MASTER

DOE/ER/10459-3

Inter-Subband Optical Absorption in an Inversion Layer
on a Semiconductor Surface in Tilted Magnetic Fields

Progress Report

R.F. O'Connell

Department of Physics and Astronomy
Louisiana State University
Baton Rouge, Louisiana 70803

July 1, 1979 - June 30, 1980

DISCLAIMER

This book 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.

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY UNDER CONTRACT NO.
DE-AS05-79ER10459

APPROVED FOR RELEASE OR
PUBLICATION - O.R. PATENT GROUP
BY *J. Leary* DATE *4-22-80*

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

fly

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.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Abstract

In a magnetic field tilted with respect to the surface of Si, Beinvogl and Koch observed combined resonance transitions, resulting from a coupling of Landau levels and subband states, in an accumulation layer on n-type (100) Si. Because of some unexplained features in the observations, we have analyzed what one should expect on theoretical grounds. As a result of both analytic and numerical calculations, we conclude that there are still unexplained discrepancies between theory and experiment, which in turn has prompted us to extend the scope of our theoretical investigations.

We have also investigated the absorption of radiation in a magnetoplasma and applied our results to the laser fusion process and we have shown how the presence of a magnetic field can give rise to increased absorption. The techniques acquired in this investigation will be very useful to us in our planned investigations of magneto-optical phenomena (particularly the Faraday Effect) in MOS systems.

This progress report is primarily concerned with a program of analysis of the so-called two-dimensional electron gas which occurs on semi-conductor surfaces in MOS (metal-oxide-semi-conductor) systems, with particular emphasis on the intersubband-cyclotron combined resonance in the surface space-charge layer in the presence of a magnetic field tilted with respect to the surface. In addition, we report on the completion of a previously initiated project, which was carried out in collaboration with Professor G.W. Ford, University of Michigan. This was concerned with the absorption of radiation in a magnetoplasma and the application of the results to the laser fusion process.

Turning first to our investigations of MOS systems, our primary focus was concerned with a recent experiment by Beinvogl and Koch.¹⁾ These authors investigated elections on Si(1,0,0), in the presence of a magnetic field tilted with respect to the sample surface (H_y and H_z components), and observed combined resonance transitions because of a coupling of Landau levels and subband states. Surprisingly, they found that the sum of the separations for the $\Delta N = -1$ and $\Delta N = 1$ transitions is $\{0.7 - (-1.6)\} \hbar\omega_c = 2.3\hbar\omega_c$ i.e. 15% higher than the expected result of $2\hbar\omega_c$.

The initial theoretical work on this problem was carried out by Ando,²⁾ leading to the "expected result" just quoted. A basic assumption made by Ando was to treat H_y as a perturbation so that its influence on the z-part of the wave function is neglected. Thus, we decided to release this restriction by carrying out a numerical calculation, which would also take into account higher

subbands. As it turned out, Ando also had a similar idea³⁾ and published his results while we were still in the early stages of our own investigation. However, it was clear from Ando's results that discrepancies between theory and experiment still exist (see figure 9 of reference 3), which encouraged us to continue with our own investigations, particularly when we were informed that the experimental results had not "gone away." It soon became clear to us that our results were no different than those of Ando.

We then decided to look carefully at an analytic approach, with emphasis on pinpointing the extent of the validity of a perturbation approach. Our results have just been written up and will be submitted for publication.⁴⁾ We concluded that, as far as an analysis of the Beinvogl-Koch observations are concerned, perturbation theory is even much better than one might have expected. Thus it was clear why the numerical investigations were not producing any better agreement between theory and experiment. Furthermore, it highlighted for us our previous suspicion that this discrepancy would only be resolved by tracking down some other effects or phenomena not considered heretofore. This is where our present emphasis lies.

Turning now to magneto-optical effects in MOS systems we decided, for several reasons, to carry out some investigations in this area. First of all this is an area of intrinsic interest and much importance, second we felt it was a good topic for the purpose of broadening our overall understanding of MOS systems, and thirdly, we enjoy the benefit of discussions with an experimentalist in our department (Dr. Piller), who hopes to carry out Faraday rotation measurements on such systems.

My entrée into the world of magneto-optics was greatly facilitated by the knowledge gained in completing, in collaboration with Professor G.W. Ford, University of Michigan, a previously initiated project on the absorption of radiation in a magnetoplasma and with application of the results to the laser fusion process. A previous investigation by Bethe⁵⁾ had not considered the effect of a magnetic field. We showed that in the presence of a magnetic field, the absorption rate can be either increased or decreased depending on the relative orientations of the polarization vector of the laser beam, the incident direction, and the magnetic field direction, and depending on the relative magnitudes of the electron's average energy due to thermal and electric field effects. In particular, for radiation incident along the magnetic direction, we showed that the absorption or right-circularly-polarized radiation is decreased whereas that of left-circularly polarized radiation is increased, if we are in the weak electric field regime (thermal effects dominate). On the other hand, in the strong electric field regime, the rate of absorption of right polarized radiation is greater than that of left. A paper detailing this work has been accepted for publication in Phys. Rev.A.⁶⁾

The work currently in progress, which will be continued during the remaining four months of this contract year - and hopefully into a new contract year - can be summarized as follows:

(a) Further investigations will be carried out into the discrepancies between the experimental results of Beinvogl and Koch and theoretical predictions. We hope to survey the various effects not included in the work, such as, for example, the effect of a magnetic field on the exchange-correlation potential. Another

topic also worthy of study is the possible implications arising from the very recent evidence⁷⁾ for the existence of a highly correlated or crystallized ground state in Si inversion layers in the extreme quantum limit. (b) The feasibility of carrying out Faraday rotation measurements on the MOS system will be investigated in detail. Such measurements are potentially useful for giving information on effective masses and collision frequencies and for analysis of various models, as for example the model of Appel and Overhauser,⁸⁾ who consider two degenerate electron systems interacting with one another.

During the current contract year, Dr. O'Connell spent 25% of his time during the academic year, and 100% for 1 1/2 months in the summer (July 1 - August 15, 1979), working on this contract.

References

1. W. Beinvogl and J.F. Koch, Phys. Rev. Lett. 40, 1736 (1978).
2. T. Ando, Solid State Commun. 21, 801 (1977).
3. T. Ando, Phys. Rev. B19, 2106 (1979).
4. R.F. O'Connell, to be submitted for publication.
5. H.A. Bethe, Los Alamos Scientific Laboratory Informal Report No. LA-5031-MS, 1972 (unpublished).
6. G.W. Ford and R.F. O'Connell, Phys. Rev. A, in press.
7. B.A. Wilson, S.J. Allen, Jr., and D.C. Tsui, Phys. Rev. Lett. 44, 479 (1980).
8. J. Appel and A.W. Overhauser, Phys. Rev. B 18, 758 (1978).

ARTICLES PREPARED FOR PUBLICATION IN CONTRACT YEAR 7/79 - 6/80

- DOE/ER/10459 -1 Intersubband-Cyclotron Combined Resonance in a
Surface Space-Charge Layer
R.F. O'Connell
to be submitted for publication
- DOE/ER/10459 -2 Absorption of Radiation in a Magnetoplasma and
Application to the Laser Fusion Process
G.W. Ford and R.F. O'Connell
Phys. Rev. A (in press)