AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

Electronic States in Systems of Reduced Dimensionality

PROGRESS REPORT

for the period
October 15, 1992 – October 14, 1993

Grant Number: DE-FG02-87ER45334

Sergio E. Ulloa

Department of Physics and Astronomy and
Condensed Matter and Surface Sciences Program

Ohio University, Athens, Ohio 45701-2979

Off.: (614) 593-1729

Fax: (614) 593-0433

ulloa@helios.phy.ohiou.edu

Date of submission: 20 May 1993

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Yoo

I. Progress Report for the Year 1992–93

The 92–93 granting period has brought the consolidation of a number of problems in the project. We have completed problems proposed in our previous report, and continue working on some of the leads suggested by our results. We have also begun work in very promising new areas, all having as a common theme the effects of electronic interactions on the properties of systems. In what follows we provide a summary of these efforts. Detailed descriptions are found in the technical reports attached as appendices to this report.

- **Magnetically modulated systems.** Together with Dr. Xiaoguang Wu (a post-doctoral fellow funded mostly by an Ohio University fellowship and partially by this grant), we have carried out studies of the single-particle and collective excitations of novel two-dimensional electronic systems. In these structures the electrons move in the presence of moderately strong magnetic fields, so that only a few Landau levels are filled and/or important. However, the magnetic field is proposed to have an *spatial* strength modulation which has strong effects on the response of the system. In particular, we have analyzed the density-density correlation function (within a random phase approximation) for varying modulation strength and period. During the period of this grant we have completed studies of the effects of one- and two-dimensional spatial modulation.

The corresponding limits for strong field modulation yield either an array of one-dimensional ‘wires’ separated by a distance equal to the period of the modulation, or an array of zero-dimensional ‘quantum dots’ in a square type of arrangement. For both types of strong field modulation we observe very interesting features of the level structure. In particular, for the two-dimensional modulation case, the levels are reminiscent of the so-called Hofstadter butterfly. Our treatment, however, explicitly incorporates the effects of inter-Landau level interactions induced by the modulation. This results in a variety of rather subtle features of the level structure, as well as important effects in the specific excitation spectrum and oscillator strength distribution.

A technical discussion of these latter results is presented in a preprint attached to this report. It has been accepted for publication as a Rapid Communication in Physical Review B (DOE-ER45334-Pub#18). A longer more detail report is to be submitted shortly to Physical Review B.

- **Raman and EELS in superlattices.** Graduate student Xiaoju Wu (supported by the Condensed Matter and Surface Sciences program at Ohio University and partially by this grant) and I have been working in the problem of calculating the dispersion relations for collective excitations in semiconductor superlattices. In particular, we have been looking at the effects of surface depletion present in realistic structures, and the signatures of the associated Tamm-like states. Raman probe yields and electron energy loss spectroscopy (EELS) in these structures have been chosen. These techniques are the most natural tools to analyze the behavior of both the single-particle and collective excitations in these systems. Unique dispersion relations have been uncovered using EELS-yield calculations, and have been reported at the March 1992 meeting of the American Physical Society. The theoretical formulation for the Raman scattering experiments has also been completed during this period and recently published as a Rapid Communication in Physical Review B (**DOE-ER45334-Pub#19**). A longer report contrasting the results of both the EELS and Raman scattering calculations for the same type of system will be soon submitted to Physical Review.
- **Ballistic quantum interference effects.** Finally, together with graduate student Yong S. Joe (partially supported by this grant, and who graduated in December 1992) we have been looking at the possible observation of strong electronic interference effects in the conductance of structures with multiply-connected areas. Ultraclean semiconductor devices, where electrons can travel ballistically at low temperatures, has opened a whole new set of possibilities for the study of both fundamentally interesting problems and perhaps novel applications. Preliminary results were reported at the March 1992 meeting of the American Physical Society. Furthermore, a publication describing the technical details of this work is now accepted for publication in April 1993 in Physical Review B (**DOE-ER45334-Pub#20**). We are also very excited about the possibilities of novel ‘quantum interference’ devices, and an additional configuration has been proposed for simpler experimental implementation. A preprint has now been submitted to Applied Physics Letters, and it is attached to this report (**DOE-ER45334-Pub#21**).
Work on this area is also expected to be continued both by collaborations with Xiaoguang Wu (the postdoctoral fellow mentioned above) at Ohio University, and with Y. S. Joe, who will be taking a position at Ball State University. Dr. Joe and his collaborators at Ball State will be in close consultation with our group, in

further developing problems in this area.

- **Quantum dot arrays.** In collaboration with Dr. Nammee Kim, a visiting research fellow supported by Ohio University, we have carried out studies of the collective excitations of two-dimensional arrays of quantum dots. These structures are a novel system where Coulomb interactions of nearby quasi-zero-dimensional objects can be studied. Our studies have been focused on the effects of carrier tunneling between neighboring dots. Although this sort of effect is present in realistic structures (specially on those used by recent experiments by the Munich group), its theoretical treatment had been non-existent until our work. A report with some of the main results has been submitted to Physical Review B for publication. A preprint of this work accompanies this report (**DOE-ER45334-Pub#22**).

Work on this general problem, although under the influence of magnetic fields, is the subject of current efforts. This project is of particular relevance to experiments, as various groups use the magnetic fields as a tunable parameter of the system which aids in the identification of the different modes. However, some puzzles remain in this field and we intent to address these in our work.

Notice also that our experience in this problem gave us a unique advantage in treating the problem discussed in the following item. Given the strong physical similarities, despite the rather different context, we were able to tackle a very different and important problem, as discussed below.

- **Optical response of undoped fullerene crystals.** Together with Xiaoju Wu, graduate student supported by Ohio University on a D. Clippinger Fellowship, we have studied the collective excitations of undoped fullerene crystals. These materials provide a unique opportunity to study the physical properties of dynamically-coupled induced moments, as an optical absorption experiment is performed. Although descriptions of the optical excitations of isolated buckyballs have appeared, no theoretical work has discussed the possibility of dipole-dipole interactions as the optical field is applied. Experimental evidence of this coupling has however appeared, as a small mode dispersion was measured in electron energy loss spectroscopy [Sohmen *et al.*, Z. Phys. B **86**, 87 (1992)]. Our calculations show that such a shift is in agreement with dipole-dipole interactions. A preliminary report of this work was presented at the 1993 March meeting of the American Physical Society in Seattle. A written report will soon follow.

We have tried to emphasize that our efforts on this project have yielded very interesting results on several camps. Experimental verification of some of our most novel and challenging predictions and proposals should be forthcoming. We are very enthusiastic about outstanding problems and plan to pursue those accordingly, as described in the attached proposal for the period 1993–1996.

II. Research Plans for the Period 1993–1996

Given the developments reported in the previous section, we plan to pursue a number of interest projects in this field. Moreover, our understanding in these systems has allowed us to branch out into naturally connected areas, such as described in the proposal *Electronic interactions in condensed matter systems*, which accompanies this report.

Please refer to that proposal for details on our research plans for the next triennium, 1993–1996.

III. Publications and Presentations for the Period

Copies of the following reprints and preprints are attached to this report. Also, a complete list of all the publications for work supported under this grant are included in Section V below.

A. Publications Prepared During Current Period

1. Xiaoguang Wu and S. E. Ulloa, *Collective excitations of a two-dimensional electronic gas in a two-dimensional magnetic field modulation*, Phys. Rev. B, Rapid Communications, **47**, 10028 (1993) [DOE-ER45334-Pub#18].
2. Xiaoju Wu and S. E. Ulloa, *Raman scattering and collective excitations in doped tunneling semiconductor superlattices*, Phys. Rev. B **47**, 6799 (1993) [DOE-ER45334-Pub#19].
3. Yong S. Joe and S. E. Ulloa, *Electroconductance oscillations and quantum interference in ballistic nanostructures*, Phys. Rev. B **47**, 9948 (1993) [DOE-ER45334-Pub#20].

4. Yong S. Joe and S. E. Ulloa, *Quantum electronic interferometer without a potential barrier*, submitted to Appl. Phys. Lett. March 1993 [DOE-ER45334-Pub#21].
5. Namnee Kim and S. E. Ulloa, *Collective modes in tunneling quantum dot arrays*, submitted to Phys. Rev. B, March 1993 [DOE-ER45334-Pub#22].

B. Reprints of Publications Previously Reported

1. Xiaoguang Wu and S. E. Ulloa, *Electronic levels and collective excitations in a two-dimensional system with a spatial magnetic field modulation*, Solid State Commun. **82**, 945 (1992) [DOE-ER45334-Pub#13].
2. Xiaoguang Wu and S.E. Ulloa, *Electronic states and collective excitations of a two-dimensional electron gas in a unidirectional magnetic-field modulation*, Phys. Rev. B **47**, 7182 (1993) [DOE-ER45334-Pub#14].

C. Presentations at Meetings and Seminars

A. Presentations by S. E. Ulloa

- **Contributed paper:** Y.S. Joe and S. E. Ulloa, *Electroconductance oscillations and quantum interference in ballistic nanostructures*, XXXV National Physics Conference, Puebla, Mexico, 26–30 October 1992.
- **Contributed paper:** X. Wu and S. E. Ulloa, *Collective modes and a dimensional crossover induced magnetically*, XXXV National Physics Conference, Puebla, Mexico, 26–30 October 1992.
- **Contributed paper:** X. Wu and S. E. Ulloa, *Collective excitations of a 2D electron gas in a spatially modulated magnetic field*, Bull. Am. Phys. Soc. **38**, 180 (1993). American Physical Society, Seattle Meeting, March 1993.
- **Contributed paper:** X. Wu and S. E. Ulloa, *Collective excitations in solid C₆₀*, Bull. Am. Phys. Soc. **38**, 441 (1993). American Physical Society, Seattle Meeting, March 1993.
- **Colloquium:** Ballistic Transport in Semiconductor Nanostructures,
 - Instituto de Física, Laboratorio de Ensenada, Ensenada, B.C., Mexico, 13 October 1992.

- Instituto de Física, Laboratorio de Cuernavaca, Cuernavaca, Morelos, Mexico, 4 November 1992.
- Department of Physics, University of Toronto, Canada, 30 November 1992.

B. Presentations by Coauthors

- **Contributed paper:** X. Wu and S. E. Ulloa, *Collective excitations of a two-dimensional electron gas in a spatially modulated magnetic field*, 40th Midwest Solid State Conference, University of Illinois at Urbana-Champaign, Urbana, IL, 2–3 October 1992. Presenter: Xiaoguang Wu.
- **Contributed paper:** G. H. Coccoletzi and S. E. Ulloa, *Periodic potential modulation on 2D excitons in quantum wells*, 40th Midwest Solid State Conference, University of Illinois at Urbana-Champaign, Urbana, IL, 2–3 October 1992. Presenter: G. H. Coccoletzi.
- **Contributed paper:** D. Kachintsev and S. E. Ulloa, *Possibility of CDW instability induced by magnetic field in planar hexagonal lattice*, 1992 Midwest Solid State Theory Conference, Madison, WI, October 23–24, 1992. Presenter: D. Kachintsev.
- **Contributed paper:** X. Wu and S. E. Ulloa, *Raman scattering and collective excitations in doped semiconductor superlattices*, 1992 Midwest Solid State Theory Conference, Madison, WI, October 23–24, 1992. Presenter: Xiaoju Wu.
- **Contributed paper:** Y. S. Joe and S. E. Ulloa, *Quantum electroconductance oscillations in ballistic nanostructures*, 1992 Midwest Solid State Theory Conference, Madison, WI, October 23–24, 1992. Presenter: Y. S. Joe.
- **Contributed paper:** D. Kachintsev and S. E. Ulloa, *Bose-Einstein condensation of two-dimensional polarized excitons*, Bull. Am. Phys. Soc. **38**, 399 (1993). American Physical Society, Seattle Meeting, March 1993. Presenter: D. Kachintsev.
- **Contributed paper:** G. H. Coccoletzi and S. E. Ulloa, *Quasi-one-dimensional excitons in coupled potential wells*, Bull. Am. Phys. Soc. **38**, 399 (1993). American Physical Society, Seattle Meeting, March 1993. Presenter: G. H. Coccoletzi.
- **Contributed paper:** D. R. Alfonso and S. E. Ulloa, *Sticking coefficients of hydrocarbon radicals on (100) diamond surfaces*, Bull. Am. Phys. Soc. **38**, 281

(1993). American Physical Society, Seattle Meeting, March 1993. Presenter: D. R. Alfonso.

- **Contributed paper:** D. R. Alfonso and S. E. Ulloa, *Chemisorption of various hydrocarbons on the (100) surface of diamond*. American Physical Society, Seattle Meeting, March 1993. Presenter: D. R. Alfonso.

IV. Current and Pending Support

Current research support is provided only by this DOE grant and a Condensed Matter and Surface Sciences Postdoctoral Fellowship (awarded to Xiaoguang Wu). No residual funds are expected from the current DOE award at the end of the period.

Substantial computational support is provided through a grant from the Ohio Supercomputer Center, Research Grant No. PHS060, 1992–1993, 800 Resource Units in Cray Y/MP Computer (roughly equivalent to 800 CPU hours of Cray time).

Support for the installation of a computational facility in the Department of Physics has also been granted to us by the U. S. National Science Foundation, Instrumentation and Laboratory Improvement, *Computational Physics Laboratory*, in collaboration with R.W. Rollins, September 1992–1994, \$30,153. *These funds provide no faculty support* but only needed hardware and software for the teaching of physics in our department.

There are no pending proposals at this time.

V. Complete List of Publications for the Period 1990–1993

1. E. Castaño, G. Kirczenow, and S. E. Ulloa, *Nonlinear transport in ballistic quantum chains*, Phys. Rev. B, (**Rapid Communications**), **42**, 3753 (1990) [(DOE-ER45334-Pub#11)].
2. J. Zhang, S.E. Ulloa, and W. L. Schaich, *Infrared active excitations in tunneling superlattices and d-parameter theory*, Phys. Rev. B **43**, 9865 (1991) [(DOE-ER45334-Pub#12)].

3. Xiaoguang Wu and S. E. Ulloa, *Electronic levels and collective excitations in a two-dimensional system with a spatial magnetic field modulation*, Solid State Commun. **82**, 945 (1992) [DOE-ER45334-Pub#13].
4. Xiaoguang Wu and S.E. Ulloa, *Electronic states and collective excitations of a two-dimensional electron gas in a unidirectional magnetic-field modulation*, Phys. Rev. B **47**, 7182 (1993) [DOE-ER45334-Pub#14].
5. X. Wu and S. E. Ulloa, *Electron-phonon interaction in double-barrier resonant tunneling*, Phys. Rev. B **44**, 13148 (1991) [DOE-ER45334-Pub#15].
6. S. E. Ulloa, A. MacKinnon, E. Castaño, and G. Kirczenow, *From ballistic transport to localization*, to appear in *Handbook on Semiconductors*, P.T. Landsberg, editor (North Holland, Amsterdam, 1992) [DOE-ER45334-Pub#16].
7. S. E. Ulloa, *Optical and Transport Properties of Electronic Structures*, Visions (publication of the Ohio Supercomputer Center), Spring/Summer 1991, pp. 11–15 [DOE-ER45334-Pub#17].
8. Xiaoguang Wu and S. E. Ulloa, *Collective excitations of a two-dimensional electronic gas in a two-dimensional magnetic field modulation*, Phys. Rev. B, to appear (1993) [DOE-ER45334-Pub#18].
9. Xiaoju Wu and S. E. Ulloa, *Raman scattering and collective excitations in doped tunneling semiconductor superlattices*, Phys. Rev. B **47**, 6799 (1993) [DOE-ER45334-Pub#19].
10. Yong S. Joe and S. E. Ulloa, *Electroconductance oscillations and quantum interference in ballistic nanostructures*, Phys. Rev. B, to appear (1993) [DOE-ER45334-Pub#20].
11. Yong S. Joe and S. E. Ulloa, *Quantum electronic interferometer without a potential barrier*, submitted to Appl. Phys. Lett. March 1993 [DOE-ER45334-Pub#21].
12. Nammee Kim and S. E. Ulloa, *Collective modes in tunneling quantum dot arrays*, submitted to Phys. Rev. B, March 1993 [DOE-ER45334-Pub#22].

*Preprints & reprints
removed & cited separately.*

**DATE
FILMED**

7 / 27 / 93

END