) softening and narrowing of the phonon distribution. These observations are consistent with an increase in the average conjugation length with pressure. Amplitude mode model analysis of the RRS data showed that the bare phonon frequencies increase with pressure, but otherwise the 1D "Peierls type" relations between the phonons and the electronic gap changes very little with pressure. We also measured a noticeable increase in the interchain interaction by measuring the decrease of the RRS intensities with pressure, quantitatively, using the anti-Stokes to Stokes RRS intensities ratio for various ω_L at high pressure.

(4) Polydiethynylsilanes

In collaboration with Tom Barton's group at Ames Laboratories we have undertaken a thorough study on a new type of π conjugated conducting polymers incorporating group IV elements such as Si and Ge. The new polymers are polydiethynylsilaes (PDES) - $(C_4H_2SiBu_2)_x$ or $(C_4H_2GeBu_2)_x$. First we have measured the ground state properties (Ref. A5) using standard optical techniques such as RRS, optical absorption, ESR and photoluminescence. We followed this by measuring some properties of the electronic excitations revealed in doping and photomodulation (Ref. B17). Then we measured the optical nonlinear properties using the DFWM technique (Ref. A12). PDES prove to have very interesting NLO properties. These materials have high values of $\chi_{(3)}$, with ultrafast response without long time tails; these properties are very promising for device application in nonlinear-optics and we would like to pursue this avenue. For that we recently got an NSF grant.

(5) Polysilane Alloys

With the PI background in a-Si:H research we became interested in novel materials involving σ conjugated polymers: the polysilanes alloys: These are polysilanes $(SiH_2)_n$ embedded in an a-Si:H matrix. We have measured the ultrashort electronic response in the visible spectral range (Refs. A1) and concluded that it is due to geminate recombination of photocarriers in small clusters of a-Si:H which are surrounded by the polysilane polymers. We have also measured the CW PM spectra and LESR and conjectured that the observed features are due to trapped photocarriers at dangling bonds; the results were published in a special issue of Jour. Non Crystal Solids (A16) devoted to optical properties of disordered semiconductors.

(6) Fullerenes

For the third period of this grant we submitted a supplement proposal allowing us to use the laboratory facilities that we have in order to study the optical properties of fullerenes (C_{60} and C_{70}) as dispersion in polystyrene and as films produced by evaporation. We have applied some of our more successful optical techniques such as RRS, electroabsorption (EA), PM, transient PA and ADMR techniques. Some of our studies have been completed and we prepare them for publications. Others are still in progress.

By RRS and electroabsorption (EA) spectroscopies in thin C_{60} films (Refs. A27 and A28) we found that the weak absorption band at 2eV has a very strong response in both RRS and EA spectra. We speculate that the weak band is caused by a forbidden transition, which, however, is associated with strong e-p coupling. We have also measured the photoexcitation properties using the PM spectroscopy: we have found that triplet excitons dominate the photophysics of undoped Fullerenes. By using the ADMR technique (B4 and B9) we found that charged excitations with spin ½ are photogenerated in C_{60} and C_{70} films. We identified them as $C_{60}^-(C_{70}^-)$ and used the PM spectra to determine their energy states in the gap.

III. PUBLICATIONS WHICH RESULTED FROM THIS PROJECT

(A) In Print

1. "Studies of Picosecond Carrier Dynamics in Polysilane Alloys; Evidence for Geminate Recombination in Small a-Si:H Clusters" (with S.G. Han, B.C. Hess, G.S. Kanner, and S. Nitta), Appl. Phys. Lett. 57, 1215 (1990).

2. "Resonant Raman Scattering Study of Polydiacetylene Films" (with L.X. Zheng, R.E. Benner and G.L. Baker), Phys. Rev. B42 (Rapid Commun.), 3235 (1990).

3. "Picosecond Acoustics in Polythiophene Thin Films" (with G.S. Kanner and B.C. Hess), Phys. Rev. B42 (Rapid Commun.), 5403 (1990).

4. "Picosecond Photomodulation Spectroscopy of Conducting Polymers with a Nondegenerated Ground State" (with G.S. Kanner), Jour. Synth. Metals 41, 1291 (1991).

5. "Optical Properties of Polydiethnylsilanes; A Quasi $(AB)_x$ Polymer" (with X. Wei et al.), Jour. Synth. Metals 42 1561 (1991).

6. "High Pressure Effects in Picosecond and cw Spectroscopy of Conjugated Polymers" (with B.C. Hess, G.S. Kanner, and G.L. Baker), Jour. Synth. Metals 41, 1285 (1991).

7. "Picosecond Lattice Dynamics in Conducting Polymer Thin Films" (with G.S. Kanner, B.C. Hess, L.X. Zheng, and R.E. Benner), Jour, Synth. Metals 41, 1393 (1991).

8. "Studies of Resonant Raman Scattering in Polydiacetylene Films" (with L.X. Zheng, R.E. Benner, and G.L. Baker), Jour. Synth. Metals 41, 235 (1991).

9. "Femtosecond Degenerate Four Wave Mixing Studies of $\chi^{(3)}$ in Conjugated Polymers" (with S.G. Han and K.S. Wong), Jour. Synth. Metals 43, 3209 (1991).

10. "Optical Studies of $BaBiO_3$; a Charge Density Wave Insulator" (with G. Ruani et al.), Jour. Synth. Metals 41-43, 3977 (1991).

11. "Studies of Resonant and Preresonant Femtosecond Degenerate Four-Wave Mixing in Unoriented Conducting Polymers", (with K.S. Wong and S.G. Han), Jour. of Appl. Phys., 70, 1896 (1991).

12. "Femtosecond Dynamics of the Nonlinear Optical Response in Polydiethynyslilane" (with K.S. Wong et al.), Appl. Phys. Lett. 58, 1695 (1991).

13. "High Pressure Effects on Ultrafast Relaxation Kinetics of Excitons in Polydiacetylene 4BCMU (with B.C. Hess, G.S. Kanner, and G.L. Baker), Phys. Rev. Lett. 66, 2364 (1991).

14. "Photoexcitation Dynamics in Polyacetylene Probed by Transient Photoinduced Resonant Raman Scattering," (with G. Lanzani et al.) Phys. Rev. Lett. 68, 3104 (1992).

15. "CDW Suppression and Photoinduced Gap States in $BaBiO_3$," (with X. Wei et al.) Solid State Commun. 81, 419 (1992).

16. "Studies of Photocarrier Relaxation Processes in Polysilane Alloys from Subpicosecond to Metastability," (with X. Wei, B.C. Hess, S.G. Han, and S. Nitta). Jour. Non Crystal. Solids 141, 66 (1992).

17. "Anomalous Optical and ESR Properties of Doped PDES," (with Q.X. Ni et al.), Phys. Rev. B (Rapid Commun.) 44, 5939 (1991).

18. "Studies of Photoexcited States in Polyacetylene and Polyparaphenylenevinylene) by Spin Dependent Photomodulation; the Case of Neutral Photoexcitations," (with X. Wei, B.C. Hess, and F. Wudl), Phys. Rev. Lett. 68, 666 (1992).

19. "Measurements of $\chi^{(3)}$ in Conducting Polymers at $\lambda = 620$ nm," (with K.S. Wong), Jour. of Synth. Metals 49, 306 (1992).

20. "Theoretical Study of PDES Polymers for Nonlinear Optical Applications," (with S. Grigoras, J. Shinar, and T.J. Barton, Jour. of Synth. Metals 50, 460 (1992).

21. "Studies of cw and Picosecond Transient Resonant Raman Scattering in Polydiacetylene Films," (with L.X. Zheng, R.E. Benner, and G.L. Baker), Jour. of Synth. Metals 49, 328 (1992).

22. "Picosecond Photoinduced RRS in cis-rich $(CH)_x$," (with G. Lanzani and L.X. Zheng), Jour. of Synth. Metals 49, 313 (1992).

23. "Optical Probes of PDES," (with X. Wei et al), Synth. Metals 50, 453 (1992).

24. "Photoinduced Absorption in Soluble Trans Polyacetylene," (with G. Lanzani, G.S. Kanner, and S. Jeglinski), Jour. of Synth. Metals 50, 461 (1992).

25. "Doping-Induced Optical Absorption and ESR of PDES Films and Solutions," (with Q.X. Ni et al.), Jour. of Synth. Metals 50, 447 (1992).

26. "Electro-absorption Spectroscopy of Conducting Polymers," (with S. Jeglinski), Jour. of Synth. Metals 50, 315 (1992).

27. "Resonant Raman Scattering Studies of Undoped Fullerenes," (with D. Dick et al.), Jour. of Synth. metals 50, 562 (1992).

28. "Electro-absorption of Undoped Fullerenes," (with S. Jeglinski et al.), Jour. of Synth. Metals 50, 562 (1992).

29. "Optical Characterization of Excited States in Undoped Fullerene Thin Films," (with X. Wei et al.), Jour. of Synth. Metals 50, 549 (1992).

30 "Picosecond and cw Optical Probes of Polydiacetylene at High Pressure," (with B.C. Hess et al.), Jour. of Synth. Metals 40, 322 (1992).

31. "Picosecond Transient PA Spectra of Conducting Polymers," (with G.S. Kanner), Jour. of Synth. Metals 49, 307 (1992).

32. "Studies of Spin States of Photoexcitations in Conducting Polymers by the SDPM Technique," (with X. Wei and B.C. Hess), Jour. of Synth. Metals 50, 450 (1992).

33. "Evolution of Polarons in Polythiophene from Femtosecond to Milliseconds," (with G.S. Kanner et al.), Phys. Rev. Lett. 69, 538 (1992).

B. Submitted for Publication

1. "Optical Studies of Photoexcitations in trans-$(CH)_x$," Proceedings of the Nobel Symposium on Conducting Polymers, NS-81, Lolea Sweden, June 1991, (in press).

2. "Picosecond Transient Spectroscopy Techniques and Application to $(CH)_x$" Proceedings of the Summer School on "Photonics in Conducting Polymers," Bolanzo Italy, June 1991, (in press).

3. "Spin Dependent Spectroscopy of Photoexcitations in Conducting Polymers and Fullerenes," 1992 - SPIE Symposium Proceedings (in press).

4. "Magneto-Optic Characterization of Excited States in C_{70}," (with X. Wei et al.), Sol. State Commun. (in press).

5. "Photoexcitations in Polythiophene at High Pressure," (with B.C. Hess and G.S. Kanner), Phys. Rev. B. (in press).

6. "Resonant Raman Scattering Spectroscopy of Polydiacetylene Films at High Pressure," (with L.X. Zheng, B.C. Hess, R.E. Benner, and G.L. Baker) Phys. Rev. B (submitted).

7. "Ultrafast Spectrscopy of Conducting Polymers," proceeding of EUCMOS XXI, Vienna, 1992. (in press)

8. "Magneto-Optical Studies of Photoexcitations in Conducting Polymers with Degenerate and Nondegenerate Ground States," (with X. Wei), Jour. of Synth. Metals. (in press)

9. "ODMR Spectroscopy of Photoexcitations in C_{60} and C_{70} Polystyrene Glasses," (with x. Wei et al.), Jour. of Synth. Metals (in press)

10. Studies of Photoexcitations in Conducting Polymers by the ADMR Technique" (with X. Wei), Synth. Metals (in press)

11. "Magneto Optical Studies of Excited States in cis rich $(CH)_x$" (with X. Wei et al.), Jour. of Synth. Metals. (in press)

12. "Intrachain Photogeneration of Polarons in Poly (3-methylthiophene)," (with J. Poplawski, E. Ehrenfruend, and A.J. Epstein), Jour. of Synth. Metals. (in press)

13. "Picosecond Transient Resonant Raman Scattering in Partially Isomerized Polyacetylene Films," (with G. Lanzani, L.X. Zheng, and R.E. Benner), Jour. of Synth. Metals (in press)

14. "Photoexcitations in $(CH)_x$ with Controlled Conjugation Length," (with G. Lanzani et al), Jour. of Synth. Metals. (in press)

C. Thesis of Graduate Students

I. Ph.D. Thesis

(1) "Picosecond Spectroscopy in Conducting Polymers", G.S. Kanner, Ph.D. Thesis, University of Utah, 1991, unpublished.

(2) "CW and Transient RRS in Polydiacetylene 4BCMU Films", L.X. Zheng, Ph.D. Thesis, University of Utah, 1991, unpublished.

(3) "Absorption Detected Magnetic Resonance in Conducting Polymers and Fullerenes", X. Wei, Ph.D. Thesis, University of Utah, 1992, unpublished.

II. Master Thesis

(1) "Electroabsorption in PDES, a Conjugated Polymer", Omar Paredes, MS Thesis, University of Utah, 1992, unpublished.

(2) "Photomodulation with FTIR," David DeTienne, MS Thesis, University of Utah, 1992, unpublished.

IV. GRADUATE STUDENTS AND POSTDOC TRAINING

A. Postdoc Fellows

(1)	Dr. B.C. Hess	1989-1990	Now at Fresno, California State University
(2)	Dr. K.S. Wong	1989-1991	Now at Hong Kong University
(3)	Dr. G.S. Kanner	1991-1992	Now at Los Alamos National Laboratory
(4)	Dr. J.M. Leng	1992-	
(5)	Dr. X. Wei	1992-	

B. Ph.D. Graduates

(1)	G.S. Kanner	1989-1991	Ph.D June 1991
(2)	L.X. Zheng	1988-1991	Ph.D September 1991
(3)	X. Wei	1988-1992	Ph.D August 1992
(4)	S.G. Han	1988-1991	Ph.D August 1991
(5)	S. Jeglinski	1990-	Ph.D expected in 1993
(6)	G. Lanzani	1989-1991	visitor from Italy Ph.D expected in December 1992
(7)	D. Dick	1991-	Ph.D expected in 1994

C. MS Graduates

(1)	Omar Paredes	May 1992
(2)	David Detienne	June 1992

V. INVITED TALKS AT SCIENTIFIC CONFERENCES WHICH RESULTED FROM THIS PROJECT

(1) "Studies of Picosecond Transient Resonant Raman Scattering in Polydiacetylenes", 176th Meeting of the Electrochemical Society, Hollywood, FL, October 1989. (Z.V. Vardeny)

(2) "Picosecond Lattice Dynamics in Conducting Polymers", General Meeting of the American Physical Society, Anaheim, CA, March 1990. (Z.V. Vardeny)

(3) "Photophysics in Conducting Polymers," Nobel Symposium, Lulea Sweden, June 1991 (Z.V. Vardeny)

(4) "Utlrafast Spectroscopy of Conducting Polymers," Plenary Presentation, Summer School on Opto-electronics, Bolzano, Italy, July 1991 (Z.V. Vardeny)

(5) "Picosecond and cw Optical Probes of Polydiacetylene at High Pressures" Int. Conf. on "Optical Probes of Conjugated Polymers," Snowbird, Utah, August 1991. (B.C. Hess)

(6) "Spin Dependent Spectroscopy of Conducting Polymers," SPIE 1992, Los Angeles, CA, January 1992. (X. Wei)

(7) "Relaxation of Photoexcitations in Conducting Polymers from Femtoseconds to Miliseconds," March APS Meeting, Indianapolis, IN, March 1992 (G.S. Kanner)

(8) "Spin Dependent Recombination Spectroscopy in Conducting Polymers and Fullerene Thin Films," EMRS Meeting, Strasbourg, June 1992 (Z.V. Vardeny)

(9) "Triplet States in Conducting Polymers and Fullerenes," 3rd Symposium on "Photoinduced Charge Transfer," Rochester, NY, July 1992 (Z.V. Vardeny)

(10) "Ultrafast Spectroscopy of Conducting Polymers" XXI Conference on Molecular Spectroscopy, Vienna, Austria, August 1992 (Z.V. Vardeny)

(11) "Absorption Detected Magnetic Resonance of Conducting Polymers" ICSM 1992, Gōthburg, Sweden, August 1992 (Z.V. Vardeny)

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