SUPERLATTICES AND NiPi STRUCTURES IN NEW FORMS OF CASCADE SOLAR CELLS

Semiannual Report No. 4

(October 23, 1985 to April 22, 1986)

for

NASA NAG3-507

(NASA-CR-176718) SUPERLATTICES AND NiPi STRUCTURES IN NEW FORMS OF CASCADE SOLAR CELLS Semiannual Report, 23 Oct. 1985 - 22 Apr. 1986 (Illinois Univ., Urbana-Champaign.) 11 p HC A02/MF A01 G3/44 N86-24007 Unclas 05932

National Aeronautics and Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135

Prepared by

J. P. Leburton and K. Hess

Department of Electrical and Computer Engineering
University of Illinois at Urbana-Champaign
1406 W. Green St.
Urbana, IL 61801

This document is the fourth Semiannual Report written under the contract NASA NAG3-507. It describes the activity of our group in the field of photovoltaic semiconductor superstructures, for the period October 23, 1985 to April 22, 1986. Progress has been accomplished in the two principal directions previously defined in our initial proposal, i.e.,

a) Theoretical investigation of the optical properties of superlattices

b) New solar cell concepts and device modeling.

Although important information concerning the optical constants of superlattices and multiple quantum well structures has been obtained from our computer model, most of the theoretical efforts have progressively shifted from the former to the latter aspect of the project because of the discovery of a new kind of photovoltaic device which may exhibit improved performances with respect to conventional solar cells.

A) <u>Optical Properties of III-V Semiconductor Superlattices and Related Alloys: Fundamental apspect</u>.

Our computer model has now been implemented to calculate the optical constants of III-V compounds and superlattices (SL) with a relatively good accuracy.

With respect to the SL absorption coefficient α, the discrepancy existing at high photon energy, i.e., $E \geq 1.9$ eV, between our theoretical results and the experimental data has been elucidated. After discussion with the group of Professor Holonyak, it appears that the high value exhibited by the absorption coefficient was an experimental artifact and that our results were close to the reality.

With respect to the SL index of refraction, it appears that our model overestimates the birefringence resulting from the anisotropy of the superstructures. Our model has been revised with a more careful analysis of the influence of the confinement caused by the multiple quantum-well structures on the electronic properties. Excitonic effects are now included in our model, and a first estimation of their contribution to the SL index of refraction shows a better agreement with the experimental data.

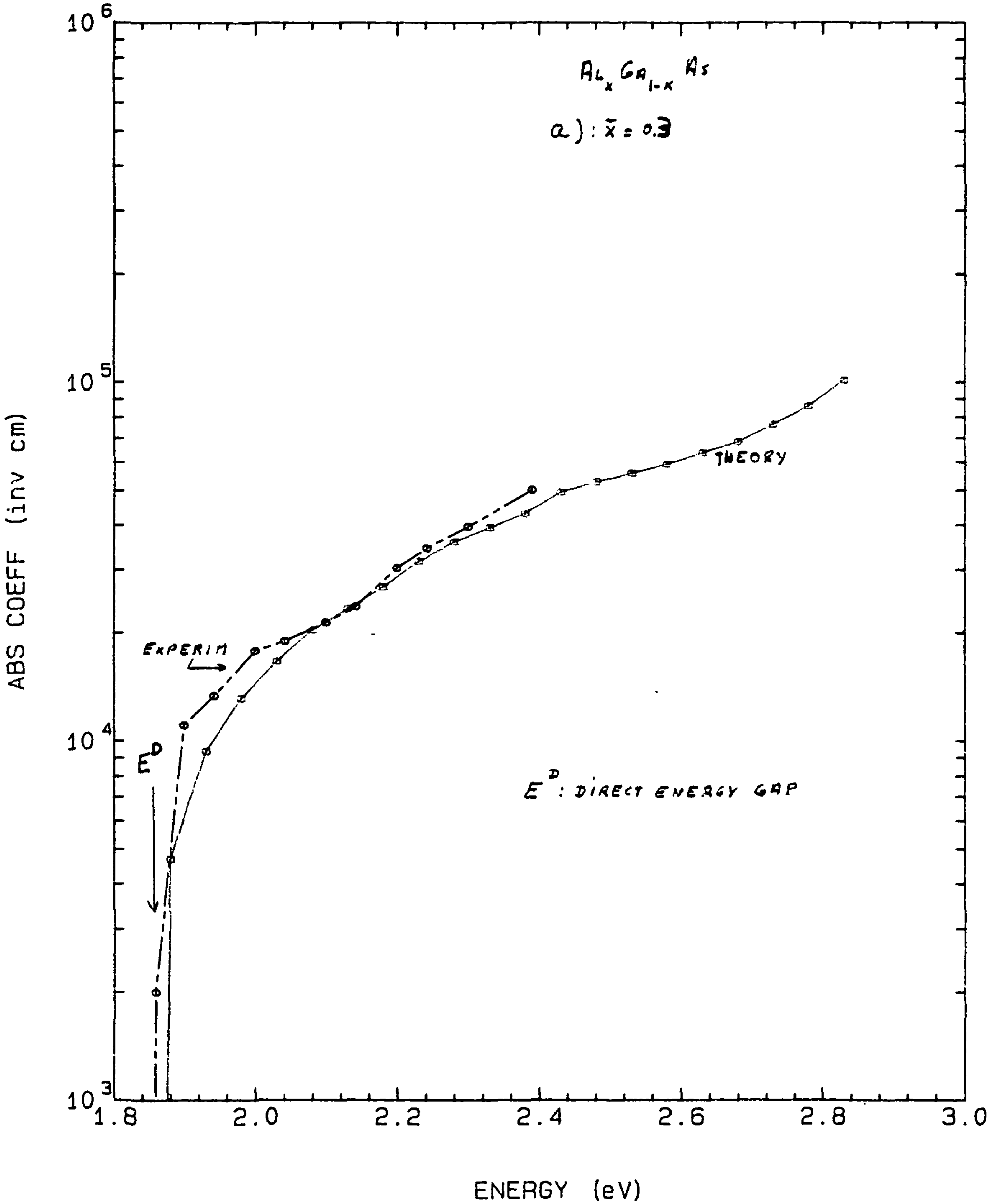
Our computer work has been extended to the study of III-V binary alloys. The influence of the disordered materials has been treated in the coherent potential approximation (C.P.A.) which allows us to account for the indirect Γ-X and Γ-L optical transitions induced by disorder scattering. Results for the absorption coefficient of $Al_xGa_{1-x}As$ with $x > 0.4$ show shoulders for photon energy corresponding to the indirect absorption (see attached figures).

Work is in progress to incorporate the optical constant program intc a general simulation code which models the new structures that we propose, for enhancing the efficiency of photovoltaic devices.

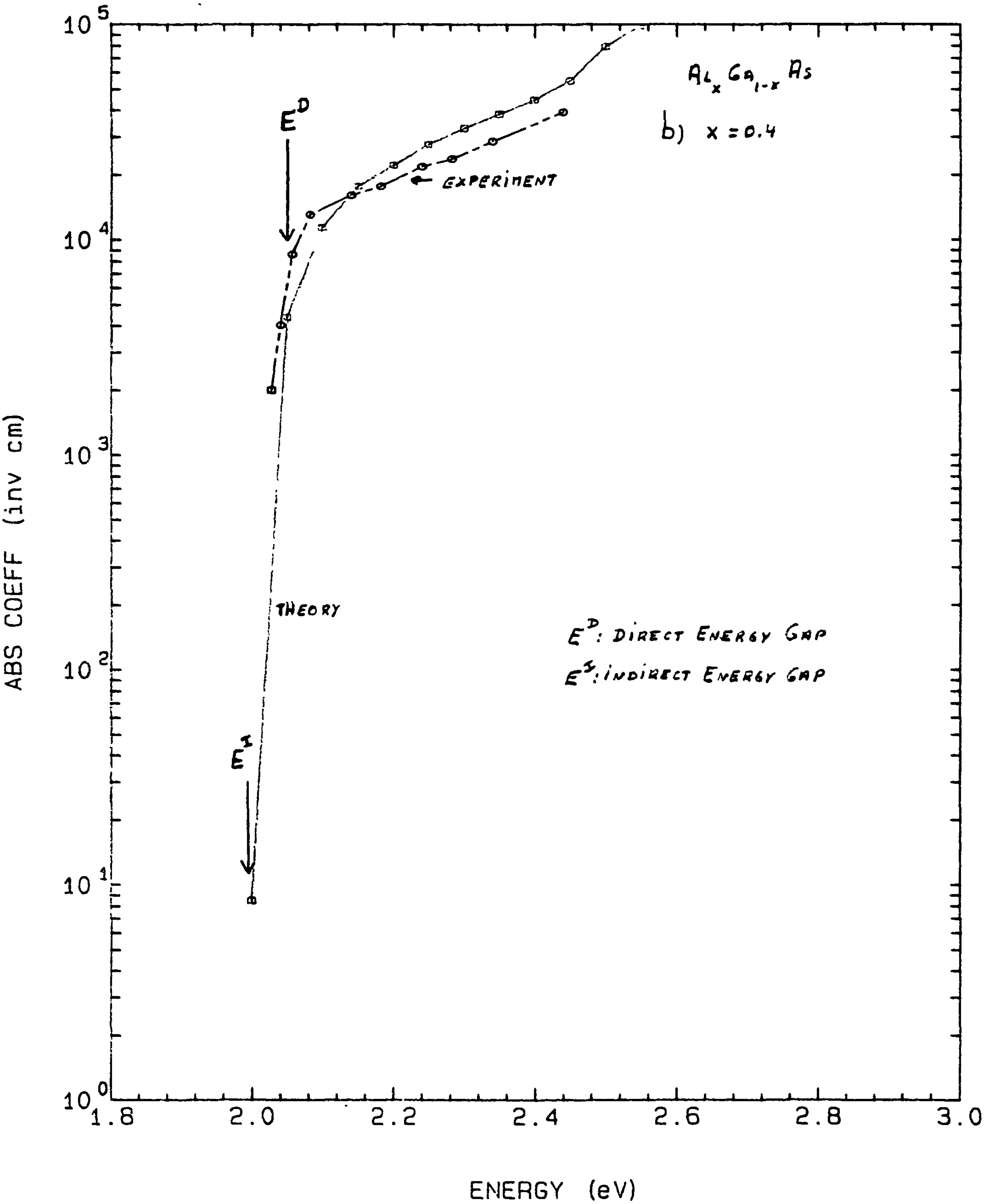
Figure Captions:

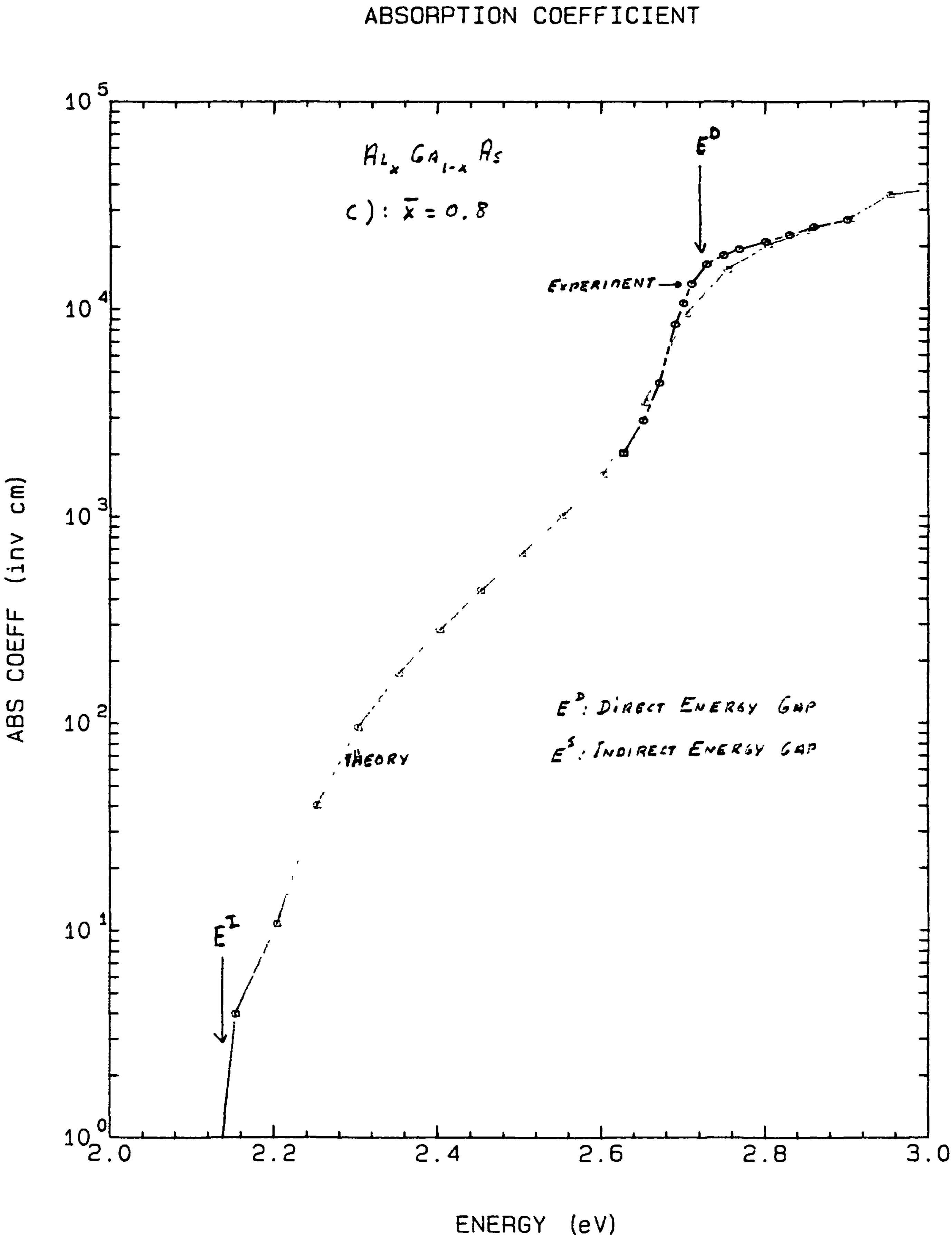
Absorption coefficient of Al_xGa_1-As as a function of the photon energy for three different ALAs compositions: a) x = 0.3; b) x = 0.4; c) x = 0.8; the absorption shoulder is quite apparent for the latter at energy below the direct gap.

ABSORPTION COEFFICIENT



ABSORPTION COEFFICIENT




ABSORPTION COEFFICIENT
ABS COEFF (inv cm)
ENERGY (eV)
Al_x Ga_1-x As
c): x̄ = 0.8
E^D
E^I
EXPERIMENT
THEORY
E^D: DIRECT ENERGY GAP
E^S: INDIRECT ENERGY GAP
10^5
10^4
10^3
10^2
10^1
10^0
2.0
2.2
2.4
2.6
2.8
3.0

B) New Photovoltaic Concepts and Modeling

The proposed device, referred to as SHEP for Superstructure High Efficiency Photovoltaic, is described briefly in the attached publications. As reported previously, efficiencies in excess of 26% have been estimated. During the last semester, we have implemented the model and concentrated on the following issues. More specfically, we have

- Added a Si_3N_4 antireflection coating model. Using published data on coating thickness and its index of refraction, we compute the reflection coefficient at each sample wavelength of the solar spectrum, rather than simply assuming uniform 5% reflectance as we had done previously.
- Developed equations for detailed modeling of series resistance effects in order to study device performance under high solar concentration. Resistive effects cause interactions between adjacent layers of the multilayer structures, so that the simpler model of multiple diodes shunting multiple current sources is no longer valid under high concentration. These equations will be incorporated into the software.
- Developed software for modeling two terminal SHEP with tunnel junction interconnect. As expected, efficiencies are somewhat lower than for three-terminal SHEPs (~ 25%). Future modeling with an InGaAs lower subcell should provide considerably higher efficiencies, since the smaller gap alloy yields a more optimal partition of the solar spectrum.
- Modified our program to include optimization of doping concentrations. Efficiencies are not particularly sensitive to doping concentration values (as long as they are not more than an order of magnitude from optimal values), so this change has produced no significant new results.
- Written software to plot spectral response curves for multilayer, multibandgap structures. Our results verify that, as anticipated, most of the

spectral response improvement occurs for carriers photogenerated by photons with energies near the bandgap which are absorbed deep in the structure. Without the additional junctions, many of these carriers are lost to recombination.

- Studied alternative optimization criteria. Instead of maximizing BOL efficiency we have tried maximizing a weighted average of BOL and EOL efficiencies (choosing an arbitrary diffusion length degradation factor for calculating EOL efficiencies) in order to obtain larger total output energy from the cell over its useful life.
- Investigated factors influencing the extent to which the space-charge recombination component of the dark current dominates the injected component. We have concluded that variations in composition have surprisingly little effect. Efficiency curves for various SHEP structures as a function of upper subcell composition were computed with and without space-charge recombination. Most of the divergence between these two sets of curves resulted not from variations in top subcell composition, but rather from changes in the amount of illumination reaching the lower subcell which affects its open-circuit voltage. The predominance of space-charge recombination dark current or injected dark current depends critically on <u>where</u> one is on the I-V curve.

Publications

During the fourth semester of the grant, two papers have been published in periodical journals, and three communications have been presented to conferences

1) K. B. Kahen and J. P. Leburton, "General theory of the transverse dielectric constant of III-V semiconducting compounds." Phys. Rev. B32, 5177 (1985)

2) K. B. Kahen and J. P. Leburton, "Optical constants of GaAs. $Al_xGa_{1-x}As$ superlattices and multiple quantum wells." Phys. Rev. B33 (April 15, 1986) in press.

Conference papers

1) M. Wagner and J. P. Leburton, "Superstructures and multijunction cells for high efficiency energy conversion," Proceedings of the 18th IEEE Photovoltaic Specialists Conference, October 21-25, 1985, Las Vegas, Nevada.

2) M. Wagner and J. P. Leburton, "Three terminal multilayer GaAs-AlGaAs cascade cells with selective electrodes," ibid.

3) M. Wagner and J. P. Leburton, "Superstructures for high efficiency photovoltaics." Workshop of the Physical Electronic Affiliates Program, April 15-16, 1986, University of Illinois, Urbana-Champaign, Illinois.

Papers in preparation

- M. Wagner and J. P. Leburton, "Superstructures for high efficiency photovoltaic" to be submitted to Appl. Phys. Letters.
- M. Wagner and J. P. Leburton, "Improved spectral response and radiation tolerance with multilayer-photovoltaic structures" to be submitted to J. of Applied Physics.

Scientific Personnel

J. P. Leburton, Principal Investigator, Assistant Professor

K. Hess, Coprincipal Investigator, Professor

K. B. Kahen, Research Assistant (Ph.D. student)

M. Wagner, Research Assistant (M.S. student)