MASTER COPY KEEP THIS COPY FOR REPRODUCTION PURPOSES

TION PAGE

Form Approved
OMB No. 0704-0188

1.	TE	3. REPORT TYPE AND DATES COVERED
	OCTOBER 1991	FINAL REPORT 15 Mar 88 - 30 Aug 91

4. TITLE AND SUBTITLE

ELEMENTARY EXCITATIONS, OPTICAL AND TRANSPORT PROPERTIES OF ARTIFICALLY STRUCTURED MATERIALS

5. FUNDING NUMBERS

DAAL03-88-K-0026 (2)

6. AUTHOR(S)

JOHN J. QUINN

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

BROWN UNIVERSITY
PROVIDENCE, RI 02912

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U. S. Army Research Office
P. O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

ARO 25167.16-PH

11. SUPPLEMENTARY NOTES

The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A NUMBER OF PROBLEMS INVOLVING THE ELECTRONIC PROPERTIES OF ARTIFICALLY STRUCTURED SEMICONDUCTORS HAVE BEEN STUDIED. THE STUDY OF THE GROUND STATE AND THE ELEMENTARY EXCITATIONS OF A DOUBLE QUANTUM WELL SYSTEM HAS REVEALED THE EXISTENCE OF A NOVEL "EXCITONIC CHARGE DENSITY WAVE STATE." DONOR STATES, BOTH SINGLY AND DOUBLY OCCUPIED, IN A MODULATION DOPED QUANTUM WELL HAVE BEEN INVESTIGATED. MAGNETIC POLARON EFFECTS IN A VARIETY OF ARTIFICIAL STRUCTURES HAVE BEEN STUDIED.

14. SUBJECT TERMS

EXCITONIC CHARGE DENSITY WAVE, DONORS IN QUANTUM WELLS, MAGNETIC POLARON

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

ARO 25167-16-PH

ELEMENTARY EXCITATIONS, OPTICAL AND TRANSPORT PROPERTIES OF ARTIFICIALLY STRUCTURED MATERIALS

FINAL REPORT

JOHN J. QUINN

OCTOBER 1991

U.S. ARMY RESEARCH OFFICE
DAAL03 - 88 - K - 0026

BROWN UNIVERSITY

A. PROBLEMS STUDIED

1. **Phase Transitions in Double Quantum Well Systems.**

The quasi two-dimensional gas of electrons (or holes) which can occur in certain narrow quantum well systems is known to undergo a transition to a Laughlin condensed state or to a charge density wave state (or Wigner crystal) at very low temperatures and high magnetic fields. We have studied the problem of a pair of two dimensional layers separated by a distance d of the order of the magnetic length $\ell = \sqrt{\hbar c/eB}$ in the presence of a strong magnetic field. Here interlayer Coulomb interactions are important and can affect the nature of the ground state.

2. **Donor States in Quantum Well Systems.**

The spin density functional technique has been used to investigate donor levels in a modulation doped quantum well. The binding energy of the D° (donor with a single bound electron) and D^{-} (donor with a pair of bound electrons) states is studied as a function of the electron concentration in the quantum well. The optical properties of a system containing N_I donors and n_s electrons (where $N_I < n_s$) is studied for N_I sufficiently small that donor-donor interactions can be ignored.

3. **Magnetic Polaron Effects in Artificially Structured Semimagnetic Semiconductors.**

The exchange interaction between a free carrier and a magnetic ion leads to a non-linear Schrodinger equation for the electronic wave function. This non-linearity can have dramatic effect on the electronic and transport properties of array of quantum wells, quantum wires and quantum dots. Several different structures have been investigated.

4. **Diagrammatic-Method for the Analyses of Finite Multilayer Structures.**

We have developed a scheme for determining the response functions and normal modes of a finite array of layers in terms of simple diagrams and rules for associating with each diagram an analytic contribution to the dispersion relation of the excitation being studied. The method has been applied to plasmons, phonons, magnons and electronic states in a finite array of thin layers. We are currently investigating the problem of direct electromagnetic generation of sound in a finite array of space charge layers on a semiconducting substrate.

B. Summary of Most Important Results

1. For a neutral system consisting of an electron layer separated from a hole layer by a distance d, the ground state for small values of d is a condensed excitonic liquid. By studying the coupled equations of motion of the exciton density, electron density and hole density fluctuations in a generalized time dependent Hartree Fock approximation, we found an instability of the homogenous excitonic liquid for d larger than critical value d_c, where d_c depends on the Landau level filling factor ν. The nature of the ground state was explored by assuming that certain correlation functions are non-vanishing in the new state. The new state is called the "excitonic charge density wave state," and its properties and elementary excitations have been investigated.

2. The conditions under which the negatively charge donor state D^- exists in the presence of a free electron gas in a narrow quantum well have been studied. The binding energy and $^1S_0$ to $^1P_1$ transition energy have been determined for various sample parameters including the free electron concentration n_s.

3 and 4. The most important results on magnetic polarons and on the novel diagrammatic technique for multilayer systems have been reported in previous reports.

C. List of Publications and Technical Reports.

- "Many-Body Effects in a Layered Electron Gas," (with P. Hawrylak and G. Eliasson) Phys. Rev. **B37**, 10187, 1988.
- "Collective Electronic Excitations in Systems with Spatially Varying Electron Density," Proc. of Taxco Workshop on Electromagnetic Properties of Surface, 1988.
- "Plasmon Bands in Metallic Superlattices: Retardation Effects," (with G. Gonzalez de la Cruz and G. Eliasson), Proc. of Taxco Workshop on Electromagnetic Properties of Surfaces, 1988.
- "Collective Excitations in a Multiple Quantum Well System with Barrier of Finite Height," Physical Review **B38**, 5617, 1988, (with Zhu, Xia, and Hawrylak).
- "Surface Magnetoplasmon Polaritons in Truncated Superlattice Systems," Phys. Rev. **B38**, 4205, 1988, (with Wallis).
- "Bulk and Surface Plasma Waves in Semiconducting Superlattices," to appear in Spatial Dispersion in Solids and Plasmons, (with G. Eliassonand P. Hawrylak) ed. P. Halevi, Cambridge University Press, 1989.
- "Collective Excitations of an Electron-Hole Plasma in Semiconductor Superlattices with Zero Valence Band Offset," Solid State Comm., **69**, 397, 1989, (with Eliasson, Hawrylak, Zhu and Xia).
- "Novel Collective Excitations Spectrum and Lifetime in a Tunneling Semiconductor Superlattice," Phys. Lett. A **135**, 307, 1989, (with Zhuand Xia).
- Quasiparticle Lifetime of Excited Carriers in a Semiconductor Superlattice," Phys. Rev., **B39**, 3305, 1989, (with Xia and Zhu).
- "Collective Excitations of Electron-Hole Plasma in Semiconductor Superlattice," to appear (1990). Trends in Plasma Physics (with Eliasson, Hawrylak, Zhu and Xia).
- "Excitonic Insulator Transition in a GaSb/Al Sb/InAs Quantum Well Structure," Solid State Commun., 75, 595, 1990, (with X. Zhu).

- "Self-Trapped Magnetic Polarons in Two-Dimensional Semimagnetic Semiconductors," Submitted to Solid State Commun., 1990, (with X. Zhu and P. Hawrylak).

- "A Novel Diagrammatic Method for the Analysis of Finite Multilayer Structures," Proc. of 20th Int. Conf. on Physics of Semiconductors, Thessaloniki, Greece, 1990, (with G. Vecris).

- "Novel Diagrammatic Method for Analyzing the Surface Electronic Modes of Finite Multilayer Structures," Proc. of the Int. Conf. on Solid Films and Surfaces, Providence, 1990 ,(with G. Vecris).

- "Novel Diagrammatic Method for the Analysis of Finite Periodic and Aperiodic Multilayer Structures," Solid State Comm. 76, 1071, 1990, (with G. Vecris).

- "Hydrogenic Impurities in Quantum Well Structures," submitted to Phys. Rev., 1991, (with X. Xia).

- "Exact Analytic Dispersion Relation for Dipolar Magnetostatic and Magnetoretarded Modes in Finite Superlattices, Phys. Rev., 1991, (with G. Vecris).

- "Excitonic Charge Density Wave Instability of Spatially Separated Electron-Hole Layers in a Strong Magnetic Field," Phys. Rev. Letters 67, 895, 1991, (with Chen).

- "Hydrogenic Impurities in Quasi Two-Dimensional Electron Gas Systems," submitted to Phys. Rev., 1991, (with X. Xia and X. Zhu).

- "Tunneling in a Periodic Array of Semimagnetic Quantum Dots" to appear in Phys. Rev., 1991, (with Hawrylak and Grabowski).

D. List of All Participating Scientific Personnel Showing Any Advanced Degrees Earned by Them While Employed on the Project.

Dr. Ximing Chen
Dr. Yun Zhu
Dr. Xiaoguong Xia, Ph.D. Brown University, 1991
Dr. Xiaodong Zhu

5. **Report of Inventions** -- None.

6. **Bibliography** -- All references are contained in the papers cited under publications.

7. **Appendix** -- Final Financial Report.

Standard Form 1035
(Duplicate)

PUBLIC VOUCHER FOR PURCHASES AND SERVICES OTHER THAN PERSONAL
CONTINUATION SHEET

Voucher No 30-FINAL
Schedule No
Sheet No 2

U.S. DEPARTMENT, BUREAU OR ESTABLISHMENT
Department of

Number and Date	Date of Delivery of Service	Articles or Services (Enter Description, Item No. of Contract or Federal Supply Schedule and other and other info deemed necessary)	QUANTITY	UNIT PRICE Cost Per	AMOUNT

BROWN UNIVERSITY
Providence, Rhode Island 02912

Contract No. DAAL03-88-K-0026

Total Estimated Costs $ 186,485 00
Overhead 0.16

Analysis of Claimed Current and Cumulative Costs

		Amount for Current Period Billed	Cumulative Amt From Inception
Major Cost Elements:			
Line 1	Salaries & Wages	$ 0.00	$ 112,565 75
Line 2	Fringe Benefits	0.00	27,671.42
Line 3	Materials & Services	0.00	5,096 09
Line 4	Travel	0.00	3,297 86
Line 5	University Services	0.00	556 26
Line 6	Sub Total	$ 0.00	$ 149,187.38
Line 7	Equipment	0.00	0.00
Line 8	Computer Charges	0.00	0.00
Line 9	Tuition	0.00	2,186 40
Line 10	Fellowships	0.00	0 00
Line 11	Subcontracts	0.00	0 00
Line 12	Total Direct Costs	$ 0.00	$ 151,373 78
	Withholding	10.00	
Line 13	Overhead @ 16%	0.00	35,111 22 *
Line 14	Total Costs	$ 10.00	$ 186,485 00

*Overhead rates of:
64% 03-15-88 to 06-30-89
16% 07-01-89 to 08-31-91