OFFICE OF NAVAL RESEARCH

Grant N00014-90-J-1193

TECHNICAL REPORT No. 28

Surface-Induced Optical Bistability in Coupled Exciton-Phonon Systems

by

D. L. Lin, Xiao-shen Li and Thomas F. George

Prepared for publication

in

Physics Letters A

Departments of Chemistry and Physics
State University of New York at Buffalo
Buffalo, New York 14260

November 1990

UNCLASSIFIED
ECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

a. REPORT SECURITY CLASSIFICATION
Unclassified

1b. RESTRICTIVE MARKINGS

a. SECURITY CLASSIFICATION AUTHORITY

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release; distribution unlimited

b. DECLASSIFICATION / DOWNGRADING SCHEDULE

. PERFORMING ORGANIZATION REPORT NUMBER(S)
UBUFFALO/DC/90/TR-28

5. MONITORING ORGANIZATION REPORT NUMBER(S)

a. NAME OF PERFORMING ORGANIZATION
Depts. Chemistry & Physics
State University of New York

6b. OFFICE SYMBOL (If applicable)

7a. NAME OF MONITORING ORGANIZATION

c. ADDRESS (City, State, and ZIP Code)
Fronczak Hall, Amherst Campus
Buffalo, New York 14260

7b. ADDRESS (City, State, and ZIP Code)
Chemistry Program
800 N. Quincy Street
Arlington, Virginia 22217

a. NAME OF FUNDING / SPONSORING ORGANIZATION
Office of Naval Research

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
Grant N00014-90-J-1193

c. ADDRESS (City, State, and ZIP Code)
Chemistry Program
800 N. Quincy Street
Arlington, Virginia 22217

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.

1. TITLE (Include Security Classification)
Surface-Induced Optical Bistability in Coupled Exciton-Phonon Systems

2. PERSONAL AUTHOR(S)
D. L. Lin, Xiao-shen Li and Thomas F. George

3a. TYPE OF REPORT	13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
		November, 1990	16

6. SUPPLEMENTARY NOTATION Prepared for publication in *Physics Letters A*

7. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	OPTICAL BISTABILITY, SURFACE-INDUCED, EXCITON-PHONON SYSTEM, REFLECTING SURFACE, POLYDIACETYLENE, THEORY

9. ABSTRACT (Continue on reverse if necessary and identify by block number)

Nonlinear optical responses of exciton-phonon-coupling systems near a reflecting surface are investigated. For a polydiacetylene chain lying parallel to the surface, optical bistability induced by the surface is discovered. It is also found that the threshold and contrast of the bistability can be controlled by adjusting the distance of the system from the surface, and that vacuum fluctuations are reduced whenever the bistability occurs. The nature of the bistability and its origin are discussed.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
Dr. David L. Nelson

22b TELEPHONE (Include Area Code)
(202) 696-4410

22c. OFFICE SYMBOL

D Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

Physics Letters A , in press

Surface-induced optical bistability in coupled exciton-phonon systems

D. L. Lin, Xiao-shen Li and Thomas F. George
Department of Physics and Astronomy
State University of New York at Buffalo
Buffalo, New York 14260

Abstract

Nonlinear optical responses of exciton-phonon-coupling systems near a reflecting surface are investigated. For a polydiacetylene chain lying parallel to the surface, optical bistability induced by the surface is discovered. It is also found that the threshold and contrast of the bistability can be controlled by adjusting the distance of the system from the surface, and that vacuum fluctuations are reduced whenever the bistability occurs. The nature of the bistability and its origin are discussed.

1990 PACS Numbers: 42.65.-k, 42.65.pc, 36.20.-r, 78.65.Hc

Ever since the mid-1940's, it has been known[1] that the spontaneous emission probability of a spin system can be dramatically influenced by its environment. In recent years, inhibited spontaneous emission has been investigated extensively in atomic systems[2] and in solids.[3] It is found that the spontaneous radiation rate is altered markedly by merely changing the surrounding material with a different index of refraction. On the other hand, a great deal of work has been devoted to the study of an adatom near a solid surface.[4,5] Optical properties are radically changed because of the presence of the surface, and the change depends on the structure of the substate material. Such problems are of fundamental importance as well as of practical interest. Fundamentally, one has to develop a quantum mechanical theory for dissipative systems to deal with such nonlinear interactions between the atom and the substrate which does not possess bulk symmetry. From a practical point of view, such studies can lead to applications in surface photochemistry and surface optics.

Instead of atoms or molecules adsorbed at a solid surface, we consider an exciton-phonon coupling system such as a one-dimensional semiconductor of polymers. In particular, we consider a sample of polydiacetylene (PDA) located near a metal surface. The system closely resembles the experimental situation[6] in which PDA films are sandwiched between other materials. PDA is a good candidate for such considerations because of its large third-order susceptibility $\chi^{(3)}$,[7] and because of its small transmission loss α.[8] Thus it possesses a fairly large ratio $\chi^{(3)}/\alpha$, which is usually a measure of the usefulness of a material employed in switching devices. Moreover, PDA is more flexible to use in the construction of waveguides.[9]

For a linear chain of PDA-toluene-sulfonate (PTS) placed at a distance d from and oriented parallel to the metal surface, we shall study its response

to a laser beam shining on it. Novel phenomena have been found recently in the study of the nonlinear optical response of PTS in a thin film in the transient regime,[10] and in an optical cavity in the steady-state regime.[11] In this Letter, our purpose is to investigate the possibility of optical multistability induced by the metal surface, even though there is no cavity to feedback the incident signal. The light-induced excitons in PTS act as emitting dipoles. The emitted light is reflected by the metal surface and interacts with the excitons themselves, and changes their dynamical behavior. In addition, the excitons are also coupled to phonon modes in PTS.[12,13] Such coupling plays a very important role in the nonlinear optical response of polymers.[10-12]

This complicated interacting system is treated by modeling the excitons and phonon modes by damped oscillators and by assuming dissipative interactions[14] between the exciton and the reflected field. Thus the problem is described by the nonhermitian Hamiltonian

$$H = H_x + H_p + H_{xp} + H_{xf} + H_{xR} \quad , \tag{1}$$

where the free exciton energy operator is

$$H_x = \hbar(\omega_x - i\frac{\gamma_x}{2})\, a^\dagger a \quad , \tag{2}$$

the free phonon energy is

$$H_p = \hbar \sum_i (\omega_i - i\frac{\gamma_i}{2})\, b_i^\dagger b_i \quad , \tag{3}$$

the exciton-phonon interaction energy is

$$H_{xp} = \hbar \sum_i \lambda_i \, a^\dagger a(b_i + b_i^\dagger) \quad , \tag{4}$$

the interaction energy between the exciton and driving field in the rotating-wave approximation (RWA) is

$$H_{xf} = -(\mu a E_0^* e^{i\omega_0 t} + \mu^* a^\dagger E_0 e^{-i\omega_0 t}) \quad , \tag{5}$$

and the interaction energy between the exciton and surface-reflected field in the RWA is

$$H_{xR} = -\mu^* a^\dagger E_R \quad . \tag{6}$$

The notation is as follows. The operators $a^\dagger(a)$ and $b_i^\dagger(b_i)$ create (annihilate) an exciton with energy $\hbar\omega_x$ and a phonon in the i-th mode with energy $\hbar\omega_i$, respectively. The corresponding decay rates are denoted by γ_x and γ_i, respectively, and λ_i is a coupling constant. The dipole moment is given as $p = \mu a$ with μ as its matrix element, and the driving field is $E = E_0 \exp(i\omega_0 t)$ with amplitude E_0 and frequency ω_0. E_R stands for the reflected field at the position of the dipole. It is proportional to p and hence can be written as $E_R = E_r a$, where E_r is a c-number. As we shall see later, E_R is in general a complex quantity, so that the interaction (6) is dissipative. We also note that the momentum dependence of the exciton has been neglected in this Hamiltonian.[10-12]

Following Dekker's quantization procedure for dissipative systems,[15] the equation of motion for the density operator of the PTS absorbate can be written as

$$\dot{\rho} = -\frac{i}{\hbar}[a^\dagger,[a,H]\rho] + \frac{i}{\hbar}[\rho[H^\dagger,a^\dagger],a]$$

$$-\frac{i}{\hbar}\sum_i [b_i^\dagger,[b_i,H]\rho] + \frac{i}{\hbar}\sum_i [\rho[H^\dagger,b_i^\dagger],b_i] \quad . \tag{7}$$

Since we are interested in the scattered field intensity I_{sc} as a function of the input optical field intensity I_{in}, the effects of quantum fluctuations are negligible,[16] and a semiclassical approach is applicable. Thus it is sufficient to use the mean values $\alpha = \langle a \rangle$, $n = \langle a^\dagger a \rangle$ and $\beta_i = \langle b_i \rangle$. The equation of motion for these variables in the Schrödinger picture can be obtained directly from Eq. (7). In the rotating frame, we have

$$\dot{\alpha} = \langle \dot{a} \rangle = \mathrm{Tr}(\dot{\rho} a)$$

$$= -[i(\Delta+\omega_s) + \frac{1}{2}\gamma_x + \gamma_s]\alpha + i\Omega - i\sum_i \lambda_i(\beta_i+\beta_i^*)\alpha \tag{8}$$

$$\dot{n} = -(\gamma_x+2\gamma_s)n - i\Omega^*\alpha + i\Omega\alpha^* \tag{9}$$

$$\dot{\beta}_i = -(i\omega_i+\frac{1}{2}\gamma_i)\beta_i - i\lambda_i n \quad , \tag{10}$$

where we have defined the detuning $\Delta = \omega_x - \omega_0$ and the Rabi frequency $\Omega = \mu^* E_0$. The surface effect on the exciton is reflected in the surface-induced frequency shift

$$\omega_s = |\mu|^2 \mathrm{Re}(E_r/\mu) \tag{11a}$$

and the decay rate

$$\gamma_s = |\mu|^2 \mathrm{Im}(E_r/\mu) \quad . \tag{11b}$$

The reflected electric field E_r in the dipole direction can be found by a classical approach. We take the oscillating dipole moment to be located at a distance d from the surface of a semi-infinite metal. From electromagnetic field theory, we find in a straightforward manner that

$$E_r^{\parallel} = \frac{i}{2} \sqrt{\epsilon}\, k_0^3\, \mu \int_0^{\infty} du\, u[R_{\perp} + (1-u^2)R_{\parallel}]/\sqrt{1-u^2} \tag{12}$$

when the dipole $\vec{p}$ is parallel to the surface, and

$$E_r^{\perp} = -i\sqrt{\epsilon}\, k_0^3\, \mu \int_0^{\infty} du\, u^3 R_{\parallel}/\sqrt{1-u^2} \tag{13}$$

when the dipole is perpendicular to the surface. Here we have defined $k_0 = \omega/c$ and

$$R_{\parallel} = \frac{\epsilon_1\mu_2 - \epsilon_2\mu_1}{\epsilon_1\mu_2 + \epsilon_2\mu_1} \quad , \tag{14a}$$

$$R_{\perp} = \frac{\mu_1 - \mu_2}{\mu_1 + \mu_2} \tag{14b}$$

$$\mu_{\ell} = \sqrt{\epsilon_{\ell}/\epsilon_1 - u^2} \quad , \qquad \ell = 1,2 \tag{14c}$$

with ϵ as the dielectric constant and the subscripts 1 and 2 labelling the medium containing the PTS chain and the metal substrate, respectively. For definiteness, we consider the case where $\vec{p}$ is parallel to the surface. It then follows directly from Eqs. (11) and (12) that

$$\gamma_s = \frac{3}{4}\gamma_0 \, \mathrm{Im} \int_0^\infty du\, u[(1-u^2)R_\parallel + R_\perp]e^{i\mu_1 x}/\mu_1 \quad , \tag{15a}$$

$$\omega_s = -\frac{3}{4}\gamma_0 \, \mathrm{Re} \int_0^\infty du\, u[(1-u^2)R_\parallel + R_\perp]e^{i\mu_1 x}/\mu_1 \quad , \tag{15b}$$

where

$$\gamma_0 = \frac{2}{3}\sqrt{\epsilon_1}\,(\frac{\omega_x}{c})^3\,|\mu|^2 = \frac{1}{2}\gamma_x \tag{16}$$

is the decay rate in the absence of the surface,[17] and $x = 2d\sqrt{\epsilon_1}\omega_x/c$.

In the steady state, the solution for α can easily be found from Eqs. (8)-(10) as

$$\alpha = \Omega/[\Delta+\omega_s-\lambda_p n-i(\gamma_s+\tfrac{1}{2}\gamma_x)] \quad , \tag{17}$$

where λ_p is defined by

$$\lambda_p = 2\sum_i \lambda_i^2\omega_i/(\omega_i^2+\tfrac{1}{4}\gamma_i^2) \simeq 2\sum_i \lambda_i^2/\omega_i \tag{18}$$

because $\omega_i >> \gamma_i$. The mean number of excitons is determined by the equation

$$\lambda_p^2 n^3 - 2(\Delta+\omega_s)\lambda_p n^2 + [(\Delta+\omega_s)^2 + (\gamma_s+\tfrac{1}{2}\gamma_x)^2]n - I_{in} = 0 \quad , \tag{19}$$

where the input laser intensity is $I_{in} = |\Omega|^2$. In the scattering region where the incident field vanishes, it is known that the positive-frequency part of the field may be written as[18]

$$E^{(+)}(\vec{r},t) = E_f^{(+)}(\vec{r},t) - \frac{\omega_x^2}{4\pi c^2 r^3} (\vec{p} \times \vec{r}) \times \vec{r}\, a(t-\tfrac{r}{c}) \quad , \tag{20}$$

where $E_f(\vec{r},t)$ describes the free propagation. The mean value of the scattered intensity, in the steady state is thus given by

$$I_{sc} = I(\vec{r})/I_0(\vec{r}) = |\alpha|^2$$

$$= I_{in}/([\Delta+\omega_s-\lambda_p n(I_{in})]^2 + (\gamma_s+\tfrac{1}{2}\gamma_x)^2) \quad , \tag{21}$$

where

$$I_0(\vec{r}) = [\frac{\omega_x^2}{4\pi c^2 r^3} (\vec{p} \times \vec{r}) \times \vec{r}]^2 \quad . \tag{22}$$

The intensity I_{sc} is studied numerically as a function of I_{in} according to Eq. (21) for a PTS chain parallel to the surface of an ideal metal for which $\epsilon_2 \to \infty$. As a realistic approximation, we have assumed that only four phonon modes[13] are strongly coupled to excitons in PTS. The parameters for these modes are:[10-13] $\omega_1 = 5.16$, $\lambda_1 = 2.0$; $\omega_2 = 3.68$, $\lambda_2 = 1.66$; $\omega_3 = 2.98$, $\lambda_3 = 0.46$; and $\omega_4 = 2.36$, $\lambda_4 = 0.48$. For simplicity we have chosen $\frac{1}{2}\gamma_x$ to be

the unit for all quantities of the dimension t^{-1} in our calculations. Optical bistability is found when the input field frequency matches the exciton frequency. Some of our results for the resonant excitation ($\Delta = 0$) are plotted in Fig. 1, clearly demonstrating that the bistability is induced by the surface. Our numerical calculation shows a strong dependence of the optical bistability on the distance d of PTS from the surface, especially when $x \leq 2.5$. As x decreases further, it is observed that the contrast of the bistability (the ratio of the intensity of the upper branch to that of the lower branch) increases markedly, and that the threshold (the smallest input field intensity for multiple solutions of I_{sc}) decreases at the same time. Furthermore, we have also found that the optical bistability appears only when γ_s becomes negative. In other words, reduced vacuum fluctuations always accompany the optical bistability.

It has been established both experimentally[2,19] and theoretically[17] that the spontaneous emission changes dramatically when the atomic system is near a reflecting surface or between two mirrors. This implies that the mode structure of the vacuum field suffers significant modification because of the finite geometry. A similar situation in solid-state physics and electronics has also been reported, and the spontaneous electron-hole recombination rate can be controlled by adjusting the mirror position or by varying the index of refraction of the medium.[3] What we have found here is that by adjusting the environmental conditions to reduce the radiation rate, one can not only produce low-noise lasers from a semiconductor quantum well but also create optical bistability from a polymer chain near a reflecting surface.

The origin of the optical bistability may be understood by looking at the driving frequency dependence of the scattered field intensity. For a

fixed driving field intensity, its frequency can be scanned over the near-resonance region. Thus the exciton number becomes a function of ω_0, as can be seen from Eq. (19). Consequently, I_{sc} can be regarded as a function of ω_0 also. Figure 2 shows the surface-induced optical bistability from the point of view of the driving field frequency instead of its intensity. It is found that there are three possible absorption rates for a certain small frequency range. The scattered intensity in the higher branch corresponds to the higher absorption rate, and in the lower branch to the lower absorption rate. Since the absorption part of the optical susceptibility is proportional to the scattered field intensity for fixed input intensity and distance x, the bistability described above is mainly an absorptive one. In other words, the surface-induced absorption rate is responsible for this particular optical bistability. This is easily understood from energy considerations, because a higher output intensity of the excitonic dipole results from more effective absorption of the input energy, and vice versa.

Acknowledgment

This work was supported in part by the Office of Naval Research.

References

1. E. M. Purcell, Phys. Rev. 69, 681 (1946).
2. W. Jhe, A. Anderson, E. A. Hinds, D. Meschede, L. Moi and S. Horache, Phys. Rev. Lett. 58, 1320 (1987); D. J. Heinzen and M. S. Feld, Phys. Rev. Lett. 59, 2623 (1987).
3. E. Yablonovitch, Phys. Rev. Lett. 58, 2059 (1987); E. Yablonovitch, T. J. Gmitter and R. Bhat, Phys. Rev. Lett. 61, 2546 (1988).
4. R. R. Chance, A. Prock and R. Silbey, Adv. Chem. Phys. 37, 1 (1978); H. F. Arnoldus, S. van Smaalen and T. F. George, Adv. Chem. Phys. 73, 679 (1989); P. T. Leung and T. F. George, Spectroscopy 4, 35 (1989).
5. X. S. Li, D. L. Lin and T. F. George, Phys. Rev. B, in press; X. S. Li, D. L. Lin, T. F. George, Y. Liu and Q. Q. Gou, Phys. Lett. A, in press.
6. B. P. Singh and P. N. Prasad, J. Opt. Soc. Am. B 5, 453 (1988); K. Sasaki, K. Fujii, T. Tomioka and T. Kinoshita, *ibid*. 457 (1988).
7. See, for instance, D. S. Chemla and J. Zyss, Eds., Nonlinear Optical Properties of Dynamic Molecules and Crystals (Academic, New York, 1987).
8. P. D. Townsend, G. L. Baker, N. E. Schlotter and S. Etemad, Synth. Met. 28, D633 (1989).
9. M. Thakur, Y. Shani, G. C. Chi and K. J. O'Brian, Synth. Met. 28, D595 (1989).
10. X. S. Li, D. L. Lin, T. F. George and X. Sun, Phys. Rev. B 40, 11728 (1989).
11. X. S. Li, D. L. Lin, T. F. George and X. Sun, Phys. Rev. B (Rapid Commun.) 41, 3280 (1980).
12. B. I. Greene, J. F. Mueller, J. Orenstein, D. H. Rapkine, S. Schmitt-Rink and M. Thakur, Phys. Rev. Lett. 61, 325 (1989); G. J. Blanchard, J. P.

Heritage, A. C. von Lehmen, G. L. Baker and S. Etemad, Phys. Rev. Lett. 63, 887 (1989).

13. D. N. Batchelder, in Polydiacetylenes: Synthesis, Structure and Electronic Properties, ed. by D. Bloor and R. R. Chance (Martinus Nijhof, Dordrecht, The Netherlands, 1985), p. 187 ff.

14. X. S. Li and C. D. Gong, Phys. Rev. A 35, 1595 (1987).

15. H. Dekker, Physica A 95, 311 (1979).

16. M. Reid, K. J. McNeil and D. F. Walls, Phys. Rev. A 24, 2029 (1981).

17. G. S. Agarwal, Phys. Rev. A 12, 1475 (1975).

18. G. S. Agarwal, Springer Tracts in Modern Physics, Vol. 70 (Springer-Verlag, New York, 1974).

19. S. Haroche and D. Kleppner, Physics Today 42(1), 24 (1989).

Figure Captions

1. Scattered field intensity I_{sc} vs the driving field intensity I_{in} for various distances x when $\Delta = 0$: (a) $x = \infty$, (b) $x = 1.5$, (c) $x = 1.1$, (d) $x = 0.9$ and (e) $x = 0.85$.

2. I_{sc} as a function of the driving field frequency ω_0 for a fixed $I_{in} = 0.10$: (a) $x = \infty$ and (b) $x = 1.5$.

Fig. 1

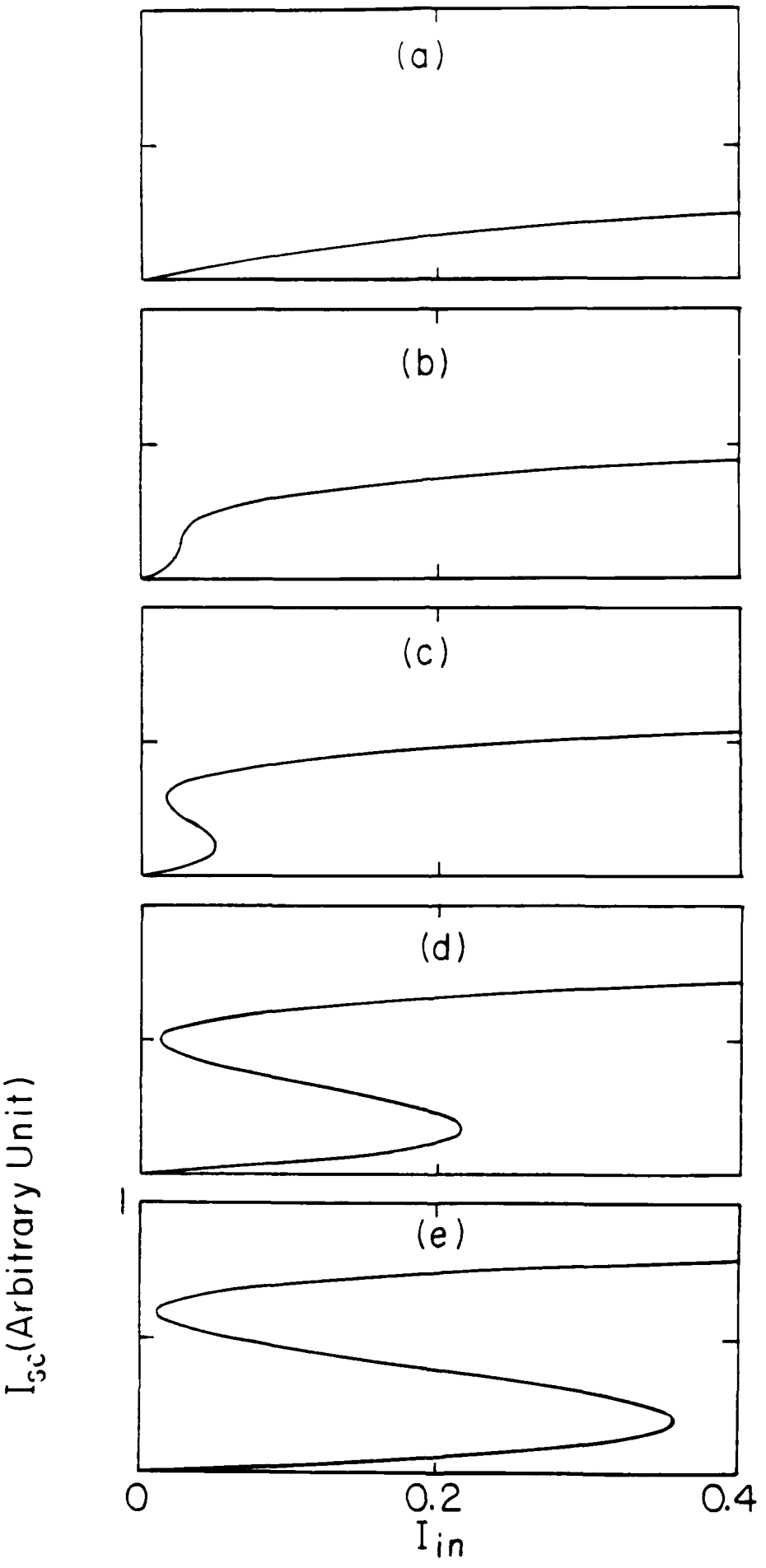
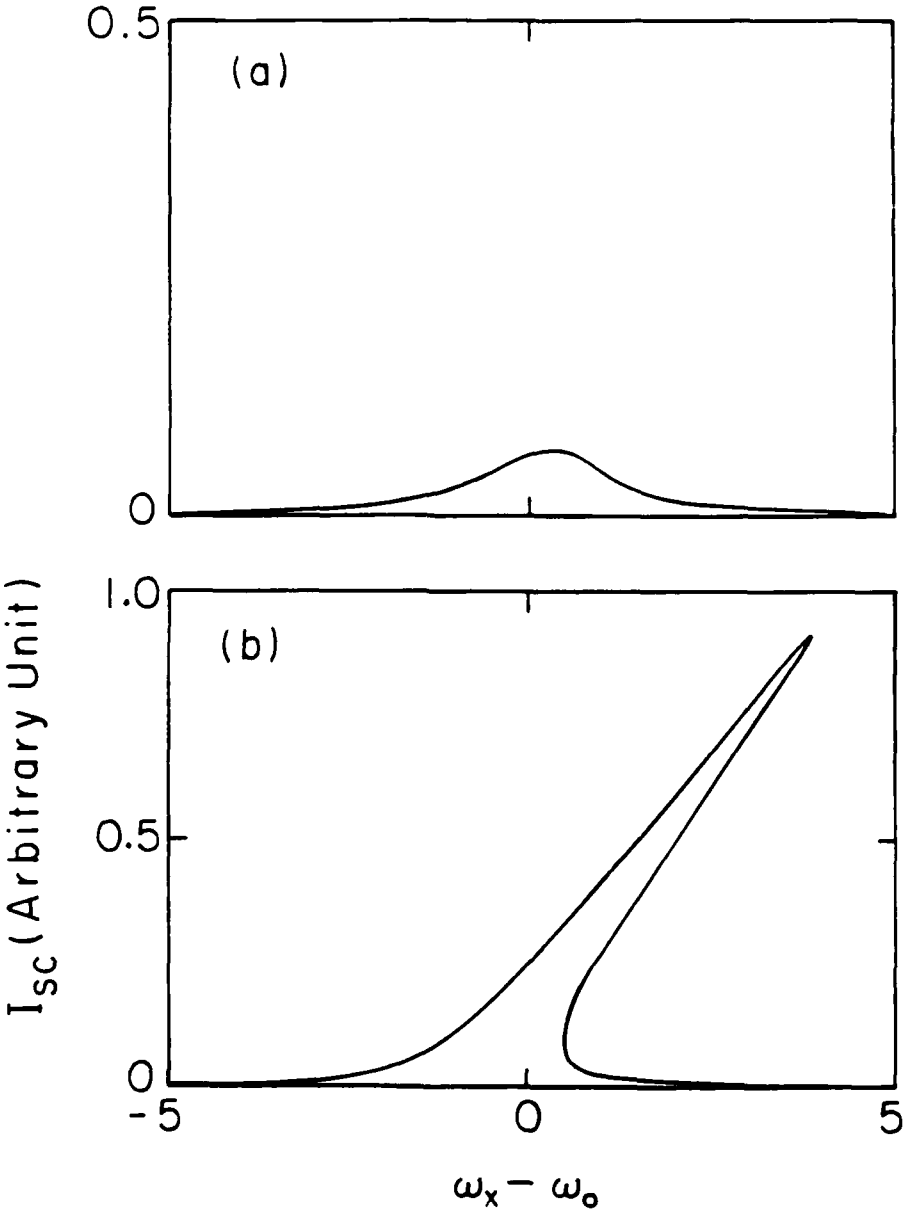


Fig. 2



TECHNICAL REPORT DISTRIBUTION LIST - GENERAL

Office of Naval Research (2)
Chemistry Division, Code 1113
800 North Quincy Street
Arlington, Virginia 22217-5000

Commanding Officer (1)
Naval Weapons Support Center
Dr. Bernard E. Douda
Crane, Indiana 47522-5050

Dr. Richard W. Drisko (1)
Naval Civil Engineering
Laboratory
Code L52
Port Hueneme, CA 93043

David Taylor Research Center (1)
Dr. Eugene C. Fischer
Annapolis, MD 21402-5067

Dr. James S. Murday (1)
Chemistry Division, Code 6100
Naval Research Laboratory
Washington, D.C. 20375-5000

Dr. David L. Nelson (1)
Chemistry Division
Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217

Dr. Robert Green, Director (1)
Chemistry Division, Code 385
Naval Weapons Center
China Lake, CA 93555-6001

Chief of Naval Research (1)
Special Assistant for Marine
Corps Matters
Code 00MC
800 North Quincy Street
Arlington, VA 22217-5000

Dr. Bernadette Eichinger (1)
Naval Ship Systems Engineering
Station
Code 053
Philadelphia Naval Base
Philadelphia, PA 19112

Dr. Sachio Yamamoto (1)
Naval Ocean Systems Center
Code 52
San Diego, CA 92152-5000

Dr. Harold H. Singerman (1)
David Taylor Research Center
Code 283
Annapolis, MD 21402-5067

Defense Technical Information Center (2)
Building 5, Cameron Station
Alexandria, VA 22314

FY90 Abstracts Distribution List for Solid State & Surface Chemistry

Professor John Baldeschwieler
Department of Chemistry
California Inst. of Technology
Pasadena, CA 91125

Professor Paul Barbara
Department of Chemistry
University of Minnesota
Minneapolis, MN 55455-0431

Dr. Duncan Brown
Advanced Technology Materials
520-B Danury Rd.
New Milford, CT 06776

Professor Stanley Bruckenstein
Department of Chemistry
State University of New York
Buffalo, NY 14214

Professor Carolyn Cassady
Department of Chemistry
Miami University
Oxford, OH 45056

Professor R.P.H. Chang
Dept. Matls. Sci. & Engineering
Northwestern University
Evanston, IL 60208

Professor Frank DiSalvo
Department of Chemistry
Cornell University
Ithaca, NY 14853

Dr. James Duncan
Federal Systems Division
Eastman Kodak Company
Rochester, NY 14650-2156

Professor Arthur Ellis
Department of Chemistry
University of Wisconsin
Madison, WI 53706

Professor Mustafa El-Sayed
Department of Chemistry
University of California
Los Angeles, CA 90024

Professor John Eyler
Department of Chemistry
University of Florida
Gainesville, FL 32611

Professor James Garvey
Department of Chemistry
State University of New York
Buffalo, NY 14214

Professor Steven George
Department of Chemistry
Stanford University
Stanford, CA 94305

Professor Tom George
Dept. of Chemistry & Physics
State University of New York
Buffalo, NY 14260

Dr. Robert Hamers
IBM T.J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10598

Professor Paul Hansma
Department of Physics
University of California
Santa Barbara, CA 93106

Professor Charles Harris
Department of Chemistry
University of California
Berkeley, CA 94720

Professor John Hemminger
Department of Chemistry
University of California
Irvine, CA 92717

Professor Roald Hoffmann
Department of Chemistry
Cornell University
Ithaca, NY 14853

Professor Leonard Interrante
Department of Chemistry
Rensselaer Polytechnic Institute
Troy, NY 12181

Professor Eugene Irene
Department of Chemistry
University of North Carolina
Chapel Hill, NC 27514

Dr. Sylvia Johnson
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

Dr. Zakya Kafafi
Code 6551
Naval Research Laboratory
Washington, DC 20375-5000

Professor Larry Kesmodel
Department of Physics
Indiana University
Bloomington, IN 47403

Professor Max Lagally
Dept. Metal. & Min. Engineering
University of Wisconsin
Madison, WI 53706

Dr. Stephen Lieberman
Code 522
Naval Ocean Systems Center
San Diego, CA 92152

Professor M.C. Lin
Department of Chemistry
Emory University
Atlanta, GA 30322

Professor Fred McLafferty
Department of Chemistry
Cornell University
Ithaca, NY 14853-1301

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

Professor Larry Miller
Department of Chemistry
University of Minnesota
Minneapolis, MN 55455-0431

Professor George Morrison
Department of Chemistry
Cornell University
Ithaca, NY 14853

Professor Daniel Neumark
Department of Chemistry
University of California
Berkeley, CA 94720

Professor David Ramaker
Department of Chemistry
George Washington University
Washington, DC 20052

Dr. Gary Rubloff
IBM T.J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10598

Professor Richard Smalley
Department of Chemistry
Rice University
P.O. Box 1892
Houston, TX 77251

Professor Gerald Stringfellow
Dept. of Matls. Sci. & Engineering
University of Utah
Salt Lake City, UT 84112

Professor Galen Stucky
Department of Chemistry
University of California
Santa Barbara, CA 93106

Professor H. Tachikawa
Department of Chemistry
Jackson State University
Jackson, MI 39217-0510

Professor William Unertl
Lab. for Surface Sci. & Technology
University of Maine
Orono, ME 04469

Dr. Terrell Vanderah
Code 3854
Naval Weapons Center
China Lake, CA 93555

Professor John Weaver
Dept. of Chem. & Mat. Sciences
University of Minnesota
Minneapolis, MN 55455

Professor Brad Weiner
Department of Chemistry
University of Puerto Rico
Rio Piedras, Puerto Rico 00931

Professor Robert Whetten
Department of Chemistry
University of California
Los Angeles, CA 90024

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

Professor Nicholas Winograd
Department of Chemistry
Pennsylvania State University
University Park, PA 16802

Professor Aaron Wold
Department of Chemistry
Brown University
Providence, RI 02912

Professor Vicki Wysocki
Department of Chemistry
Virginia Commonwealth University
Richmond, VA 23284-2006

Professor John Yates
Department of Chemistry
University of Pittsburgh
Pittsburgh, PA 15260