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Theoretical models and computational codes have been developed to describe chemical and physical phenomena associated with solids, microstructure clusters and polymers, with special attention given to nonlinear optical effects and ultrafast processes. The following topics have been investigated: light-induced drift of electrons in semiconductor heterostructures; photoinduced electron transfer in coupled quantum wells; quantum beats in time-resolved luminescence spectra; scale-invariant theory of optical properties of fractals; optical properties of small silicon clusters; boron-nitrogen-substituted fullerenes; and nonlinear optical response in polymers irradiated by laser fields.

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Summary

The objective under the current ONR grant was to develop theoretical models and computational codes to describe chemical and physical phenomena associated with solids, microstructure clusters and polymers, with special attention given to nonlinear optical effects and ultrafast processes. Several key results are summarized below.

● Light-Induced Drift of Electrons in Semiconductor Heterostructures. A novel effect of light-induced drift (LID) for quantum confined electrons has been predicted. This effect manifests itself as the electric current in the heterostructure plane in response to optical excitation with frequency close, but not exactly equal, to a resonance with an intersubband transition in the heterostructure. The current reverses its direction with a change in the detuning sign and vanishes if the radiation polarization is normal to the heterostructure plane. The LID effect is based upon the difference in relaxation times of an electron in different confined states. The current density has been estimated to be rather high, which makes the LID effect promising for applications in photonics.

● Photoinduced Electron Transfer in Coupled Quantum Wells. An effect of counterfield electron transfer has been predicted for an asymmetric double quantum well subjected to photoexcitation resonant with an intersubband electronic transition. The effect manifests itself in the transfer of electrons from one quantum well to the other well in the direction *opposite* to the one favored by the bias electric field. A quantitative theory of the effect has been developed on the basis of the density-matrix technique, which takes into account all types of relaxation. This technique has also been extended to describe the light-induced drift effect under optically saturated conditions. The theory shows that the counterfield electron transfer should be pronounced at realistic conditions and readily detectable. The transfer quantum yield is predicted to be high, up to 0.5 or greater. This effect is promising for use in far-infrared photodetection and in optoelectronic (photonic) devices, in particular, in photonic memory.

● Quantum Beats in Time-Resolved Luminescence Spectra. Using the above biased asymmetric double quantum well, analytical expressions have been developed for time-dependent luminescence intensities and numerically demonstrated to elucidate the characteristics of π -phase-shifted quantum beats. It is seen analytically as well as numerically that the magnitude of the tunneling interaction can be quantitatively estimated by the beat modulation depth.

● Scale-Invariant Theory of Optical Properties of Fractals. Surface-enhanced Raman scattering (SERS) from colloidal metal clusters, which are known to be fractal, is up to a millionfold greater in intensity than ordinary Raman scattering. Although there are some theories previously in the literature which qualitatively explain this magnitude of enhancement, none of them is capable of describing the spectral profiles of SERS. Under this ONR program a quantitative scale-invariant theory of SERS from fractals has been developed. The theory is supported by extensive numerical calculations with the use of supercomputers. The theory predicts scaling behavior of the SERS enhancement factor in terms of a properly chosen spectral variable. The theory also quantitatively describes the experimental spectral profiles of the SERS enhancement without a single adjustable parameter. The scale-invariant theory has also been extended to describe nonlinear optical polarizabilities of fractals.

● Optical Properties of Small Silicon Clusters. The geometry and electronic structure of small silicon clusters, Si_7 , Si_{10} (three isomers) and Si_{13} , has been established using the tight-binding model by global optimization of the cohesion energy. Expressions for linear and nonlinear polarizabilities of the clusters have been found using the single-particle density-matrix technique in the form of the sum-over-one-electron-states. Kleinman's conjecture for hyperpolarizabilities has been shown to be violated in the practically important frequency-degenerate case. Polarizabilities governing various optical phenomena, such as scattering and absorption, second-harmonic generation, optical rectification, nonlinear corrections to the refraction index, phase conjugation, etc., have been evaluated for a series of wavelengths. The linear absorption and hyperpolarizabilities have been shown to depend primarily on the symmetry of the clusters and only secondarily on their size. The hyperpolarizabilities prove to be high for the low-symmetry clusters.

● Boron-Nitrogen-Substituted Fullerenes. For the systems $(@B_2C_{58})$, $(@N_2C_{58})$, $(@BNC_{58})$, $(@C_{12}B_{24}N_{24})$ and $(@B_{30}N_{30})$, MNDO (modified neglect of differential overlap) calculations have been carried out for the heats of formation from benzene, naphthalene and their BN analogues, and it is found that all these hybrids are approximately as stable as buckminsterfullerene. Surprisingly, it is predicted that $(@B_{30}N_{30})$ is stable and should be relatively simple to synthesize from borazine.

● Nonlinear Optical Response in Polymers Irradiated by Laser Fields. A new phenomenon of splitting in the pump-probe spectrum of conjugated polymers has been found. Numerical results with parameters pertaining to a polydiacetylene-toluene-sulfonate (PTS) single crystal in an optical cavity have been obtained, yielding a spectrum of three dispersion structures: one is centered at the exciton resonance, and the other two are at one phonon frequency and two phonon frequencies below the resonance, respectively. Strong responses have been found around the threshold of the pump-field intensity for the occurrence of optical bistability. In addition, the transient pump-probe spectrum for a PTS single crystal has been calculated by solving numerically a set of Bloch-like optical differential equations. Phonon-induced excitonic bleaching is clearly shown. The above results are in qualitative agreement with experimental observations. Finally, surface-induced optical bistability has been found for a PTS chain near a metal surface. The bistability is accompanied by a reduced vacuum fluctuation.

Research Personnel

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Publications (Technical Reports)

Each manuscript listed below corresponds by number to the Technical Report previously submitted to the Office of Naval Research for Grant N00014-90-J-1193. The major portion of these are referred journal articles, and the remainder are invited book chapters and conference proceedings.

1. D. M. Lindsay, Y. Wang and T. F. George, "The Hückel Model for Small Metal Clusters. IV. Orbital Properties and Cohesive Energies for Model Clusters of up to Several Hundred Atoms," *Journal of Cluster Science* **1**, 107-26 (1990).
2. X. S. Li, D. L. Lin, T. F. George and X. Sun, "New Type of Optical Bistability in Polymers Mediated by Phonons," *Physical Review B (Rapid Communications)* **41**, 3280-3 (1990).
3. X. S. Li, D. L. Lin, T. F. George and X. Sun, "Nonlinear Optical Processes in One-Dimensional Polymers," in *Laser Surface Microprocessing*, edited by V. I. Konov, B. S. Luk'yanchuk and I. Boyd, *Proceedings of the Society of Photo-Optical Instrumentation Engineers* **1352**, 285-96 (1990).
4. D. Sahu, A. Langner and T. F. George, "BCS Primer: A Guide to Computational Methods in Superconductivity Theory," *Journal of Chemical Education* **67**, 738-42 (1990).
5. X. S. Li, D. L. Lin and T. F. George, "Spontaneous Decay and Resonance Fluorescence of an Admolecule Near a Rough Silver Surface with Random Roughness," *Physical Review B* **41**, 8107-11 (1990).
6. D. L. Lin, R. Chen and T. F. George, "Optical Phonons and Electronic Properties in Double Heterostructures," in *Quantum-Well and Superlattice Physics III*, edited by G. H. Döhler, E. S. Koteles and J. N. Schulman, *Proceedings of the Society of Photo-Optical Instrumentation Engineers* **1283**, 273-86 (1990).
7. X. S. Li, D. L. Lin, T. F. George, Y. Liu and Q. Q. Gou, "Decay Rate and Resonance Fluorescence Spectrum of a Molecule Near a Composite Material Surface," *Physics Letters A* **145**, 444-8 (1990).
8. D. Sahu, A. Langner and T. F. George, "Reply to 'Coupled s- and d-Wave States in the Thorium-Doped Heavy-Fermion Superconductor UBe_{13} ' by H. Pleiner and H. R. Brand," *Physical Review B*. This was accepted for publication, but it was withdrawn after Pleiner and Brand were persuaded to withdraw their Comment.
9. L. N. Pandey, T. F. George and M. L. Rustgi, "Intersubband Transitions in an Asymmetric Quantum Well with a Thin Barrier or Delta-Function Potential," *Journal of Applied Physics (Communications)* **68**, 1933-6 (1990).

10. X. S. Li, D. L. Lin, T. F. George and X. Sun, "Phonon-Mediated Excitonic Optical Bistability in Polymers," *Physical Review B* **42**, 2977-81 (1990).
11. D. A. Jelski, T. F. George and J. M. Vienneau, "Tight-Binding and Hückel Models of Molecular Clusters," in *Clusters of Atoms and Molecules*, edited by H. Haberland (Springer-Verlag, Berlin), in press.
12. T. T. Rantala, D. A. Jelski and T. F. George, "Electronic and Structural Properties of Si₁₀ Cluster," *Journal of Cluster Science* **1**, 189-200 (1990).
13. A. N. Grigorenko, P. I. Nikitin, D. A. Jelski and T. F. George, "Two-Dimensional Treatment of Nonlinear Thermoelectricity in Homogeneous Metals," *Physical Review B* **42**, 7405-8 (1990).
14. T. F. George and H. F. Arnoldus, "Spectroscopy and Laser-Induced Chemistry Near Surfaces," in *Lasers in Science and Technology*, edited by J. G. Eden and M. H. Nayfeh (Gordon and Breach, New York), in press.
15. X. Xia, X. S. Li, D. L. Lin and T. F. George, "Phonon-Mediated Splitting in Optical Susceptibility of Polymers," *Physical Review B (Rapid Communications)* **42**, 4790-3 (1990).
16. Z. G. Shuai, J. N. Liu, X. Sun, C. Q. Wu, R. Fu, X. S. Li, D. L. Lin and T. F. George, "The Optical Gap and Nonlinear Property of Conducting Polymers," in *Proceedings of China-Materials Research Society International '90, Beijing, China*, Volume 3: *Polymers and Biomaterials*, edited by H. Feng, Y. Han and L. Huang (Elsevier, Amsterdam, 1991), pp. 191-4.
17. X. Sun, Z. G. Shuai, C. Q. Wu, R. T. Fu, R. Fu, X. S. Li, D. L. Lin and T. F. George, "Third-Harmonic Generation of Conducting Polymers," in *Proceedings of China-Materials Research Society International '90, Beijing, China*, Volume 5: *Mechanical Properties/Materials Design*, edited by D. Wu (Elsevier, Amsterdam, 1991), pp. 659-63.
18. D. Sahu, A. Langner and T. F. George, "Specific Heat of Anisotropic Superconductors," *Quarterly Report of the New York State Institute on Superconductivity* **3(1)**, 2-3 (1990).
19. C. W. Jun, C. I. Um and T. F. George, "Coefficients of the Second Viscosity in Thin Liquid-Helium Films," *Physical Review B* **43**, 2748-55 (1991).
20. T. T. Rantala, M. I. Stockman, D. A. Jelski and T. F. George, "Linear and Nonlinear Optical Properties of Small Silicon Clusters," *Journal of Chemical Physics* **93**, 7427-38 (1990).
21. L. N. Pandey, T. F. George, M. L. Rustgi and D. Sahu, "Change in Density of States in a Resonant Tunneling Structure due to a Scattering Center in the Well," *Journal of Applied Physics* **68**, 5724-8 (1990).

22. I. Last and T. F. George, "Semiempirical Study of Rare Gas and Rare Gas-Hydrogen Ionic Clusters: R_n^+ , $(R_nH)^+$ and $(R_nH_2)^+$ for $R \equiv Ar, Xe$," *Journal of Chemical Physics* **93**, 8925-38 (1990).
23. P. C. Das, A. Puri and T. F. George, "Photodissociation Near a Rough Metal Surface: Effect of Reaction Fields," *Journal of Chemical Physics* **93**, 9106-12 (1990).
24. T. T. Rantala, M. I. Stockman and T. F. George, "Monte-Carlo Simulation of Spectral, Polarization-Selective Hole Burning in Fractal Clusters," in *Scaling in Disordered Materials: Fractal Structure and Dynamics*, edited by J. P. Stokes, M. O. Robbins and T. A. Witten, *Proceedings of Symposium W (Extended Abstracts, EA-25) of the Materials Research Society 1990 Fall Meeting* (Materials Research Society, Pittsburgh, 1990), pp. 117-20.
25. V. A. Markel, L. S. Muratov, M. I. Stockman and T. F. George, "Scale-Invariant Theory of Optical Properties of Fractal Clusters," in *Scaling in Disordered Materials: Fractal Structure and Dynamics*, edited by J. P. Stokes, M. O. Robbins and T. A. Witten, *Proceedings of Symposium W (Extended Abstracts, EA-25) of the Materials Research Society 1990 Fall Meeting* (Materials Research Society, Pittsburgh, 1990), pp. 219-22.
26. H. F. Arnoldus and T. F. George, "Detection of Three-Photon Relaxation of an Atom Near a Phase Conjugator Through Absorption Measurements," *Physical Review A (Brief Reports)* **43**, 591-2 (1991).
27. L. N. Pandey, M. I. Stockman, T. F. George and D. Sahu, "Theoretical Studies of Electron Transport in Quantum-Well Structures," in *Nonlinear Optics*, edited by S. G. Rautian (Nova Science Publishers, Commack, New York, 1992), pp. 65-70.
28. D. L. Lin, X. S. Li and T. F. George, "Surface-Induced Optical Bistability in Coupled Exciton-Phonon Systems," *Physics Letters A* **152**, 229-33 (1991).
29. T. T. Rantala, M. I. Stockman, D. A. Jelski and T. F. George, "Optical (Hyper)Polarizabilities of Small Silicon Clusters," in *Clusters and Cluster-Assembled Materials*, edited by R. S. Averback, J. Bernholc and D. L. Nelson (Materials Research Society, Pittsburgh), *Materials Research Society Symposium Proceedings* **206**, 85-90 (1991).
30. L. N. Pandey and T. F. George, "Escape Time from a Biased Asymmetric Double Quantum Well," *Journal of Applied Physics (Communications)* **69**, 2711-3 (1991).
31. L. N. Pandey and T. F. George, "Position Expectation Value and Oscillator Strength of a Biased Asymmetric Quantum Well," *Superlattices and Microstructures* **10**, 5-11 (1991).
32. X. Xia, X. S. Li, D. L. Lin and T. F. George, "Transient Dynamics in Excitonic Bistability in Polymers," *Physical Review B* **43**, 5219-22 (1991).
33. M. I. Stockman, L. N. Pandey and T. F. George, "Light-Induced Drift of Quantum-Confining Electrons in Semiconductor Heterostructures," *Physical Review Letters* **65**, 3433-6 (1990).

34. X. Sun, Z. Shuai, R. Fu, K. Nasu, X. S. Li, D. L. Lin and T. F. George, "Spectrum of the Third-Order Non-Linear Susceptibility of Trans-Polyacetylene," *Journal of Physics: Condensed Matter (Letters)* **2**, 9713-6 (1990).
35. V. A. Markel, L. S. Muratov, M. I. Stockman and T. F. George, "Theory and Numerical Simulation of Optical Properties of Fractal Clusters," *Physical Review B* **43**, 8183-95 (1991).
36. A. N. Grigorenko, P. I. Nikitin, D. A. Jelski and T. F. George, "Thermoelectric Phenomena in Metals Under Large Temperature Gradients," *Journal of Applied Physics (Communications)* **69**, 3375-7 (1991).
37. I. Last and T. F. George, "Cooperative Absorption-Induced Charge Transfer in a Solid," *Chemical Physics Letters* **177**, 315-20 (1991).
38. H. F. Arnoldus and T. F. George, "Spectral and Temporal Distribution of Phase-Conjugated Fluorescent Photons," *Journal of Modern Optics* **38**, 1429-39 (1991).
39. H. R. Lee, T. F. George and K. S. Sohn, "Cluster Calculation of CuO_2 in High- T_c Superconductors," in *The Challenges to Advanced New Materials, Twelfth Kyungpook National University International Seminar Proceedings* (Taegu, Korea, 1990), pp. 79-89.
40. H. F. Arnoldus and T. F. George, "Phase-Conjugated Fluorescence," *Physical Review A* **43**, 3675-89 (1991).
41. T. Hai, Z. Y. Li, D. L. Lin and T. F. George, "Critical Behavior in Magnetic Superlattices," *Journal of Magnetism and Magnetic Materials* **97**, 227-34 (1991).
42. D. L. Lin, R. Chen and T. F. George, "Interface-Phonon-Mediated Magnetopolaronic Effect on Impurity Transition Energies in Quantum Wells," *Physical Review B (Rapid Communications)* **43**, 9328-31 (1991).
43. H. F. Arnoldus and T. F. George, "Heisenberg Approach to Photon Emission Near a Phase Conjugator," *Physical Review A* **43**, 6156-61 (1991).
44. V. V. Dodonov, T. F. George, O. V. Man'ko, C. I. Um and K. H. Yeon, "Propagators for Quantum Oscillator Chains," *Journal of Soviet Laser Research* **12**, 385-94 (1991).
45. H. F. Arnoldus and T. F. George, "Resonance Fluorescence Spectrum of an Atom Near a Phase Conjugator," *Journal of Physics B: Atomic, Molecular and Optical Physics* **24**, 2653-64 (1991).
46. M. I. Stockman, T. F. George and V. M. Shalaev, "Field Work and Dispersion Relations of Excitations on Fractals," *Physical Review B* **44**, 115-21 (1991).
47. B. L. Swift, D. A. Jelski, D. E. Higgs, T. T. Rantala and T. F. George, "Comment on 'Effect on Surface Reconstruction on Stability and Reactivity of Si Clusters'," *Physical Review Letters* **66**, 2686 (1991).

48. Y. Q. Ma, Z. Y. Li, D. L. Lin and T. F. George, "Trimodal Random-Field Ising Systems in a Transverse Field," *Physical Review B (Brief Reports)* **44**, 2373-6 (1991).
49. D. L. Lin, R. Chen and T. F. George, "Polaron Ground State in a Double Heterostructure of Polar Crystals," *Journal of Physics: Condensed Matter* **3**, 4645-53 (1991).
50. X. Sun, Z. Shuai, J. Liu, R. Fu, X. S. Li, D. L. Lin and T. F. George, "Is a Conjugated Polymer a Mott or a Peierls Insulator?," *Synthetic Metals* **43**, 3549-52 (1991).
51. K. H. Yeon, T. F. George and C. I. Um, "Exact Solution of a Quantum Forced Time-Dependent Harmonic Oscillator," in *Workshop on Squeezed States and Uncertainty Relations*, edited by D. Han, Y. S. Kim and W. W. Zachary, *National Aeronautics and Space Administration Conference Publication* **3135**, 347-63 (1992).
52. M. I. Stockman, L. N. Pandey and T. F. George, "Reply to Comment on 'Light-Induced Drift of Quantum-Confined Electrons in Semiconductor Heterostructures' by A. A. Grinberg and S. Luryi," *Physical Review Letters* **67**, 157 (1991).
53. I. Last and T. F. George, "Charge Motion Effects in Ionic Clusters," *Chemical Physics Letters* **183**, 547-51 (1991).
54. L. N. Pandey, T. F. George and D. Sahu, "Width Anomaly in Resonant Tunneling Structures," *Solid State Communications* **79**, 399-402 (1991).
55. H. F. Arnoldus and T. F. George, "Phonon Relaxation and Lineshapes of Adsorbates," in *Trends in Chemical Physics*, Volume 1, edited by J. Menon (Research Trends, Council of Scientific Research Integration, Trivandrum, India, 1991), pp. 349-55
56. Z. D. Liu, X. Li, D. L. Lin and T. F. George, "Two-Mode Squeezing of Cavity Fields," *Physical Review A (Brief Reports)* **44**, 6144-6 (1991).
57. X. Li, Z. D. Liu, D. L. Lin and T. F. George, "Transient Hole Burning in Exciton-Phonon Systems," *Physics Letters A* **159**, 365-8 (1991).
58. D. L. Lin, X. Li, Z. D. Liu and T. F. George, "Surface Effect on Optical Bistability in Coupled Exciton-Phonon Systems Inside a Cavity," *Physics Letters A* **159**, 369-73 (1991).
59. Z. Huang, D. A. Jelski, R. Wang, D. Xie, C. Zhao, X. Xia and T. F. George, "Polarizabilities of Trans and Cis Polyacetylene and Interactions Among Chains in Crystalline Polyacetylene," *Journal of Canadian Chemistry* **70**, 372-6 (1992).
60. C. I. Um, S. K. Yoo and T. F. George, "Ground-State Properties of ^3He Impurity in Liquid ^4He Monolayers," *Journal of Low Temperature Physics* **85**, 331-46 (1991).
61. D. A. Jelski, B. L. Swift, T. T. Rantala, X. Xia and T. F. George, "Structure of the Si_4 Cluster," *Journal of Chemical Physics* **95**, 8552-60 (1991).

62. D. A. Jelski, T. T. Rantala and T. F. George, "Chemical Reactivity and Electronic Structure of Silicon Microclusters," in *On Clusters and Clustering: From Atoms to Fractals*, edited by P. Reynolds (North-Holland, Amsterdam), in press.
63. H. F. Arnoldus and T. F. George, "Conditions for Sub-Poissonian Photon Statistics in Phase-Conjugated Resonance Fluorescence," *Optics Communications* **87**, 127-33 (1992).
64. X. Sun, Z. Shuai, K. Nasu, D. L. Lin, T. F. George, "Electron Interaction and Optical Gap of Conjugated Polymers," *Physical Review B* **44**, 11042-7 (1991).
65. J. R. Bowser, D. A. Jelski and T. F. George, "Stability and Structure of $C_{12}B_{24}N_{24}$: A Hybrid Analog of Buckminsterfullerene," *Inorganic Chemistry (Communications)* **31**, 154-6 (1992).
66. X. Li, D. L. Lin and T. F. George, "Optical Nonlinearity in Coupled Exciton-Phonon Systems Near Metal Surfaces," *Synthetic Metals*, in press.
67. R. Chen, J. P. Cheng, D. L. Lin, B. D. McCombe and T. F. George, "Variational Approach to Quasi-Two-Dimensional Hydrogenic Impurities in Arbitrary Magnetic Fields," *Physical Review B (Brief Reports)* **44**, 8315-8 (1991).
68. D. L. Lin, X. Li and T. F. George, "Anomalous Hole Burning in Polymers with Inhomogeneous Broadening," *Synthetic Metals*, in press.
69. X. Sun, K. Nasu, C. Wu, L. Li, D. L. Lin and T. F. George, "Frequency Dependence of Two-Photon Resonances and Damping in Polymers," *Synthetic Metals*, in press.
70. D. L. Lin, X. Li, Z. Y. Li and T. F. George, "Percolation Effects on the Decay of Admolecules," *Physical Review B* **45**, 2138-41 (1992).
71. H. F. Arnoldus, T. F. George and C. I. Um, "Statistics of Fluorescent Photons Emitted Near a Phase Conjugator," *Journal of the Korean Physical Society* **24**, S91-5 (1991).
72. M. I. Stockman, L. S. Muratov, L. N. Pandey and T. F. George, "Light-Induced Electron Transfer Counter to an Electric Field Force in an Asymmetric Double Quantum Well," *Physics Letters A* **163**, 233-8 (1992).
73. M. I. Stockman, L. S. Muratov, L. N. Pandey and T. F. George, "Kinetics of Intersubband Optical Excitation and Photoinduced Electron Transfer in an Asymmetric Double Quantum Well," *Physical Review B* **45**, 8550-61 (1992).
74. R. Chen, D. L. Lin and T. F. George, "Effects of Electron-Interface-Phonon Interactions on Magnetopolaronic Impurity Transitions in Quantum Wells," *Chinese Journal of Physics* **30**, 165-76 (1992).

75. F. L. Li, X. S. Li, D. L. Lin and T. F. George, "Dynamics of an M-Level Atom Interacting with Cavity Fields. III. Nonclassical Behavior of the Initially Squeezed Field," *Physical Review A* **45**, 3133-8 (1992).
76. S. J. Lee, N. H. Shin, J. J. Ko, C. I. Um and T. F. George, "Crossovers of the Density of States in Two-Direction Double-Barrier Resonant-Tunneling Structures," *Physical Review B* **45**, 9173-8 (1992).
77. V. V. Dodonov, T. F. George, O. V. Man'ko, C. I. Um and K. H. Yeon, "Exact Solutions for a Mode of the Electromagnetic Field in a Resonator with Time-Dependent Characteristics of the Internal Medium," *Journal of Soviet Laser Research* **13**, 219-30 (1992).
78. X. Xia, X. Li, D. L. Lin and T. F. George, "Hole Burning in the Resonance Fluorescence of Impurity Centers," *Physical Review B* **45**, 8316-20 (1992).
79. X. Xia, D. A. Jelski, J. R. Bowser and T. F. George, "MNDO Study of Boron-Nitrogen Analogues of Buckminsterfullerene," *Journal of the American Chemical Society* **114**, 6493-6 (1992).
80. I. Last and T. F. George, "Rare Gas Clusters Containing Charged Atoms," in *Current Topics in Ion Chemistry and Physics*, Volume 1, edited by C. Y. Ng, T. Baer and I. Powis (Wiley, New York, 1992), in press.
81. H. F. Arnoldus and T. F. George, "Spontaneous Decay on an Atom Near a Phase Conjugator," *Journal of Quantum Nonlinear Phenomena*, in press.
82. M. I. Stockman, V. M. Shalaev, M. Moskovits, R. Botet and T. F. George, "Enhanced Raman Scattering by Fractal Clusters: Scale Invariant Theory," *Physical Review B* **46**, 2821-30 (1992).
83. H. F. Arnoldus and T. F. George, "Fluctuations and Squeezing in Resonance Fluorescence Emitted Near a Phase Conjugator," *Physical Review A (Brief Reports)* **46**, 679-81 (1992).
84. X. Li, D. L. Lin and T. F. George, "Cooperative Effects on Transient Spectral Hole Burning," *Journal of Modern Optics*, in press.
85. Y. Ohtsuki, L. N. Pandey and T. F. George, "Theoretical Study of Phase-Shifted Quantum Beats in Time-Resolved Luminescence Spectra from a Biased Asymmetric Double Quantum Well," *Chemical Physics Letters* **196**, 619-23 (1992).
86. C. I. Um, C. W. Jun and T. F. George, "Coefficients of the Second Viscosity in Bulk Liquid Helium," *Physical Review B (Brief Reports)* **46**, 5746-9 (1992).
87. L. N. Pandey and T. F. George, "Intersubband Transitions in Quantum-Well Heterostructures with Delta-Doped Barriers," *Applied Physics Letters* **61**, 1081-3 (1992).

88. C. I. Um, S. T. Nam, S. Y. Lee and T. F. George, "Temperature Variation of the Elementary Excitation Spectrum of Thin Liquid ^4He Films," *Physical Review B* **46**, 6346-60 (1992).
89. M. I. Stockman, L. S. Muratov and T. F. George, "Theory of Light-Induced Drift of Electrons in Coupled Quantum Wells" *Physical Review B* **46**, 9595-602 (1992).
90. D. L. Lin, X. Li, Z. D. Liu and T. F. George, "Internal Explosion in Laser Ablation of Superconducting Targets," *Journal of Applied Physics*, in press.
91. M. I. Stockman, L. S. Muratov, L. N. Pandey and T. F. George, "Photoinduced Electron Transfer Counter to the Bias Field in Coupled Quantum Wells," in *Photo-Induced Space Charge Effects in Semiconductors: Photoconductivity, Spectroscopy and Electro-optics*, edited by K. W. Goossen, N. M. Haegel and D. D. Nolte (Materials Research Society, Pittsburgh), *Materials Research Society Symposium Proceedings* **261-Q2**, in press.
92. X. Li, D. L. Lin, T. F. George and X. Sun, "Transient Nonlinear Optical Phenomena in Exciton-Phonon Systems," *Physical Review B*, in press.