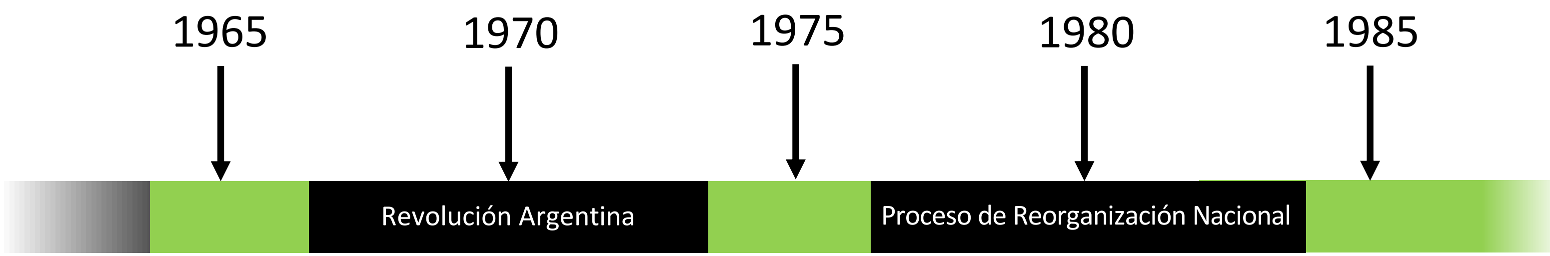
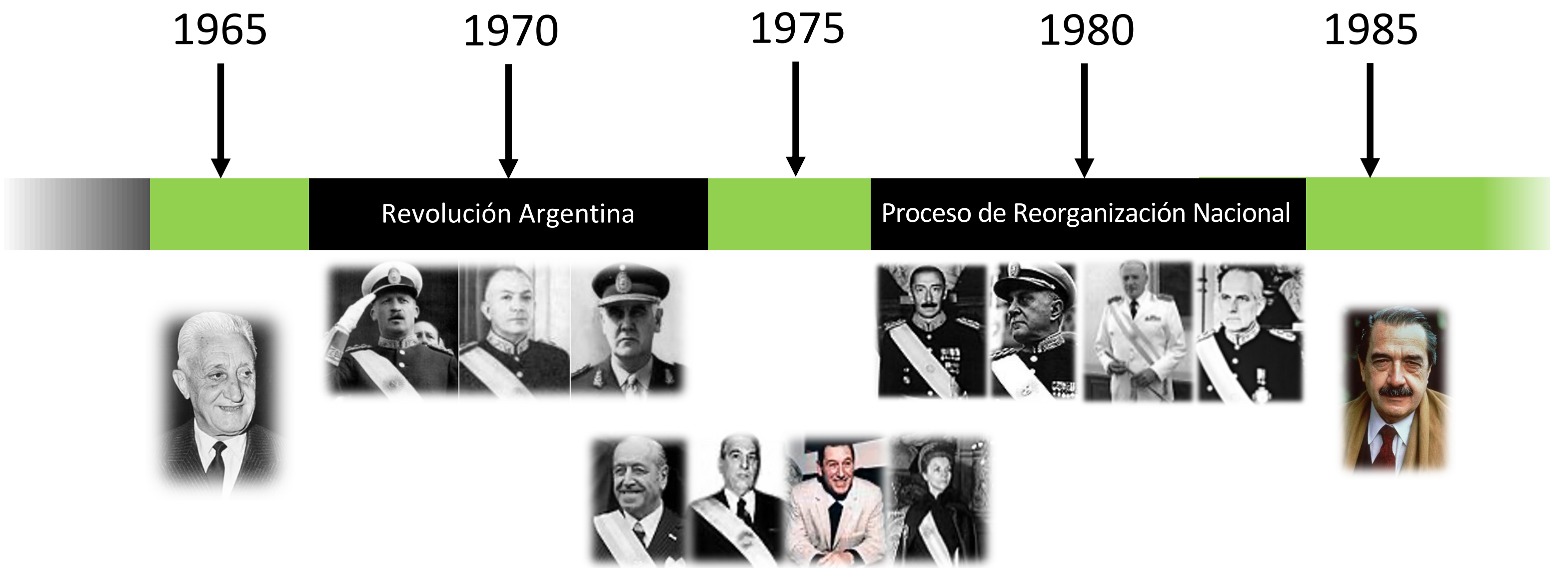
# Aron Pinczuk:

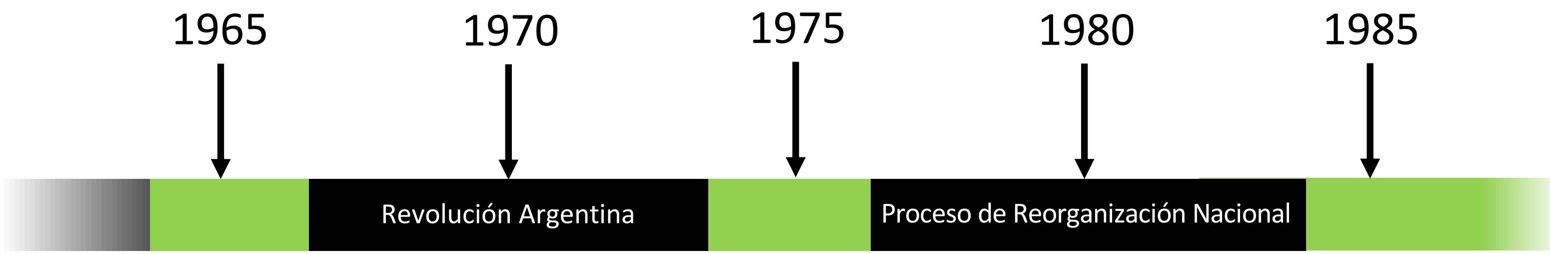
## The early days of light scattering in solids at Penn, the return to Argentina and the pioneering work on two-dimensional electrons at Bell Labs




During the first three decades of the 20th century, Argentina outgrew Canada and Australia in population, total income, and per capita income. By **1913, Argentina was the world's 10th wealthiest state per capita**. Beginning in the 1930s, however, the Argentine economy deteriorated notably. The single most important factor in this decline has been **political instability** since 1930, when a **military junta** took power, ending seven decades of civilian constitutional government. Argentina was one of the most stable and conservative countries until the Great Depression, after which it turned into one of the most unstable. Despite this, up **until 1962** the Argentine per capita GDP was higher than that of Austria, Italy, Japan and of its former colonial master, Spain.
https://en.wikipedia.org/wiki/Economic_history_of_Argentina



1965
1970
1975
1980
1985
Revolución Argentina
Proceso de Reorganización Nacional

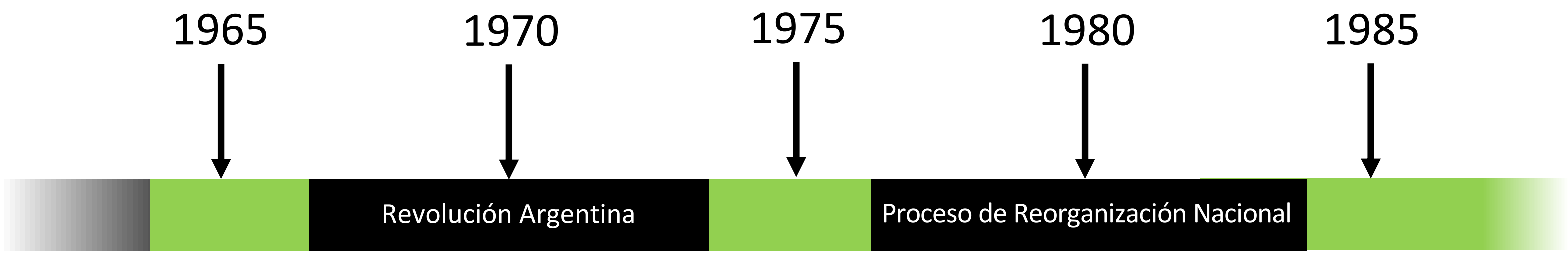

1965
1970
1975
1980
1985
Revolución Argentina
Proceso de Reorganización Nacional


LISTA REFORMISTA
integrada por
GUILLERMO SARMIENTO
CECN
ACHE PINCZUK
MUR del cefmym
DAVID SCHIFFRIN
MAR de Quimica
RICARDO BADUEL
MUR del cefmym
ALEJO LEVENSON
MAR de Quimica
DANIEL WISNIVESKY
Una permanente consulta a los estudiantes.
EL 1 Y 2 DE OCTUBRE
VOTA
LISTA REFORMISTA
ACHE PINCZUK
MUR del cefmym

1959-1960


29 de Julio
LA NOCHE DE LOS
BASTONES LARGOS


1966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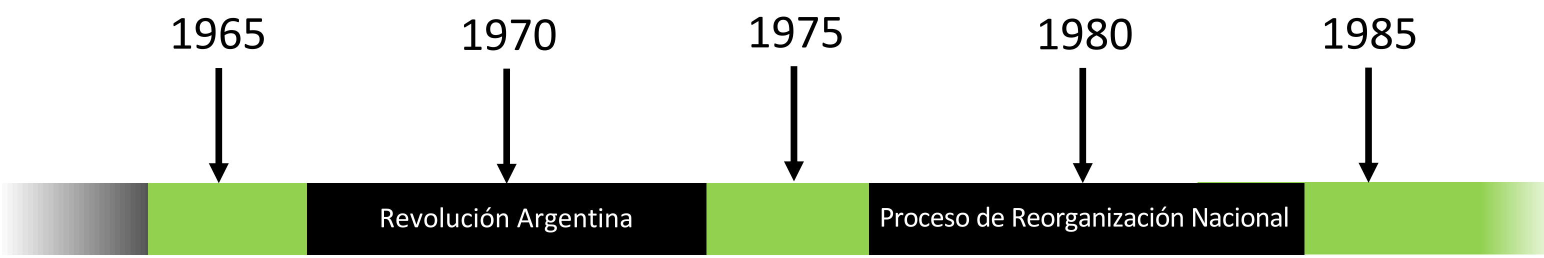
1970
1975
1980
1985
Revolución Argentina
Proceso de Reorganización Nacional


LUZ y FUERZA
LUZ y FUERZA
LUZ y FUERZA
EL CORDOBAZO - 1969

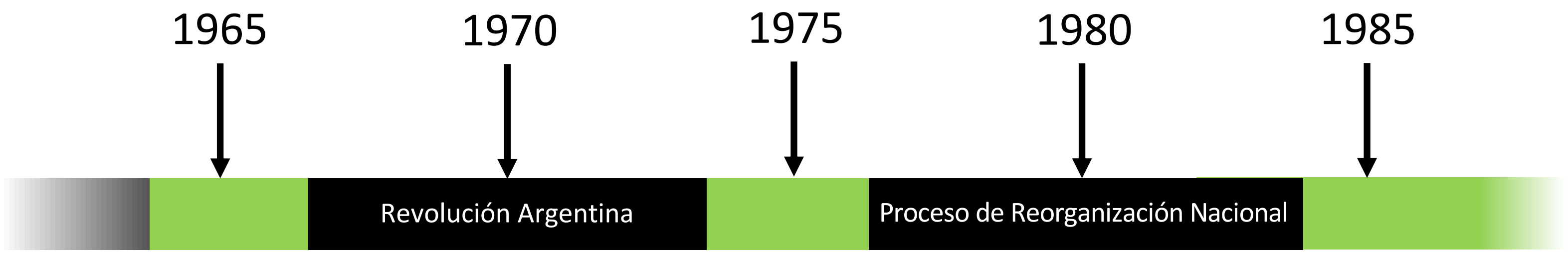

¿DONDE ESTAN, LOS CENTENARES DE BEBES NACIDOS EN CAUTIVERIO?
ABUELAS DE PZA DE MAYO


HOMENAJE A LAS VÍCTIMAS DEL TERRORISMO DE ESTADO DE NUESTRA FACULTAD
EXACTAS


1965
1970
1975
1980
1985
Revolución Argentina
Proceso de Reorganización Nacional


40 ANIVERSARIO
2/4/1982
GUERRA DE LAS MALVINAS
La guerra de las Malvinas (en inglés, Falklands War) fue un conflicto armado entre Argentina y Reino Unido desatado en 1982, en el cual se disputó la soberanía de las Islas Malvinas, Georgias del Sur y Sandwich del Sur, ubicadas en el Atlántico Sur
El 2 de abril de 1982, Argentina sufría una crisis económica que ponía en riesgo al régimen. Su presidente, Leopoldo Galtieri, lanzó un ataque contra las Islas Malvinas para contentar a los ciudadanos que reclamaban la soberanía de las islas
Margaret Thatcher, primera ministra inglesa dijo: "Un territorio de soberanía británica ha sido invadido por una potencia extranjera. El Gobierno ha decidido enviar una gran fuerza expedicionaria" Había comenzado la guerra...
A 12.000 km de las Malvinas
La flota inglesa salió de Portsmouth y se reunió con barcos que provenían de diferentes colonias británicas. Utilizaron la isla Ascensión, cedida por EE. UU., como base operativa antes de partir rumbo al Atlántico Sur
REINO UNIDO
Portsmouth
Océano Atlántico
Gibraltar
Bermuda
Belice
Ascensión
ARGENTINA
Islas Malvinas
Barcos ingleses hundidos
Principales enfrentamientos
Barcos argentinos hundidos
Coventry
Estrecho San Carlos
Narval
Atlantic Conveyor
Isla Trinidad
Douglas
Antelope
Isla Gran Malvina
Isla Soledad
Puerto Stanley
Ardent
Bahía Agradable
Darwin-Pradera del ganso
Puerto Fox
SIR Gatahad
Isla San José
Ara Bahía Buen Suceso
Ara Río Cacaraña
Ara Isla de los Estados
Sheffield
30 km








Argentine
Anticommunist
Alliance


1965 | 1970 | 1975 | 1980 | 1985

Revolución Argentina

Proceso de Reorganización Nacional


# ARON PINCZUK TIMELINE 1965-1985

1965 1970 1975 1980 1985

Revolución Argentina

Proceso de Reorganización Nacional

Penn University of Pennsylvania

CNEA

Max-Planck-Institut für Festkörperforschung

Bell Laboratories

IBM

CNEA

Max-Planck-Institut für Festkörperforschung

University of Illinois Urbana-Champaign

University of Michigan

Research Assistant: 1972-73

Licenciado (Master): 1973

Ph.D. Student: 1973-75

# PHILADELPHIA 1965-1971

# EARLY DAYS OF LIGHT SCATTERING IN SOLIDS

(mid to late 1960s)

- **FIRST OPERATING LASER (1960)**
- **He-Ne ION LASER (1962)**
- **ARGON ION LASER (1964)**
- **KRYPTON ION LASER (1964)**

Solid State Communications, Vol. 5, pp.429-433, 1967. Pergamon Press Ltd. Printed in Great Britain

THE RAMAN SPECTRUM OF $BaTiO_3$

A. Pinczuk,* W. Taylor, E. Burstein

Department of Physics, and Laboratory for Research on the Structure of Matter, University of Pennsylvania†, Philadelphia, Pennsylvania

and

I. Lefkowitz

Pittman-Dunn Laboratory, Frankford Arsenal, Philadelphia, Pennsylvania

(Received 22 March 1967 by E. Burstein)

The polarization of the Raman Spectrum of $BaTiO_3$ was studied for different scattering geometries. The frequencies and symmetries of most of the Raman active pure symmetry phonons were determined. A trans... ...symmetry was found in the vici... ...an Spectra of... Lyddan...

...spectra were excited with... laser operated at 6328 Å. Two sca... ...metries were used: the usual right angle geometry, and the backward scattering arrangement. The latter proved to be very useful in studying the $A_1$ modes. The scattered light was analyzed with a double grating monochromator designed by Dr. A. Filler of the University of Pennsylvania. The detector was a S-20 photomultiplier and the spectrum was recorded on a ...tal output at intervals of either 1.7 or ...$^{-1}$ using a photon counting electr...

# EARLY DAYS OF LIGHT SCATTERING IN SOLIDS

(mid to late 1960s)

- **FIRST OPERATING LASER (1960)**
- **He-Ne ION LASER (1962)**
- **ARGON ION LASER (1964)**
- **KRYPTON ION LASER (1964)**

Solid State Communications, Vol. 5, pp. 429-433, 1967. Pergamon Press Ltd. Printed in Great Britain

THE RAMAN SPECTRUM OF $BaTiO_3$

A. Pinczuk,* W. Taylor, E. Burstein

VOLUME 21, NUMBER 15 PHYSICAL REVIEW LETTERS 7 OCTOBER 1968

[5]K. Ohta, talk presented at a meeting of the Physical Society of Japan, April, 1966 (unpublished).
[6]J. J. Hopfield and D. G. Thomas, Phys. Rev. 122, 35 (1961).
[7]R. G. Wheeler and J. O. Dimmock, Phys. Rev. 125, 1805 (1962).
[8]J. C. Miklosz and R. G. Wheeler, Phys. Rev. 153, 913 (1967).

RAMAN SCATTERING FROM InSb SURFACES AT PHOTON ENERGIES NEAR THE $E_1$ ENERGY GAP*

A. Pinczuk and E. Burstein
Physics Department and Laboratory for Research on the Structure of Matter, University of Pennsylvania, Philadelphia, Pennsylvania
(Received 3 September 1968)

EXCITON-ENHANCED RAMAN SCATTERING BY OPTICAL PHONONS

E. Burstein*† and D. L. Mills‡
Physics Department, University of California, Irvine, California
and
A. Pinczuk* and S. Ushioda*
Physics Department and Laboratory for Research on the Structure of Matter, University of Pennsylvania, Philadelphia, Pennsylvania

THEORY

Solid State Communications, Vol. 6, pp. 407 - 411, 1968. Pergamon Press. Printed in Great Britain

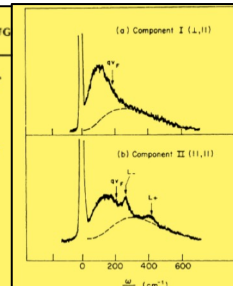
RAMAN SCATTERING BY POLARITONS*

THEORY

VOLUME 27, NUMBER 6 PHYSICAL REVIEW LETTERS 9 AUG

Resonant Light Scattering by Single-Particle Electronic Excitations in *n*-GaAs†

A. Pinczuk,* L. Brillson, and E. Burstein
*Department of Physics and Laboratory for Research on the Structure of Matter, University of Pennsylvania, Philadelphia, Pennsylvania 19104*
and
E. Anastassakis
*Department of Physics, Northeastern University, Boston, Massachusetts 02115*
(Received 29 March 1971)



Elias Burstein

VOLUME 15, NUMBER 17 PHYSICAL REVIEW LETTERS 25 OCTOBER 1965

RAMAN SCATTERING BY *F* CENTERS

J. M. Worlock and S. P. S. Porto
Bell Telephone Laboratories, Murray Hill, New Jersey
(Received 10 September 1965)

*F* centers in alkali-halide crystals possess strong broad absorption and fluorescence bands in the near ultraviolet, visible, and near infrared. The breadth of these bands is characteristic of electronic transitions in the alkali halides, and is indicative of strong coupling between electrons and phonons. Much

horizontal and perpendicular to the polarization of the beam. The narrow linear source of scattered radiation was focused onto the entrance slit of the spectrometer, and polarization of the Raman radiation was observed simply by inserting a polarizer in front of the entrance slit.

VOLUME 22, NUMBER 15 PHYSICAL REVIEW LETTERS 14 APRIL 1969

(1961) [translation: Soviet Phys.—Solid State 3, 1737 (1961)].
[2]R. Loudon, J. Phys. (Paris) 26, 677 (1965), and Advan. Phys. 13, 423 (1964).
[3]A. K. Ganguly and J. L. Birman, Phys. Rev. 162, 806 (1967).
[4]R. C. C. Leite, T. C. Damen, and J. F. Scott, in Proceedings of the International Conference on Light Scattering Spectra of Solids, New York University, September, 1968, edited by G. B. Wright (to be published).
[5]As discussed in the text, we cannot distinguish free and bound excitons in this experiment.
[6]R. Loudon, J. Phys. (Paris) 26, 677 (1965).
[7]M. A. Nusimovici and J. L. Birman, Phys. Rev. 156, 925 (1967).
[8]R. C. C. Leite and J. F. Scott, Phys. Rev. Letters 22, 130 (1969).
[9]Present work. We find $\omega_{LO} = 253\ \text{cm}^{-1}$, $\omega_{2\,LO} = 500\ \text{cm}^{-1}$. We have also been informed of similar observations in InSb (A. Pinczuk, private communication).
[10]P. J. Dean, Phys. Rev. 168, 889 (1968).

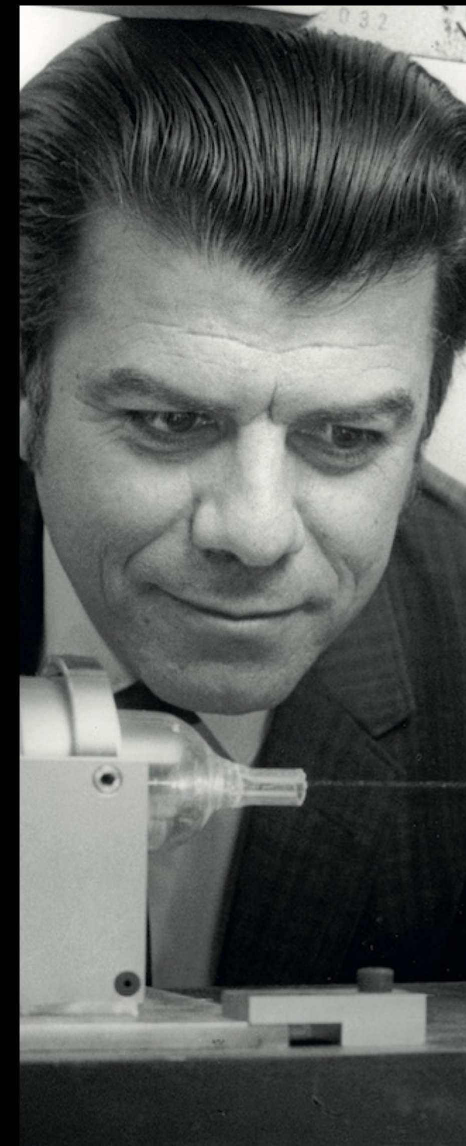
MULTIPLE-PHONON-RESONANCE RAMAN EFFECT IN CdS*

Miles V. Klein† and S. P. S. Porto
Department of Physics and Department of Electrical Engineering,
University of Southern California, Los Angeles, California 90007
(Received 23 January 1969)

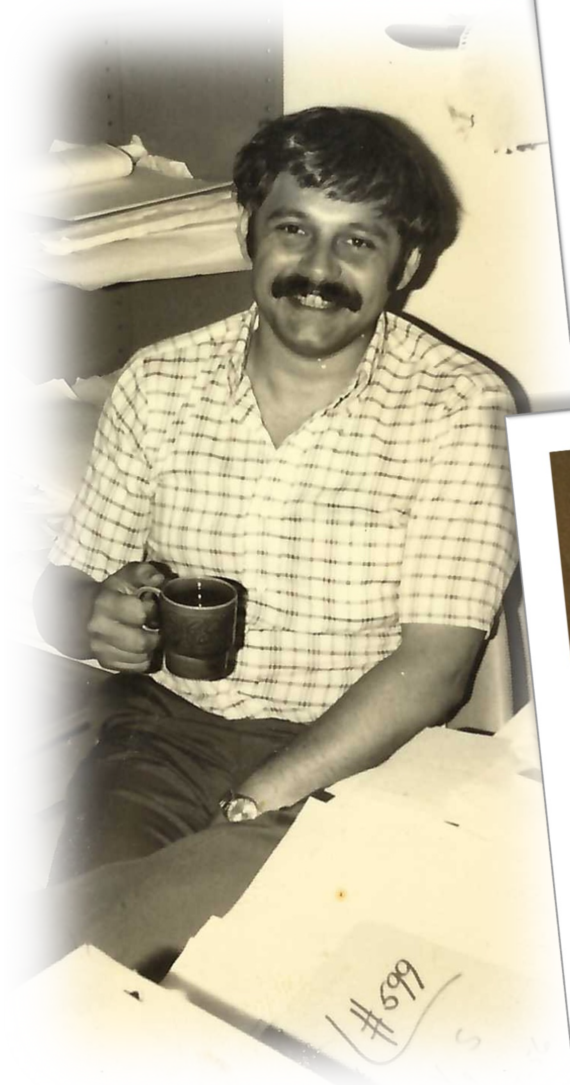
Solid State Communications, Vol. 8, pp. 133–138, 1970. Pergamon Press. Printed in Great Britain

EFFECT OF STATIC UNIAXIAL STRESS ON THE RAMAN SPECTRUM OF SILICON

E. Anastassakis,* A. Pinczuk and E. Burstein
Physics Department and Laboratory for Research on the Structure of Matter†
University of Pennsylvania, Philadelphia, Pa. 19104
and
F.H. Pollak and M. Cardona
Physics Department,‡ Brown University, Providence, Rhode Island
(*Received* 1 *December* 1969 *by E. Burstein*)



Sergio Porto




1960s


ARGENTINA
(1971- 1975)

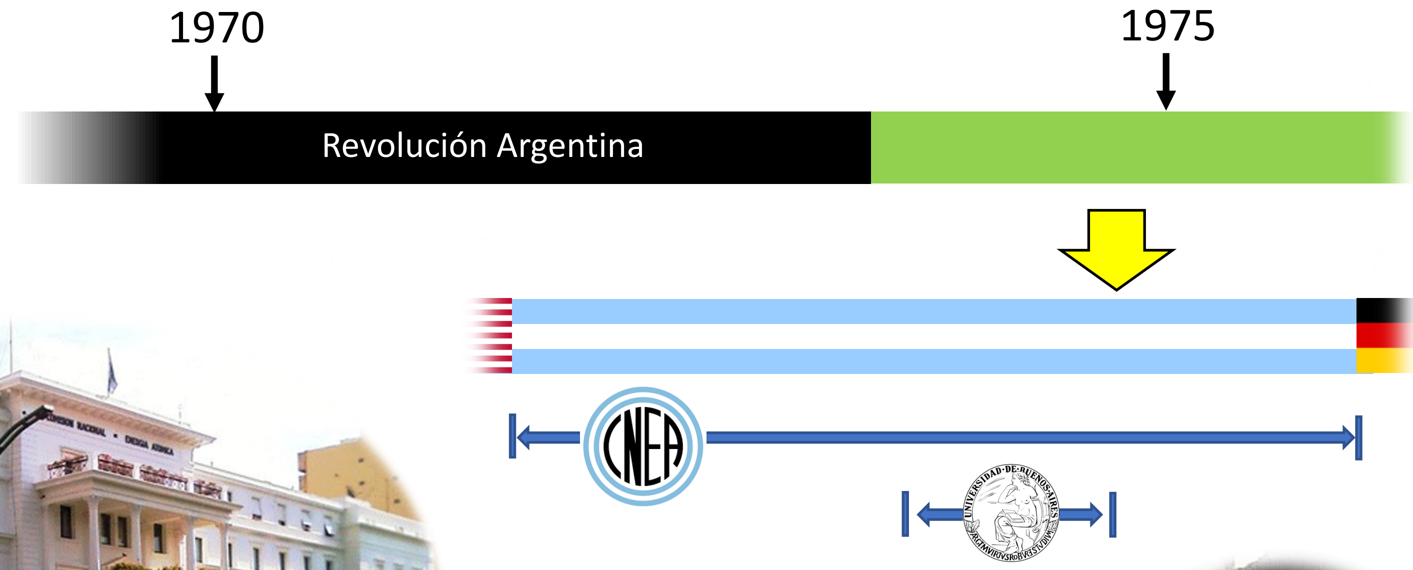
ATOMIC ENERGY COMMISSION

UNIVERSITY OF BUENOS AIRES

Member of the Scientific Staff
1971-1975

Lab Director
1973-1974

Chair, Department of Physics
April-October 1974




Atomic Energy Comission

Eduardo Fradkin
Susana Vaizman
Jorge Hirsch
Pedro Eggarter

Lab Director
1973-1974

Chair, Department of Physics
April-October 1974

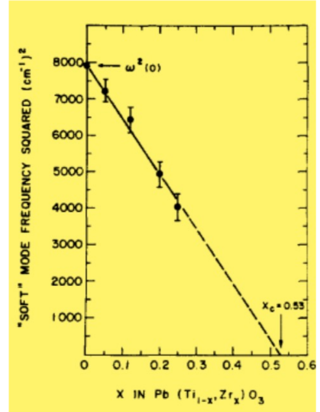
Solid State Communications, Vol. 12, pp. 1035–1038, 1973. Pergamon Press. Printed in Great Britain

'SOFT' OPTICAL PHONONS AND THE MORPHOTROPIC PHASE TRANSITION OF THE $Pb(Ti_{1-x}, Zr_x)O_3$ SYSTEM

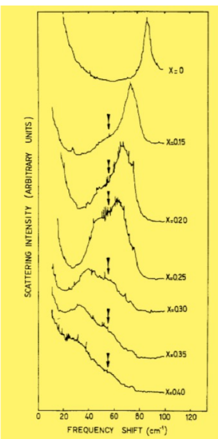
A. Pinczuk*

Dto. de Instrumentación, Comisión Nacional de Energía Atómica, Av. del Libertador 8250, Buenos Aires S.29, Argentina

(*Received 16 August 1972; in revised form 19 January 1973 by E. Burstein*)








*Ferroelectrics*
1974, Vol. 7, pp. 275–277

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RAMAN SCATTERING FROM SOFT E(T
OF THE $Pb(Ti_{1-x} Zr_x)O_3$ SYST

R. MERLIN

*Dpto. de Física, Fac. de Cs. Exactas y Natural*
*Ciudad Universitaria, Buenos Aires, Argentin*

and

A. PINCZUK†

*Dpto. de Instrumentación, Com. Nac. de Energía A*
*Avda. del Libertador 8250, Buenos Aires S29, Arg*

(*Received September 10, 1973*)

*Ferroelectrics*
1977, Vol. 16, p. 127

© Gordon and Bre

SOFT E(TO) PHONONS AND THE PHASE TR
OF THE $Pb(Ti_{1-x}, Zr_x)O_3$ AND $(Pb_{1-3x/2}, La_x)TiO$

R. MERLIN, A. PINCZUK and J. A. SANJURJO

*Com. Nac. de Energía Atómica, Buenos Aires, Argentina*

(*Received December 3, 1975*)

Raman Spectra of Polycrystalline Solids; Application to the $PbTi_{1-x}Zr_xO_3$ System*

Gerald Burns and Bruce A. Scott
*IBM Watson Research Center, Yorktown Heights, New York 10598*
(Received 24 August 1970)

VOLUME 25, NUMBER 17 PHYSICAL REVIEW LETTERS 26 OCTOBER 1970

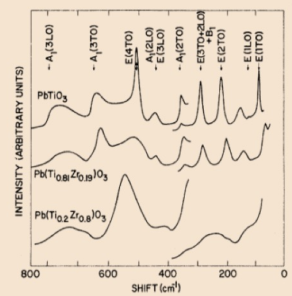



FIG. 2. Experimental Raman powder patterns measured at 23°C for three samples in the $PbTi_{1-x}Zr_xO_3$ system. The arrows refer to the results in single-crystal PbTiO3 (Ref. 7). (Note the gain change and overlap at ≈350 cm⁻¹.)

He-Ne laser, 1-m Jarrell-Ash double monochromator, 2-sec time constant). The arrows in Fig. 2 indicate the positions of the pure modes observed in single crystal $PbTiO_3$.[7] All of these

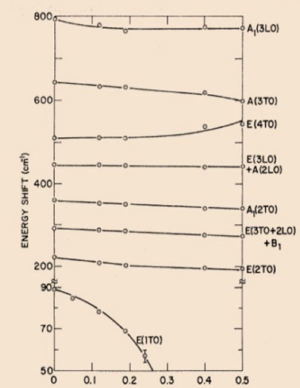
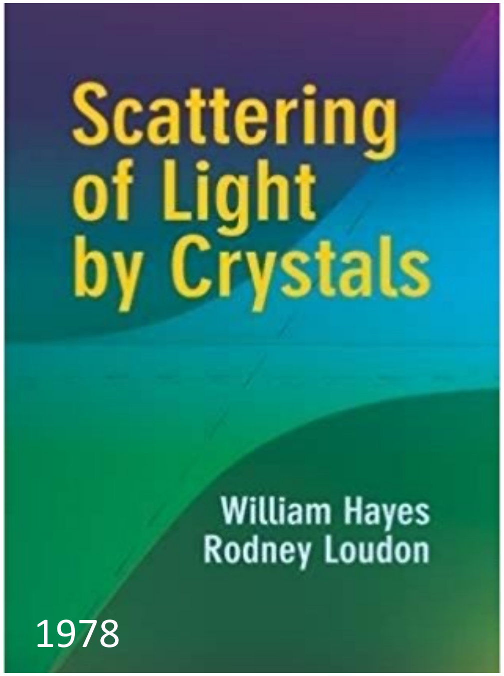



FIG. 3. Experimental results at 23°C in the tetragonal phase of the $PbTi_{1-x}Zr_xO_3$ system. For $x > 0.25$, $E(1TO)$ could not be measured because of low energy shifts and laser scattering background.


1975


Scattering of Light by Crystals
William Hayes
Rodney Loudon
1978

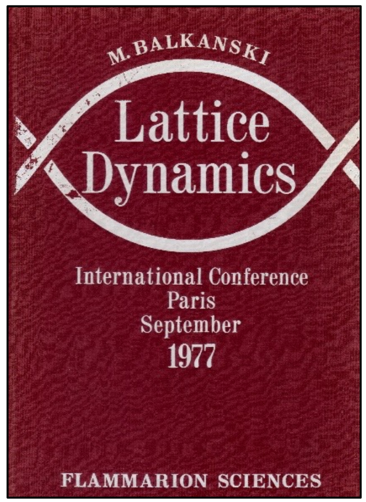

UNICAMP
THIRD
INTERNATIONAL
CONFERENC
LIGHT SCATT
IN S
JULY 28
AUGUST 1,
1975
INSTITUTO DE FÍSICA "GLEB WATAGHIN" CAMPINAS, SP, BRASIL

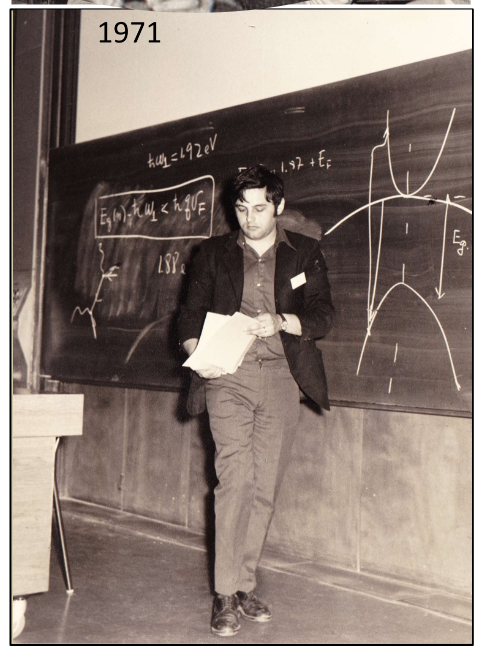

1971

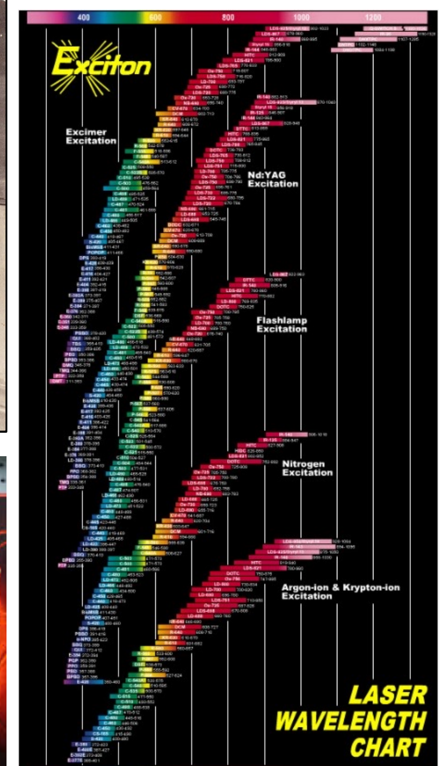

Spex 1403

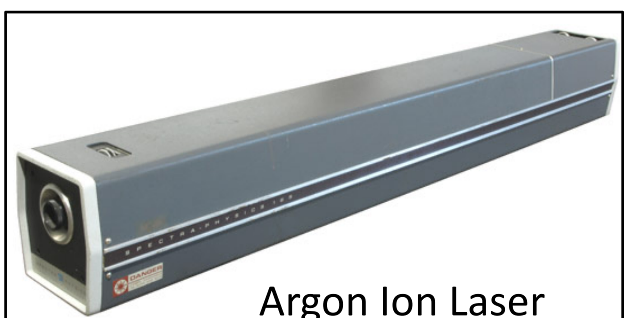

Jarrell-Ash 25-300


III CONFERÊNCIA INTERNACIONAL
DE ESPALHAMENTO DE LUZ EM SÓLIDOS
CAMPINAS 28 JULHO A 1º AGOSTO DE 1975
UNICAMP. ESTADO DE SÃO PAULO BRASIL.

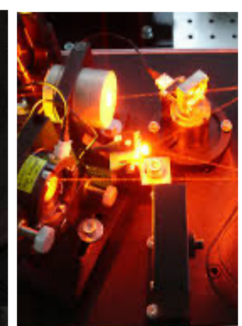

M. BALKANSKI
Lattice Dynamics
International Conference
Paris
September
1977
FLAMMARION SCIENCES


1971


400
600
800
1000
1200
Exciton
Excimer Excitation
Nd:YAG Excitation
Flashlamp Excitation
Nitrogen Excitation
Argon-ion & Krypton-ion Excitation
LASER WAVELENGTH CHART

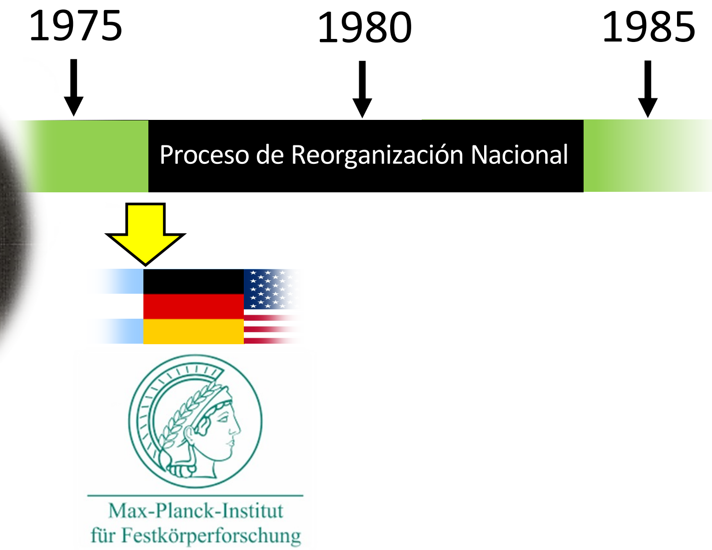

Argon Ion Laser


DANGER



# NATO ARW: Light Scattering in Semiconductor Structures and Superlattices
Mont Tremblant, Québec, Canada (1990)

# International Conference on Solid State Spectroscopy, Schwäbisch Gmünd, Germany, (1999)




Señor
Presidente de la
Comisión Nacional de Energía
Atómica
Capitán de Navío Carlos Castro Madero

de avatares políticas inexplicables. Amo profundamente a la Argentina y le deseo un futuro mejor en el que su talento cienfífico pueda desarrollarse en un ambiente más propicio que el actual y el de los últimos años.

Entretanto, Señor Presidente, le agradecería sumamente el que Vd., personalmente, revisase la decisión tomada respecto a Pinczuk y examinase las consecuencias de tan injustificada acción. No me queda la menor duda de que en este caso va a tener que ser anulada la decisión tomada.

Respetuosamente le saluda,

Manuel Cardona

Director

MAX-PLANCK-INSTITUT
FÜR FESTKÖRPERFORSCHUNG
7000 STUTTGART 80
BÜSNAUER STRASSE 171

Distinguido Dr. Pinasco: esta carta ha sido mandada al Sr. Presidente de la Comisión. Afectuosamente Manuel Cardona




# The 'Disappeared' from the Atomic Energy Commission during the Dirty War 1976-1983

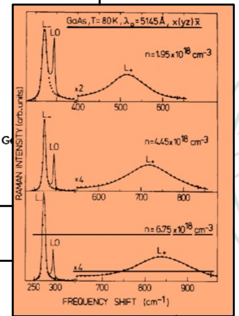
Solid State Communications, Vol. 21, pp. 959-962, 1977. Pergamon Press. Printed in Great Britain

RAMAN SCATTERING BY WAVEVECTOR DEPENDENT COUPLED PLASMON - LO PHONONS OF n - GaAs

A. Pinczuk[+], G. Abstreiter, R. Trommer and M. Cardona

Max-Planck-Institut für Festkörperforschung, D-7000 Stuttgart 80, Federal Republic of G

(Received 20 January 1977 by M. Cardona)




Solid State Communications, Vol.30, pp.703-707.
Pergamon Press Ltd. 1979. Printed in Great Britain.

COUPLED PLASMON-LO PHONON MODES AND LINDHARD-MERMIN DIELECTRIC FUNCTION OF n-GaAs

G. Abstreiter[+], R. Trommer[++], M. Cardona

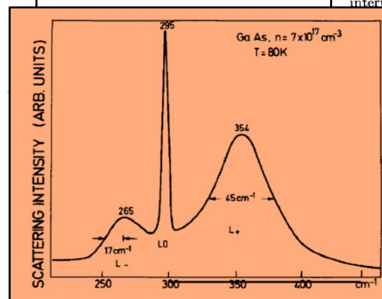
Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1
7000 Stuttgart 80, Federal Republic of Germany

and

A. Pinczuk[*]

Bell Telephone Laboratories, Holmdel, N.J. 07733, U.S.A.

Received: March 25, 1979, by M. Cardona



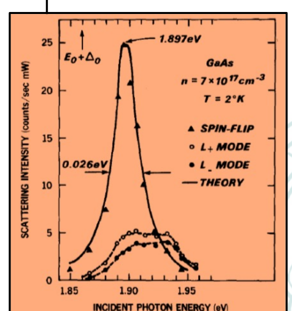

Solid State Communications, Vol.30, pp.429-432.
Pergamon Press Ltd. 1979. Printed in Great Britain.

RESONANCE ENHANCEMENT OF RAMAN SCATTERING BY ELECTRON-GAS EXCITATIONS OF n-GaAs

A. Pinczuk[+]
Bell Telephone Laboratories
Holmdel, New Jersey 07733

G. Abstreiter, R. Trommer, and M. Cardona
Max-Planck-Institut für Festkörperforschung
Heisenbergstrasse 1, 7000 Stuttgart 80, F.R.G.

Received March 2, 1979 by M. Cardona






phys. stat. sol. (b) 83, 99 (1977)

Subject classification: 1.2 and 14.4.1; 6; 20.1; 22.8.1

*Fachbereich Physik der Universität Osnabrück[1]) (a) and Max-Planck-Institut für Festkörperforschung, Stuttgart[2]) (b)*

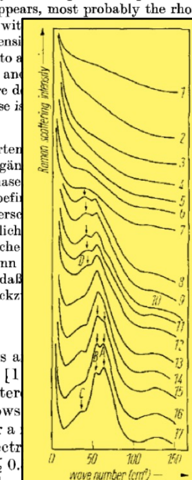
**Temperature and Hydrostatic Pressure Dependence of Vibrational Modes in $PbTi_{1-x}Zr_xO_3$**

By

D. Bäuerle (a, b), W. B. Holzapfel (b), A. Pinczuk[3]) (b), and Y. Yacoby[4]) (b)

The room temperature Raman spectra of $PbTi_{0.1}Zr_{0.9}O_3$ at hydrostatic pressures up to 68.5 kbar indicate three phase transitions. At 5.71 kbar a new phase appears, most probably the rhombohedral high-temperature phase, $F_{R(HT)}$, which is in coexistence wit… er-ature phase $F_{R(LT)}$. Between 8 and 9.1 kbar the relative intensi… wo additional structures appear. It is likely that this change is due to a… ab-ic antiferroelectric phase. A further transition between 39.7 an… ely interpreted on the basis of the present data. The temperature d… ra …vidence that the additional structure in the $F_{R(LT)}$ phase is… nit … $PbTi_{1-x}Zr_xO_3$ seems to show one-mode behaviour.

…Ramanspektren von $PbTi_{0.1}Zr_{0.9}O_3$ zeigen bei Zimmerten… em …im Bereich zwischen 0 und 68,5 kbar drei Phasenübergän… ue …uf, vermutlich die rhomboedrische Hochtemperaturphase… nz …r rhomboedrischen Niedertemperaturphase, $F_{R(LT)}$, befi… bar …sich die relativen Intensitäten aller Linien, und es ersc… ak- …Diese Veränderung in den Spektren rührt wahrscheinlich… des …s in die antiferroelektrische Phase, die orthorhombische… rer …übergang, der zwischen 39,7 und 42 kbar auftritt, kann… Die …raturabhängigkeit der Ramanspektren läßt vermuten, daß… der …Phase auf eine Verdopplung der Elementarzelle zurückz… $O_3$ …in-Moden-Verhalten.




## 1. Introduction

…correlation between structural phase transitions a… ies …and a growing interest not only in pure systems [1… u- …tions as well [4 to 10]. In this connection our main inter… he solid solution $PbTi_{1-x}Zr_xO_3$ [4 to 8]. This material shows… c-tural phase transitions and is in addition important for a… a-tions due to its piezoelectric, pyroelectric, and dielectr… $O_3$ is ferroelectric with tetragonal structure for $x \lessapprox 0.$… for $0.52 \leqq x \leqq 0.94$ [11, 12]. In the rhombohedral phase, the s… es: Below the paraelectric–ferroelectric phase transition, in the so-called $F_{R(HT)}$ phase, the material is isomorphic with rhombohedral $BaTiO_3$. At lower temperatures, in the so-called $F_{R(LT)}$ phase, there is in addition to the ferroelectric distortion a staggered rotation of the oxygen octahedra around the (111) axis. For compositions $0.94 \leqq x \leqq 1.0$ the material becomes antiferroelectric with orthorhombic structure.

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[2]) 7000 Stuttgart-80, BRD.
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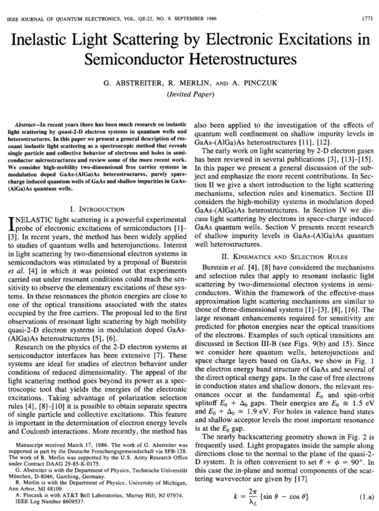
[4]) Racach Institute of Physics, Hebrew University, Jerusalem.



IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. QE-22, NO. 9, SEPTEMBER 1986 1771

# Inelastic Light Scattering by Electronic Excitations in Semiconductor Heterostructures

G. ABSTREITER, R. MERLIN, AND A. PINCZUK

*(Invited Paper)*

*Abstract*—**In recent years there has been much research on inelastic light scattering by quasi-2-D electron systems in quantum wells and heterostructures. In this paper we present a general description of resonant inelastic light scattering as a spectroscopic method that reveals single particle and collective behavior of electrons and holes in semiconductor microstructures and review some of the more recent work. We consider high-mobility two-dimensional free carrier systems in modulation doped GaAs-(AlGa)As heterostructures, purely space-charge induced quantum wells of GaAs and shallow impurities in GaAs-(AlGa)As quantum wells.**

## I. Introduction

INELASTIC light scattering is a powerful experimental probe of electronic excitations of semiconductors [1]–[3]. In recent years, the method has been widely applied to studies of quantum wells and heterojunctions. Interest in light scattering by two-dimensional electron systems in semiconductors was stimulated by a proposal of Burstein *et al.* [4] in which it was pointed out that experiments carried out under resonant conditions could reach the sensitivity to observe the elementary excitations of these systems. In these resonances the photon energies are close to one of the optical transitions associated with the states occupied by the free carriers. The proposal led to the first observations of resonant light scattering by high mobility quasi-2-D electron systems in modulation doped GaAs-(AlGa)As heterostructures [5], [6].

Research on the physics of the 2-D electron systems at semiconductor interfaces has been extensive [7]. These systems are ideal for studies of electron behavior under conditions of reduced dimensionality. The appeal of the light scattering method goes beyond its power as a spectroscopic tool that yields the energies of the electronic excitations. Taking advantage of polarization selection rules [4], [8]–[10] it is possible to obtain separate spectra of single particle and collective excitations. This feature is important in the determination of electron energy levels and Coulomb interactions. More recently, the method has also been applied to the investigation of the effects of quantum well confinement on shallow impurity levels in GaAs-(AlGa)As heterostructures [11], [12].

The early work on light scattering by 2-D electron gases has been reviewed in several publications [3], [13]–[15]. In this paper we present a general discussion of the subject and emphasize the more recent contributions. In Section II we give a short introduction to the light scattering mechanisms, selection rules and kinematics. Section III considers the high-mobility systems in modulation doped GaAs-(AlGa)As heterostructures. In Section IV we discuss light scattering by electrons in space-charge induced GaAs quantum wells. Section V presents recent research of shallow impurity levels in GaAs-(AlGa)As quantum well heterostructures.

## II. Kinematics and Selection Rules

Burstein *et al.* [4], [8] have considered the mechanisms and selection rules that apply to resonant inelastic light scattering by two-dimensional electron systems in semiconductors. Within the framework of the effective-mass approximation light scattering mechanisms are similar to those of three-dimensional systems [1]–[3], [8], [16]. The large resonant enhancements required for sensitivity are predicted for photon energies near the optical transitions of the electrons. Examples of such optical transitions are discussed in Section III-B (see Figs. 9(b) and 15). Since we consider here quantum wells, heterojunctions and space charge layers based on GaAs, we show in Fig. 1 the electron energy band structure of GaAs and several of the direct optical energy gaps. In the case of free electrons in conduction states and shallow donors, the relevant resonances occur at the fundamental $E_0$ and spin-orbit splitoff $E_0 + \Delta_0$ gaps. Their energies are $E_0 \cong 1.5$ eV and $E_0 + \Delta_0 \simeq 1.9$ eV. For holes in valence band states and shallow acceptor levels the most important resonance is at the $E_0$ gap.

The nearly backscattering geometry shown in Fig. 2 is frequently used. Light propagates inside the sample along directions close to the normal to the plane of the quasi-2-D system. It is often convenient to set $\theta + \phi = 90°$. In this case the in-plane and normal components of the scattering wavevector are given by [17]

$$k = \frac{2\pi}{\lambda_L} \{\sin\theta - \cos\theta\} \quad (1.a)$$

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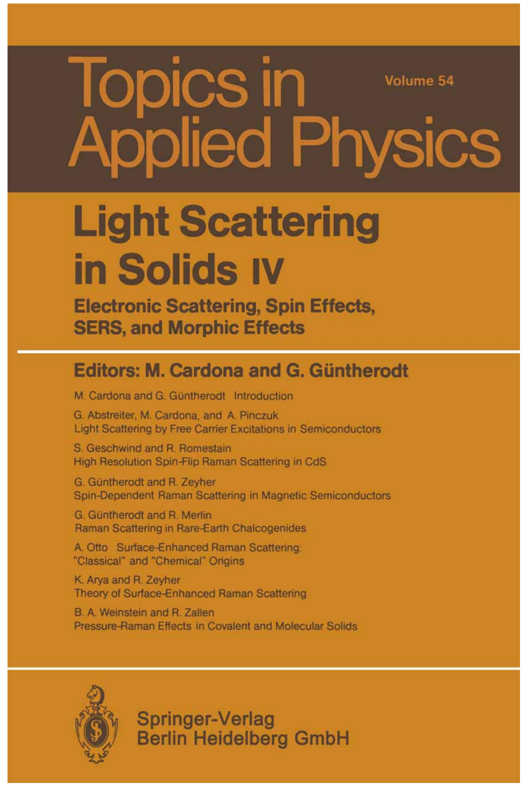


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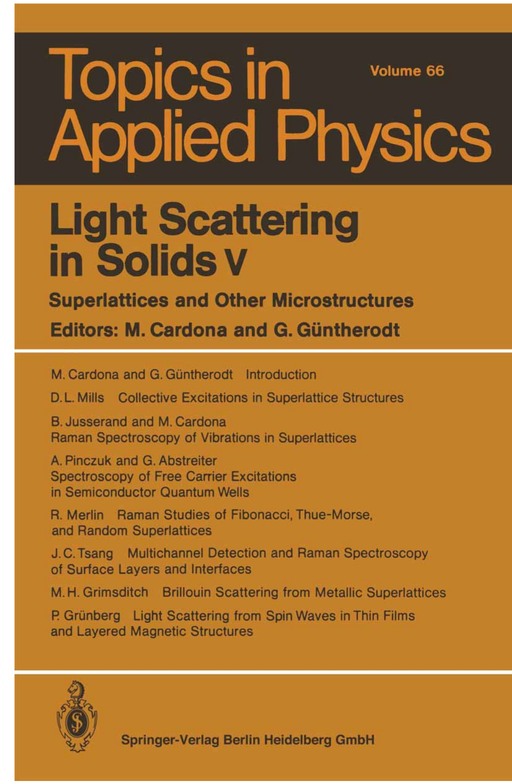


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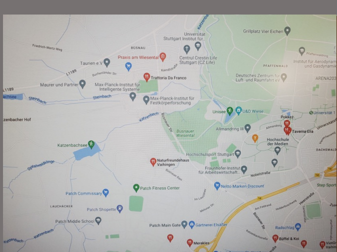

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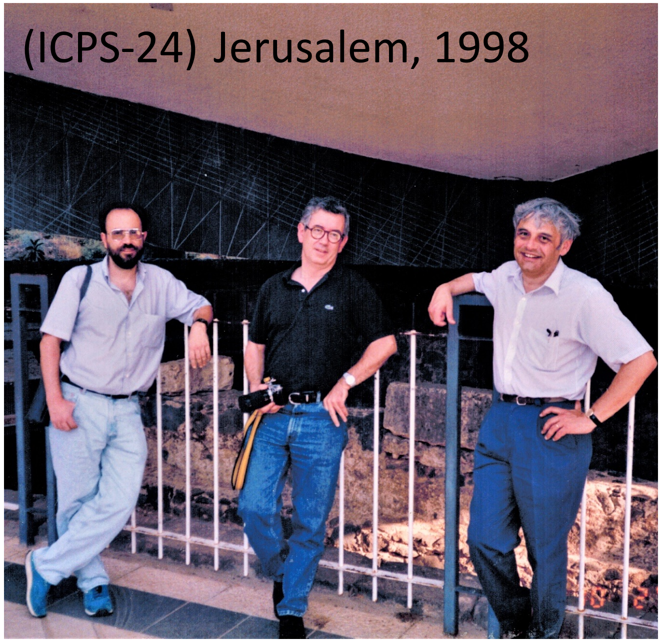

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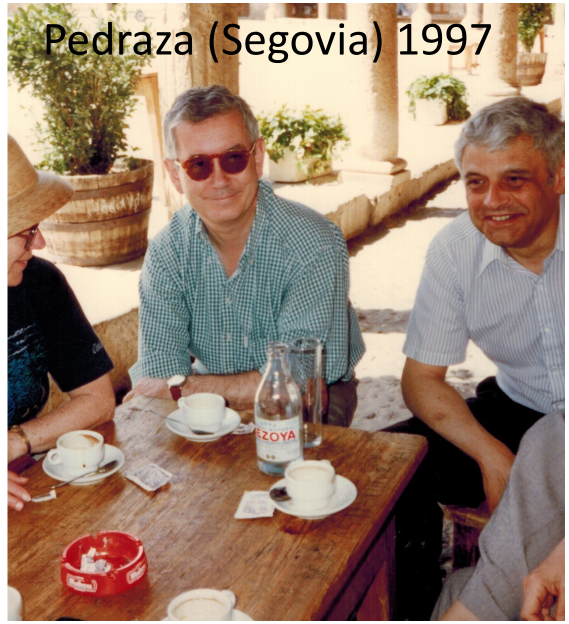


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# THE MADRID CONNECTION

APS March Meeting 1999

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# THE MADRID CONNECTION

- “Optical study of the one-dimensional electron gas in cleaved-edge-overgrown semiconductor quantum wires, J. Rubio, C. Pascual, A. Pinczuk, B.S. Dennis, L.N. Pfeiffer, K.W. West and J.M. Calleja,” Physica E **12,** 722 (2002)

- “Observation of sharp collective excitations at the one-dimensional electron gas in cleaved-edge overgrown semiconductor quantum wires,” J. Rubio, J.M. Calleja, A. Pinczuk, B.S. Dennis, L.N. Pfeiffer and K.W. West, Solid State Commun. **125**, 149 (2003).

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- “One-dimensional plasmon dispersion and dispersionless intersubband excitations in GaAs quantum wires,” A. R. Goñi, A. Pinczuk, J. S. Weiner, J. M. Calleja, B. S. Dennis, L. N. Pfeiffer, and K. W. West, Phys. Rev. Lett. **67**, 3298 (1991).

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## Dr. Honoris Causa, UAM (1997)


VOLUME 68, NUMBER 24 PHYSICAL REVIEW LETTERS 15 JUNE 1992

**Spectroscopic Measurement of Large Exchange Enhancement of a Spin-Polarized 2D Electron Gas**

A. Pinczuk,[1] B. S. Dennis,[1] D. Heiman,[2] C. Kallin,[3] L. Brey,[4] C. Tejedor,[4] S. Schmitt-Rink,[5] L. N. Pfeiffer,[1] and K. W. West[1]

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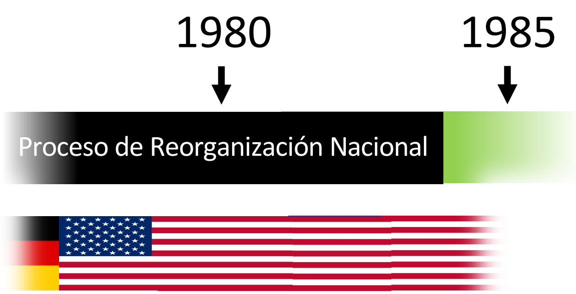
(Received 13 February 1992)

Exchange enhancements of the spin-polarized 2D electron gas are determined for the first time by inelastic light scattering from spin-flip inter-Landau-level and intersubband excitations. In the magnetic quantum limit $\nu=1$ the splitting between long wavelength magnetoplasmons and spin-flip inter-Landau-level excitations is a direct spectroscopic measurement of the enhanced exchange energy. At $\nu=1$ the enhancements in GaAs quantum wells are in agreement with the Hartree-Fock approximation.

Aron Pinczuk worked as a Visiting Scientist at IBM Research in Yorktown Heights 1977-1978. He was a member of the Technical Staff at Bell Telephone Laboratories (renamed AT&T Bell Laboratories in 1984 and then Lucent Technologies in 1996) during 1978-1998.




IBM

Bell Laboratories

AT&T Bell Laboratories

Solid State Communication, Vol.29, pp.515-518.
Pergamon Press Ltd. 1979. Printed in Great Britain.

IBM

**Mechanism of the Ferroelastic Transition of $BiVO_4$**

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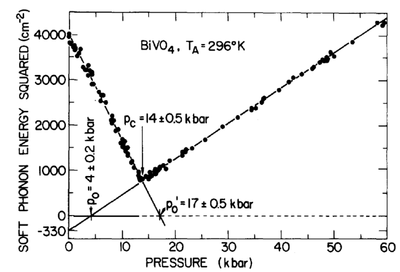
Yorktown Heights, New York 10598

Received 22 December, 1978 by E. Burstein)

iVO$_4$ has a pure ferroelastic transition at $T_c$=528°K and atmospher- We elucidated the mechanism of this transition by studying the ptical phonon, with the symmetry of the ferroelastic strain, under static pressures at room temperature. A free-energy analysis, e optical-acoustical phonon couplings, shows that the transition is e q≈0 soft optical phonon.




Solid State Communications, Vol. 25, pp. 381-384, 1978. Pergamon Press. Printed in Great Britain

IBM

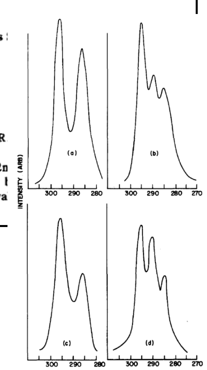
**RESONANCE ENHANCED UMKLAPP RAMAN PROCESSES IN $GaAs$-$Ga_{1-x}Al_xAs$**

G. A. Sai-Halasz, A. Pinczuk, P. Y. Yu, and L. Esaki

IBM Thomas J. Watson Research Center
Yorktown Heights, New York 10598

(Received 21 September; in revised form 8 November 1977, by R

We report the observation of umklapp Raman scattering of phonons with wavevector of 2n superlattices with period d, due to resonance enhancements at transitions from valence minibands. We also observed, for the first time, minizone formation in the spin-orbit split va




**Raman scattering in superlattices: Anisotropy of polar phonons**

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*Coordinated Science Laboratory and Materials Research Laboratory, University of Illinois at Urbana-Champaign, Urbana, Illinois, 61801*

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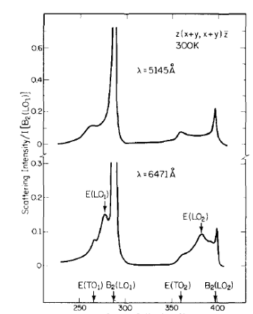
(Received 28 June 1979; accepted for publication 17 October 1979)

Raman experiments on polar phonons in $GaAs$-$Ga_{1-x}Al_xAs$ superlattices are report data from the literature, and its interpretation in terms of folding of the phonon Brill and scattering from $q \neq 0$ phonons induced by electronic zone folding, are discuss alternative explanation is presented based on optical anisotropy induced by layering. results show good agreement with experiment.



Solid State Communications, Vol. 32, pp.1001-1003.
Pergamon Press Ltd. 1979. Printed in Great Britain.

Bell Laboratories

OBSERVATION OF INTERSUBBAND EXCITATIONS
IN A MULTILAYER TWO DIMENSIONAL ELECTRON GAS

A. Pinczuk, H. L. Störmer, R. Dingle, J. M. Worlock
W. Wiegmann, and A. C. Gossard
Bell Telephone Laboratories
Holmdel and Murray Hill, N. J.
(Received 20 August 1979 by E. Burstein)

We report the observation, by resonant inelastic light scattering, of intersubband excitations of the multilayer two dimensional electron gas, in modulation doped GaAs-AlGaAs heterojunction superlattices. These are the first measurements of these transitions by any technique, and furnish intersubband energies in good agreement with calculated values. The spectral bands are broad, and nearly Lorentzian in shape: the implied relaxation rates scale linearly with band energy and are significantly faster than transport relaxation rates. Finally, the polarized spectra reveal differences between spin-flip and non spin-flip excitations which are unique to multilayer two dimensional electron gases.

A high mobility two-dimensional electron gas has been recently produced in the GaAs layers of modulation doped GaAs-AlGaAs heterojunction superlattices made by molecular beam epitaxy[1,2]. We report here measurements by resonant inelastic light scattering of electronic intersubband excitations in this structure. This is the first observation by any technique of the spacings between the energy subbands in a multilayer two-dimensional electron gas (2DEG).

The work of Esaki, Tsu, and coworkers[3], and of Dingle, et. al.[4], has shown that the electron states in undoped GaAs-AlGaAs superlattices are quantized into discrete states for motion perpendicular to the layers, and two-dimensional bands for motion in the plane of the layers. In modulation doped superlattices, as illustrated in Fig. 1a, the potential wells and thereby the discrete subband levels are strongly affected by the charge distributions in the layers. Until the present work, these levels had not been observed. The powerful far infrared techniques that have been used in the spectroscopy of inversion and accumulation layers[5], based on the modulation of an external gate voltage, probably cannot be used in superlattices. In fact, it is unlikely that any infrared technique can fully succeed because of the opacity of polar semiconductors in the reststrahl region.

Our results show, on the other hand, that resonant inelastic light scattering near the $E_o + \Delta_o$ optical energy gap, is ideally suited for the study of this new multilayer 2DEG. Several publications presaged this success. Burstein, Pinczuk and Buchner[6] first proposed the use of this method for studying the excitations in 2DEG's. Pinczuk, et. al.[7] found that light scattering by both single particle and collective excitations in bulk n-type GaAs is strongly enhanced near the $E_o + \Delta_o$ resonance, while the luminescence is relatively weak. Finally, Abstreiter and Ploog[8] have recently reported a resonant inelastic light scattering experiment showing evidence for an intersubband transition

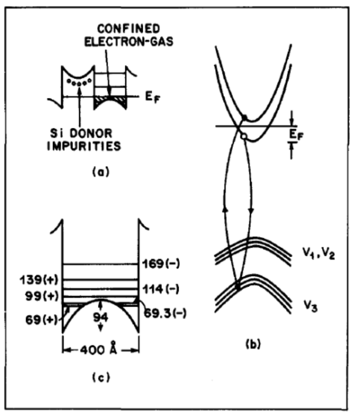



FIG. 1: (a) Model of the conduction band edge of modulation doped heterojunction superlattices.
(b) Schematic diagram of conduction and valence subbands, showing the optical transitions contributing to light scattering near the $E_o + \Delta_o$ resonance.
(c) Calculated subband energy levels for sample 1

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OBSERVATION OF INTERSUBBAND EXCITATIONS
IN A MULTILAYER TWO DIMENSIONAL ELECTRON GAS

A. Pinczuk, H. L. Störmer, R. Dingle, J. M. Worlock
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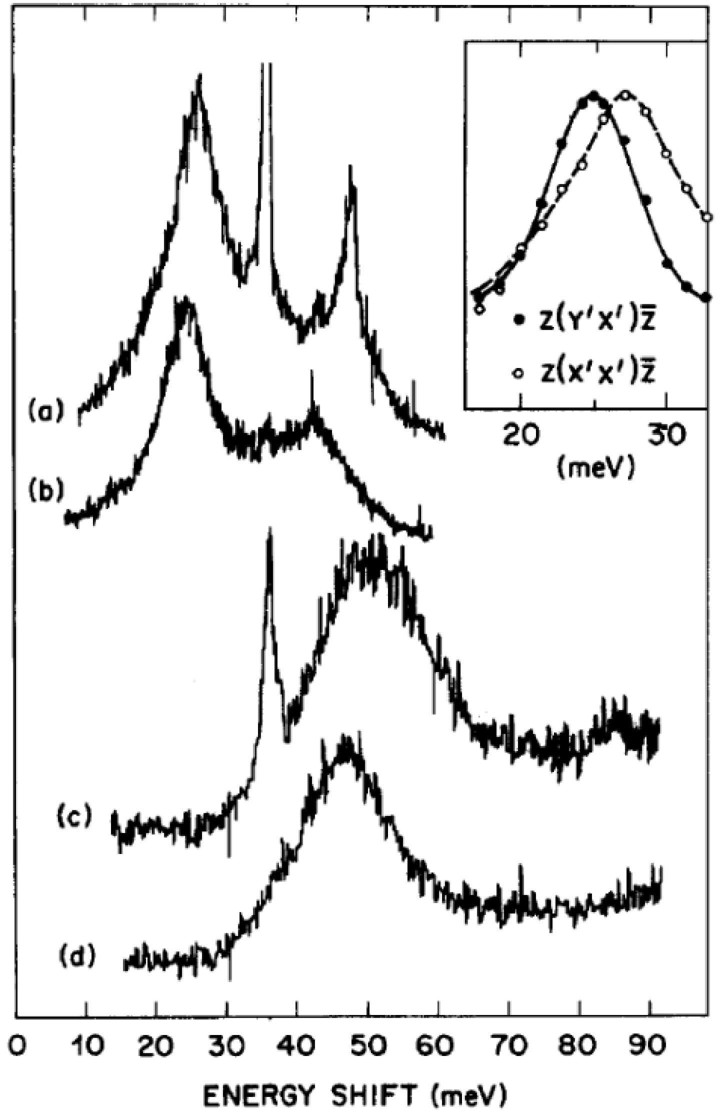


Bell Laboratories

1982

PHYSICAL REVIEW B VOLUME 26, NUMBER 2 15 JULY 1982

**Plasma dispersion in a layered electron gas: A determination in GaAs-(AlGa)As heterostructures**

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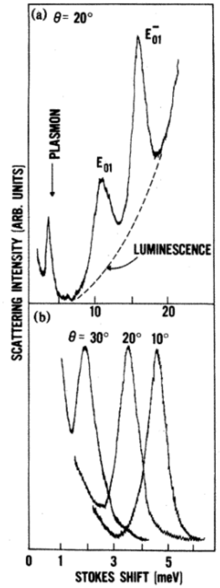
A. C. Gossard and W. Wiegmann
*Bell Laboratories, Murray Hill, New Jersey 07974*
(Received 30 April 1982)

The dispersion of the plasma frequency of layered electron gases in GaAs-(AlGa)As heterostructures was determined by inelastic light scattering. The measured dispersions differ from that in two- and three-dimensional plasmas. They are *linear* in the in-plane component of the wave vector. This observation confirms predictions of theoretical models.

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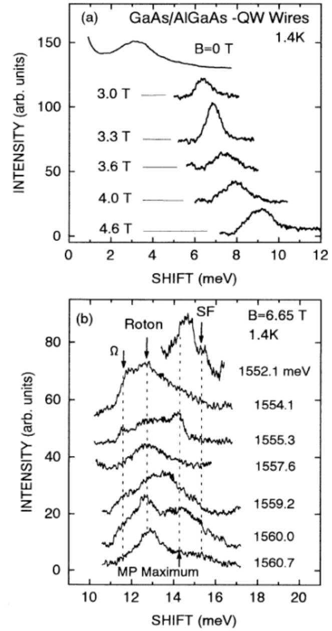



VOLUME 70, NUMBER 8 PHYSICAL REVIEW LETTERS 22 FEBRUARY 1993

**Observation of Magnetoplasmons, Rotons, and Spin-Flip Excitations in GaAs Quantum Wires**

A. R. Goñi,[(a)] A. Pinczuk, J. S. Weiner, B. S. Dennis, L. N. Pfeiffer, and K. W. West
*AT&T Bell Laboratories, Murray Hill, New Jersey 07974*
(Received 2 November 1992)

Inelastic light scattering spectra of the one-dimensional electron gas in GaAs quantum wires embedded in a strong perpendicular magnetic field show long-wavelength collective excitations and display multiple structures that indicate the magnetoroton density of states. The observed shift of the $q \sim 0$ intersubband magnetoplasmons from the cyclotron frequency is the signature of 1D behavior. At low temperatures spin polarization of the 1D system is revealed by the exchange enhancement of spin-flip excitations.

PACS numbers: 71.45.Gm, 78.30.Fs

1698 IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. 24, NO. 8, AUGUST 1988

# Light Scattering Determinations of Band Offsets in Semiconductor Heterostructures

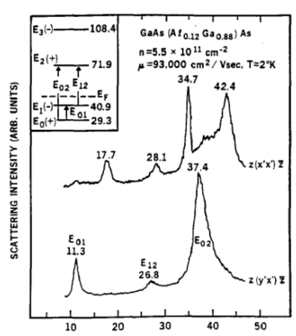
J. MENÉNDEZ AND A. PINCZUK
(*Invited Paper*)

1988

***Abstract*—Inelastic light scattering is used to determine the band offsets in semiconductor heterojunctions. The conduction band discontinuity is obtained from energy level spacings measured in *electronic* light scattering spectra of photoexcited quantum-well heterostructures. The method has been applied to GaAs-AlGaAs, GaSb-AlGaSb and InGaAs-GaAs heterojunctions. This paper reviews the light scattering determinations of band offsets. These results are compared with those obtained with more conventional methods. We also consider the impact of the light scattering results on chemical trends and the influence of strain in the band lineup problem.**

cepted as well established [14], [15] have been recently challenged and shown to be incorrect [16].

Band offsets appear naturally when effective mass theory is applied to semiconductor heterostructures [17]. However, the concept of a spacially dependent band structure used in an effective mass analysis is only meaningful for perturbations with characteristic lengths much longer than the lattice spacing. This is actually not the case in a heterojunction, where the potential changes




# THE ARGENTINA CONNECTION

# ARON PINCZUK