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REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) ARO 20055.5-PH
6a. NAME OF PERFORMING ORGANIZATION Optical Sciences Center University of Arizona 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION U. S. Army Research Office
6c. ADDRESS (City, State, and ZIP Code) Tucson, Arizona 85721	7b. ADDRESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U. S. Army Research Office 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAG29-83-K-0100
8c. ADDRESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NC

11. TITLE (Include Security Classification)

Investigation of the Elastic and Structural Properties of Langmuir-Blodgett Films

12. PERSONAL AUTHOR(S)

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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 83/8/1 TO 86/7/31	86/10/29	

16. SUPPLEMENTARY NOTATION 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 positio policy, or decision, unless so designated by other documentation.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Langmuir-Blodgett films, scanning tunneling microscopy studi infrared absorption. Raman scattering, structural propertie (see reverse side)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Raman and Brillouin scattering, infrared Fourier transform absorption spectroscopy and scanning tunneling electron microscopy have all been used in this program to investigate the elastic and structural properties of Langmuir-Blodgett (LB) films, a class of materials which hold considerable promise for many applications in electronics and optics.

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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted.
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18. (continued)
anomolous melting, Brillouin scattering, film elastic properties, molecular reorientation.

19. (continued)

Many new measurements and discoveries have been made. To summarize:

(1) Two-step melting of an LB filming was observed for the first time by infrared spectroscopy. The onset of strong disorder in the hydrocarbon tail was found at temperatures lower than those at which the head-group lattice melts.

(2) Thermal and UV polymerization of LB films was followed spectroscopically and found to lead to equivalent structures. Conditions for polymerization without lattice distortion were found.

(3) Scanning tunneling microscopy was used to image LB molecules on the surface for the first time.

(4) The elastic properties of a cadmium arachidate LB film were measured for the first time. Namely $c_{44} < 4.0 \times 10^{8}$ N/m^2, $c_{66} < 4.5 \times 10^{9}$ N/m^2, $c_{11} \simeq 1.1 \times 10^{10}$ N/m^2, $c_{33} \simeq 2.1 \times 10^{10}$ N/m^2, $c_{13} \simeq 1.0 \times 10^{10}$ N/m^2, and $c_{12} > 3 \times 10^{10}$ N/m^2. The shear elastic constant c_{44} is quite small for a solid film. There is evidence for molecular orientation in the depolarized spectra of the CdA films. Strong similarities in acoustic properties between these LB films and smectic B liquid crystals were found.

Final Report

1. INTRODUCTION

It is only in the last few years that the potential of Langmuir-Blodgett films for applications in electronics, electrooptics, energy conversion etc. has been demonstrated. Although optimal configurations or materials have not been achieved, effects and phenomena have been observed to prove feasibility. Their uniqueness arises from the facts (1), that the films can be fabricated one monolayer (20-40Å thick) at a time with very simple and reproducible techniques[1], and (2), that their properties can be engineered by adding functional side-groups at various positions along the back-bone chain[2]. In fact it has been projected that molecular electronics, that is electronics based on devices of molecular dimensions, may be a reality by the year 2020[2]. In fact, because of their potential for molecular engineering, the list of potential and demonstrated applications seems to be endless, limited only by the ingenuity of researchers in the field.

The most common type of LB films are composed of long chain molecules of the form $(CH_2)_n$, to which are attached the various molecular subgroups that allow the properties of the film to be designed for specific applications. Crosslinking with chemical bonds introduces increased structural strength. These films, fabricated one monolayer at a time by the Langmuir-Blodgett technique[1], have hydrophilic head groups attached to hydrophobic tails and they form structures with well-defined orientations when compressed together on a water surface. As a properly prepared substrate is successively dipped through the LB molecule-loaded water surface, successive monolayers are deposited to produce oriented films 1 - 1,000's of layers thick. This special fabrication technique should (and does) result in films with unique structural and elastic properties, i.e. they should be two-dimensional in character with weak inter-plane coupling and strong inter-molecular coupling inside a given plane.

As pointed out by Roberts[2] in his recent review article, there is a scarcity of information about the structural and elastic properties of LB films, despite the fact that for device applications, a material must have acceptable mechanical properties. During the duration of this contract we have made considerable progress in applying various techniques to the measurement of the structural and elastic properties of LB films.

The structural characterization work was performed at IBM San Jose. Raman scattering, Fourier transform infrared absorption spectroscopy (FTIR) and scanning tunneling electron microscopy (STM) have all been used to characterize the structure of the molecules in Langmuir-Blodgett films. The first two techniques have been used to determine the average orientation of the molecules, as well as the intramolecule vibration frequencies and force constants. STM provided a picture of the molecules right at a interface. The highlights are that with FTIR it was observed that the monolayer assemblies melt in a two step process[3]: first the tails become disordered and then at the bulk melting point the head groups melt. Polarized Raman spectra[4] show that up to close to the bulk melting point there is little evidence for any conversion from the all trans configuration to any gauche bonds configurations. Disordering of the tails must be mainly by chain tilting. Further molecules with unsaturation can now be polymerized with little in-plane expansion[5] by a mixture of the cis and trans isomers. This is important to prevent peeling or cracking on the substrate. These polymerized films exhibit enhanced stability and interesting structural changes from polymerization. The scanning tunneling microscopy observations[6] were the first of a lipid bilayer and gave lattice spacings in close agreement with electron diffraction results[7]. This means that we can make organic films and measure their molecular orientation and packing, and most significantly see an image of them. Details of the various measurements are given in section 2.

The intermolecular forces which bond adjacent layers and maintain the individual molecules within each plane determine the mechanical integrity of the film, and are reflected directly in the response of the medium to applied stresses, that is in the elastic constants. Brillouin scattering was used to measure the elastic constants since it is does not perturb the film. We have built a state-of-the-art Brillouin spectrometer and have performed the first Brillouin scattering measurements on LB films[8,9]. The highlights are as follows: we have found very small values for the shear elastic constants c_{44} and c_{66} of cadmium arachidate, the classic LB molecule for which the most information is available. This explains the relative ease with which LB films are removed via the scotch tape test. We have also found that shear stresses applied parallel to the LB layers are strongly coupled to the reorientation of individual cadmium arachidate molecules. These results have raised fundamental questions about the distinction between solid-phase LB films and liquid-phase smectic B liquid crystal media. In fact, De Gennes in his classic book[10] on "The Physics of Liquid Crystals" speculates on a solid-phase version of smectic B liquid crystals which seems to describe many of the properties of LB films.

2. RESULTS

2.1 Structural Characterization of LB Films

In order to understand phase transitions in L-B film systems, the infrared spectra of L-B films were measured as a function of temperature. Surprisingly, a two step melting process in Langmuir-Blodgett monolayers was observed and for the first time we observed structural changes which occurred during heating, melting and annealing cycling. Prior to the melting point, a pretransitional disordering of the hydrocarbon tails was observed by changes in the spectrum. This was followed by a breakup of the head groups at the lattice melting point. When the temperature was cycled from room temperature to a few degrees below the melting point, the monolayer assembly was recovered. At higher temperature the lattice assumes a new structure and the monolayer assembly structure can not be recovered.

In order to prepare more stable films, the two isomers, octadecyl fumaric acid and octadecyl maleic acid ($C_{18}H_{37}OCOCH{=}CHCOOH$) were synthesized, and Langmuir-Blodgett films of their cadmium salts were prepared on silver, aluminum and KRS-5 substrates. The orientation of the molecules relative to the substrate surface and the lateral packing of the chains in the unit cell were studied by means of transmission and glancing angle reflection infrared spectroscopy. Polymerizations of these films by both UV radiation or thermal heating were followed spectroscopically as a function of the exposure time. By comparison of these films with films polymerized on a water surface, it was concluded that all three polymerization processes produce films with similar molecular structures. Now one isomer expanded on polymerization and the other contracted. A proper mixture gave a film with no expansion or contraction - an important attribute to prevent peeling or cracking and instability.

As an alternative to transferring a film and then polymerizing it on the substrate, we transferred a monolayer of a polymer, poly(octadecylmethacrylate), directly to a solid substrate. This comb-like polymer was transferred to a solid hydrophilic surface as either a single monolayer in a polar heads down and aliphatic tails up configuration, or as a multilayer structure by Z-type head-to-tail deposition. IR spectroscopy in transmission and reflection at grazing incidence, gave noticeably anisotropic spectra, indicative of an orientation of the methacrylate and hydrocarbon side chains relative to the surface. In particular, the C=O stretching vibration at 1742 cm^{-1}, which is usually the most intense in isotropic films of methacrylate polymers, showed a considerable anisotropic character, indicating that change in the dipole moment of the C=O bond is primarily parallel to the surface. Likewise other bands attributable to backbone and side chain vibrations have been identified and used to determine the orientation of the respective groups relative to the surface providing a molecular picture of the polymer topography. This approach of direct transfer broadens our ability to fabricate stable films and should find considerable utility. We need to identify the appropriate molecular parameters for effective production of molecular monolayers.

An image of a lipid layer was obtained at molecular resolution by scanning tunneling microscopy. This work was in collaboration with A. Bryant, D. Smith and C.F. Quate at Stanford University. This image was a top view image, consisting of a Langmuir-Blodgett film deposited as a double layer of cadmium arachidate on a graphite (001) surface. By rapidly scanning the tip parallel to the film plane and recording the current, a lateral resolution of better than one angstrom was achieved. The images showed the packing of the lipid molecules in the film plane and allowed for a direct verification of the order as well as the nature and distribution of defect sites. The measured molecular spacing of 4.9 angstroms was in agreement with electron diffraction data. This technique is expected to provide valuable information about thermally or light induced order-disorder transitions in ultrathin organic films, as well as about the molecular organization in composite films.

2.2 Measurement of Elastic Properties

Brillouin scattering has proven over the years to be a very powerful tool for measuring the elastic properties of a variety of media[11]. It is especially applicable to investigating LB films because it is non-contact in nature. We have spent a great deal of time perfecting our Fabry-Perot interferometer. It is a multi-pass tandem device (two Fabry-Perots in series, swept in perfect synchronization) with the light passed back-and-forth through each interferometer a minimum of three times via corner cubes. All alignments etc. are stabilized to within 5 angstroms via capacitive feedback circuits.

We have performed the first experimental investigation of the elastic properties of L-B films. The Brillouin spectra of Langmuir-Blodgett films contain a rich variety of features, most of which we have been able to interpret. We find them to be highly anisotropic, with shear properties reminiscent of smectic B liquid crystal media[12], and we have observed depolarized spectra usually associated with molecular orientational fluctuations in a liquid. Strong coupling between the shear strains that slide the LB monolayers relative to each other and the reorientation of the LB molecules has been observed in some of the depolarized spectra. This result raises some questions concerning the liquid-like properties of these films.In addition, the large anisotropy leads to "bunching" of the guided acoustic waves.

The L-B films used were formed from cadmium salts of the fatty acid, arachidic acid, $CH_3(CH_2)_{18}COOH$, hereafter referred to as CdA. Film samples ranging in thickness from 11 up to 401 layers thick (27.8 Å per layer as measured by x-ray diffraction) were fabricated on both molybdenum and BK-7 glass substrates using a Joyce-Loebel Langmuir trough. Standard substrate cleaning and deposition techniques were used. The first layer was deposited with the hydroxyl group attached to the substrate, and successive layers were deposited with alternating orientations, commonly referred to as "Y" type.

A typical Brillouin spectrum from the CdA samples is shown in Fig. 1. The polarized backscattering spectrum of a molybdenum substrate coated with 75 layers shows three distinctive features arising from at least three guided acoustic modes. The peak corresponding to the smallest frequency shift is due to the Rayleigh wave. The velocity is obtained from the frequency shift and the scattering geometry (which gives κ_p). The variation of the Brillouin frequency shifts versus film thickness is illustrated in Fig. 2. In two separate experiments the elastic constants c_{33}, c_{44}, and c_{66} were measured, and the remaining constants c_{13} and c_{11} were obtained by a parameterized fit to an acoustical model of the L-B film.

The value for c_{33} was obtained by observing backscattering at near normal incidence from longitudinal phonons in a 301-layer sample coated onto a BK-7 glass substrate. The angle of incidence of the incident light was 14°, and the scattered light was collected normal to the surface. A frequency shift of 23.6 GHz was measured for the longitudinal phonons traveling along a direction 7° from the surface normal. The sound speed of the longitudinal phonons is 3980 m/sec using an index of refraction of $n_0 = 1.525$. We have measured the density of CdA films with Rutherford backscattering to be 1.32 (±0.06) g/cm^3. Therefore $c_{33} \cong 2.1 \times 10^{10}$ N/m^2.

The values c_{44} and c_{66} were estimated by observing guided Love modes in the L-B film. "s" polarized light at an angle of incidence of 60° was directed onto a 301 layer L-B sample; the "p" polarized scattered light was collected along the surface normal. No guided Love modes were observed as shown in Fig. 3. Since there are no clear features larger than 3 GHz it is possible to place limits on the values of c_{44} and c_{66}. The scattering angle within the film is 146°, therefore

$$c_{66} \sin^2\theta + c_{44} \cos^2\theta \; < \; 3.6 \times 10^9 \text{ N/m}^2$$

where θ is the direction of the acoustic wave in the film. Here $\theta = 17°$, therefore $c_{44} < 4 \times 10^8$ N/m^2 and $c_{66} < 4.5 \times 10^9$ N/m^2.

Using the values for c_{33} and c_{44}, the remaining elastic constants c_{11} and c_{13} can be obtained by a parameterized fit to a model of the Rayleigh wave thickness dispersion data. The parameterized model of the Rayleigh wave velocity was constructed by modeling the L-B film as a hexagonal film (symmetry axis normal to the surface) on an isotropic substrate. The calculated Rayleigh wave dispersion curve, as well as dispersion curves for the higher order guided wave modes, are shown in Fig. 4 for comparison with experiment. Note the "bunching" of the guided-wave modes at velocities near the Rayleigh wave velocity of the free substrate. It is a direct consequence of the large difference between the shear and compressional elastic moduli, and is not obtained for isotropic films. It is scattering from two of these modes that gives rise to the remaining two peaks in Fig. 1.

No depolarized scattering was observed from Love waves; the spectrum is shown in Fig. 3. The long diffuse tails, which appear to be due to Brillouin features centered at or near zero frequency shift, may arise from molecular orientational fluctuations as in molecular liquids. The appearance of these features suggests that the individual long chain L-B molecules are undergoing orientational fluctuations inside the L-B lattice, leading to a large damping of the shear waves polarized parallel to the layers.

These results show that the elastic properties of these L-B films are highly anisotropic. The compressional constants are comparable to those obtained for oriented polymer films.[14] In contrast, the resistance to shear strains is small, as evidenced by the small shear elastic constants, much smaller than those observed in polymers. These properties are similar to results reported previously for smectic B liquid crystals, raising interesting questions about the similarities and differences between L-B films and smectic B liquid crystal media. Similarly DeGennes has identified a solid form for smectic B liquid crystal media that appears to have similar properties to L-B films.[16]

In summary, the elastic constants of L-B deposited films of CdA have been measured for the first time by Brillouin spectroscopy: namely $c_{44} < 4.0 \times 10^{8}$ N/m^2, $c_{66} < 4.5 \times 10^{9}$ N/m^2, $c_{11} \cong 1.1 \times 10^{10}$ N/m^2, $c_{33} \cong 2.1 \times 10^{10}$ N/m^2, $c_{13} \cong 1.0 \times 10^{10}$ N/m^2, and $c_{12} > 3 \times 10^{10}$ N/m^2. The shear elastic constant c_{44} is quite small for a solid film. There is evidence for molecular reorientation in the depolarized spectra of the CdA films.

REFERENCES

1. G.L. Gaines, Jr., *Insoluble Monolayers at Liquid-Gas Interfaces* (Wiley-Interscience, New York, 1966), Chapter 8.
2. reviewed recently by G.G. Roberts, Advances in Physics, **34**, 475 (1985)
3. C. Naselli, J.F. Rabolt and J.D. Swalen, J. Chem. Phys. **82**, 2136 (1985)
4. J.P. Rabi, J.F. Rabolt and J.D. Swalen, Bull. Amer. Phys. Soc. **31**, 405 (1986)
5. J.P. Rabe, J.F. Rabolt, C.A. Brown and J.D. Swalen, J. Chem. Phys. (in press)

6. J.P. Rabe, Ch. Gerber, J.D. Swalen, D.P.E. Smith, A. Bryant and C.F. Quate, Bull. Amer. Phys. Soc. 31, 289 (1986)

7. A. Fischer and E. Sachmann, J. Physique, 45, 517 (1984)

8. R. Zanoni, C. Naselli, J. Bell, G. Stegeman, R. Sprague, C. Seaton and S. Lindsay, "Brillouin spectroscopy of Langmuir-Blodgett films", in press, Thin Solid Films

9. R. Zanoni, J. Bell, C. Naselli, C.T. Seaton and G.I. Stegeman, "Elastic properties of Langmuir-Blodgett films", in press, Phys. Rev. Lett.

10. P.G. deGennes, *The Physics of Liquid Crystals*, (Clarendon Press, Oxford, 1974)

11. D.L. Mills and K.R. Subbaswamy, in *Progress in Optics, Vol XIX*, edited by E. Wolfe (North Holland, Amsterdam, 1981) p47 and references contained there-in.

12. Y. Liao, N.A. Clark and P.S. Pershan, Phys. Rev. Lett., 30, 639 (1973); reviewed by S. Candau and S.V. Letcher, in *Advances in Liquid Crystals*, G.H. Brown editor, (Academic Press, New York, 1978) p. 168

PUBLISHED PAPERS

1. C. Naselli, J.F. Rabolt and J.D. Swalen, "Order-disorder transitions in Langmuir-Blodgett monolayers. I. Studies of two-dimensional melting by infrared spectroscopy", J. Chem. Phys., 82, 2136 (1985)

2. J.F. Rabolt, M. Jurich and J.D. Swalen, "Infrared reflection-absorption studies of thin films at grazing incidence", Applied Spectroscopy, 39, 269 (1985)

3. J.D. Swalen and J.F. Rabolt, "Characterization of orientation and lateral order in thin films by Fourier transform infrared spectroscopy", book chapter for Fourier Transform Infrared Spectroscopy, Vol 4, Academic Press, Chapter 7, p283

4. R. Zanoni, C. Naselli, J. Bell, G. Stegeman, R. Sprague, C. Seaton and S. Lindsay, "Brillouin spectroscopy of Langmuir-Blodgett films", Solid Thin Films, 134, 179 (1985)

5. J.P. Rabe, J.F. Rabolt, C.A. Brown, J.D. Swalen, "Order-disorder transitions in Langmuir-Blodgett Films. II IR studies of the polymerization of CD-Octadecylfumarate and CD-Octadecylmaleate, J. Chem. Physics, 84, 4096 (1985)

6. S.J. Mumby, J.D. Swalen and J.F. Rabolt, "Orientation of Poly(ODM) and P(OA) in Langmuir-Blodgett monolayers investigated by polarized infrared spectroscopy", Macromolecules, 19, 1054 (1986)

7. C. Naselli, J.P. Rabe, J.F. Rabolt and J.D. Swalen, "Thermally induced order-disorder transitions in L-B films", Thin Solid Films, 134, 173 (1985)

8. R. Zanoni, J. Bell, C.T. Seaton, G.I. Stegeman, W.R. Bennett and C.M. Falco, "Brillouin sattering from multilayer films", Proceedings of the International Symposium on Surface Waves on Solids, in press, Novosibirsk, USSR, July 1986

9. R. Zanoni, J. Bell, C. Naselli, C.T. Seaton and G.I. Stegeman, "Elastic properties of Langmuir-Blodgett films", in press, Phys. Rev. Lett.

CONFERENCE PRESENTATIONS

1. J.P. Rabe, J.F. Rabolt, C.A. Brown and J.D. Swalen, "Polymerization of two unsaturated fatty acid esters in Langmuir-Blodgett films as studied by infrared spectroscopy", presented at March APS meeting and the Second International Conference on LB Films, July, 1985, Schenectady, New York

2. J.P. Rabe, C. Naselli, J.F. Rabolt and J.D. Swalen, "Thermally induced order-disorder transitions in Langmuir-Blodgett films", presented at March APS meeting and Second International Conference on LB Films, July, 1985, Schenectady, New York

3. J. Bell, R. Zanoni, G.I. Stegeman, C. Karaguleff, C.T. Seaton and J.F. Rabolt, "Brillouin scattering of liquid-solid interfaces via evanescent fields", paper WF3, Technical Program, Annual Meeting of the Optical Society of America, San Diego, 1984

4. R. Zanoni, J. Bell, G.I. Stegeman, J.F. Rabolt and C. Karaguleff, "Brillouin spectroscopy of thin glass films", paper WF4, Technical Program, Annual Meeting of the Optical Society of America, San Diego, 1984

5. R. Zanoni, C. Naselli, J. Bell, C.T. Seaton, G.I. Stegeman and S. Lindsay, "Elastic onstants of Langmuir-Blodgett films measured by Brillouin spectroscopy", presented at the Second International Conference on LB Films, July, 1985, Schenectady, New York

6. R. Zanoni, C. Naselli, J. Bell, G. Stegeman and C. Seaton, "Brillouin spectra of Langmuir-Blodgett films", presented at the Annual Optical Society of America conference, October 1985, Washington, DC

7. R. Zanoni, C. Naselli, J. Bell, G. Stegeman and C. Seaton, "Brillouin spectra of several monolayer films", presented at 8'th Course on Electromagnetic Surface Excitations, Ettore Majorana Centre for Scientific Culture, July 1985, Erice, Sicily, Italy

8. R. Zanoni, J. Bell, C. Naselli, G.I. Stegeman and C.T. Seaton, "Brillouin scattering from Langmuir-Blodgett films", paper HI11 presented at APS Meeting, Las Vegas, March 1986

9. G.I. Stegeman, "Brillouin spectroscopy of L-B films", invited paper at Gordon Conference on Organic Films, Santa Barbara, February 17-21 (1986)

10. R. Zanoni, J. Bell, C. Naselli, G.I. Stegeman and C.T. Seaton, "Elastic properties of Langmuir-Blodgett films", paper TUC6 presented at OSA Meeting, Seattle Washington, October 1986

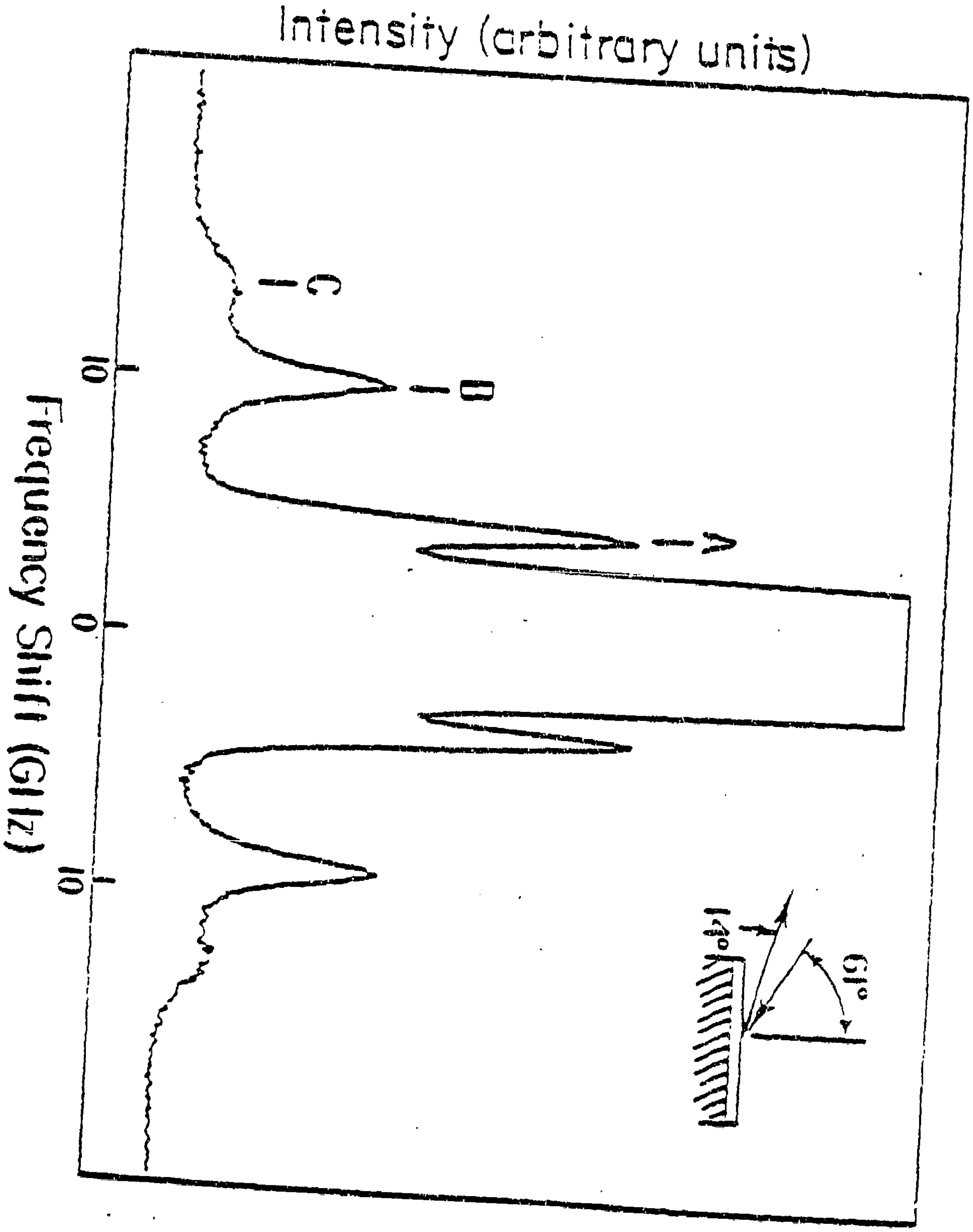
Figure Captions

Fig. 1. Typical Brillouin spectrum of 75 layers of CdA coated onto a molybdenum substrate. The scattering geometry is illustrated in the upper right corner.

Fig. 2. Brillouin spectra of CdA film samples on molybdenum. The samples range in thickness from 11 to 401 monolayers thick.

Fig. 3. Depolarized scattering from a CdA sample 301 layers thick. No phonon modes were observed larger than 3 GHz.

Fig. 4. Comparison of Brillouin scattering measurements with Rayleigh and Sezawa dispersion curves for a hexagonal film with $c_{33} = 2.1 \times 10^{10}$ N/m^2, $c_{13} = 1.0 \times 10^{10}$ N/m^2, $c_{44} = 4.0 \times 10^{10}$ N/m^2, and $c_{12} = 3.0 \times 10^{10}$ N/m^2 deposited on a polycrystalline molybdenum substrate.



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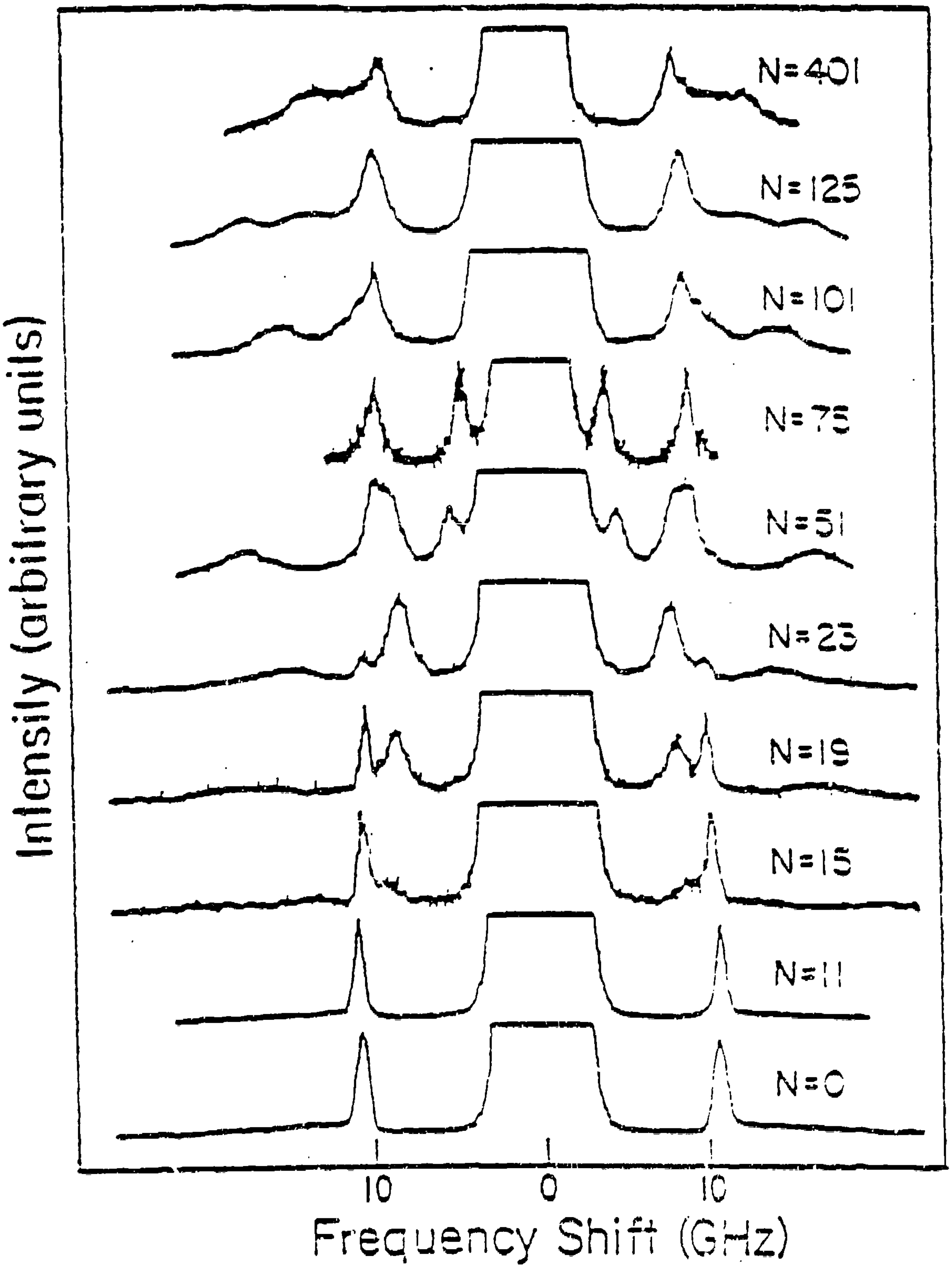

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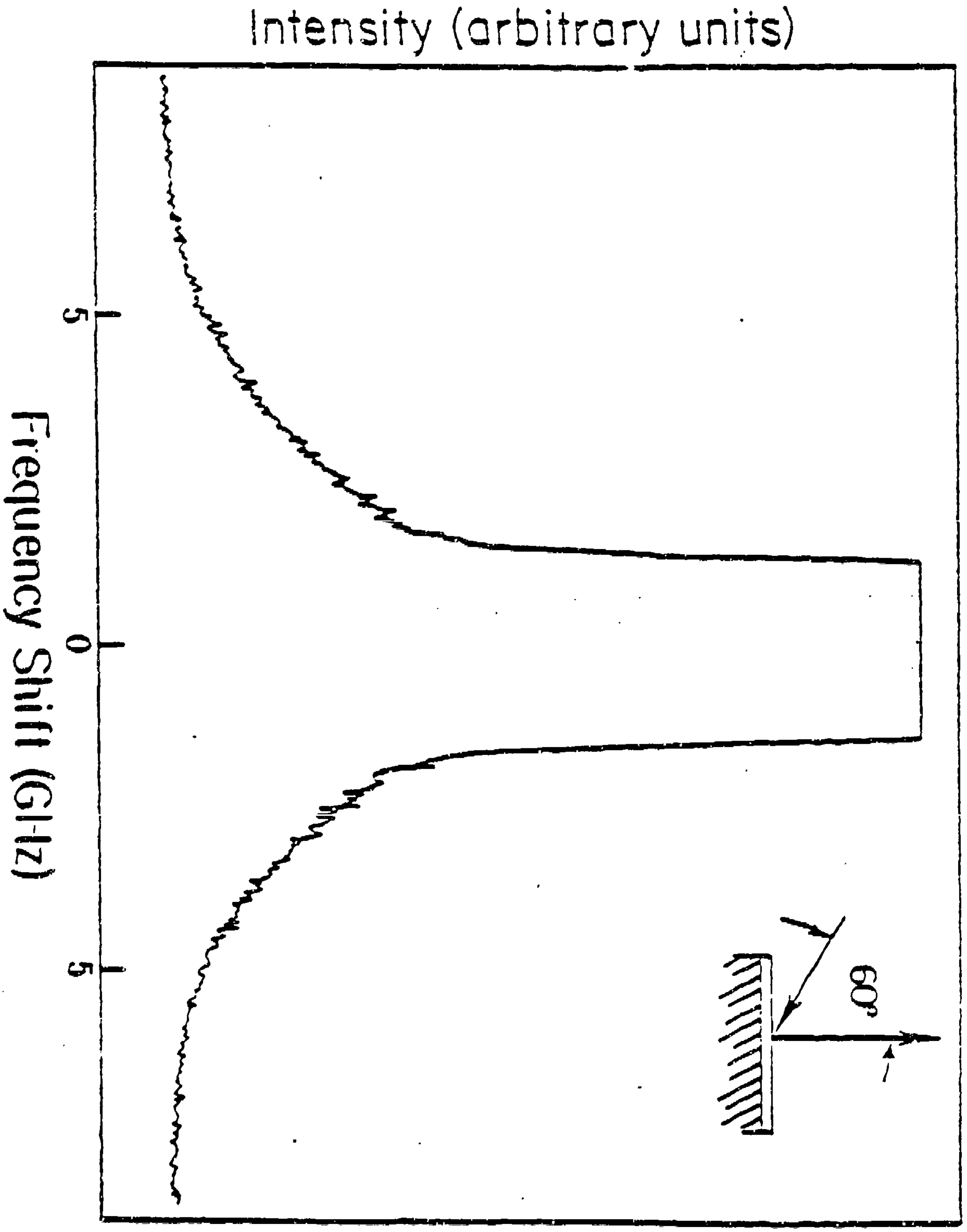

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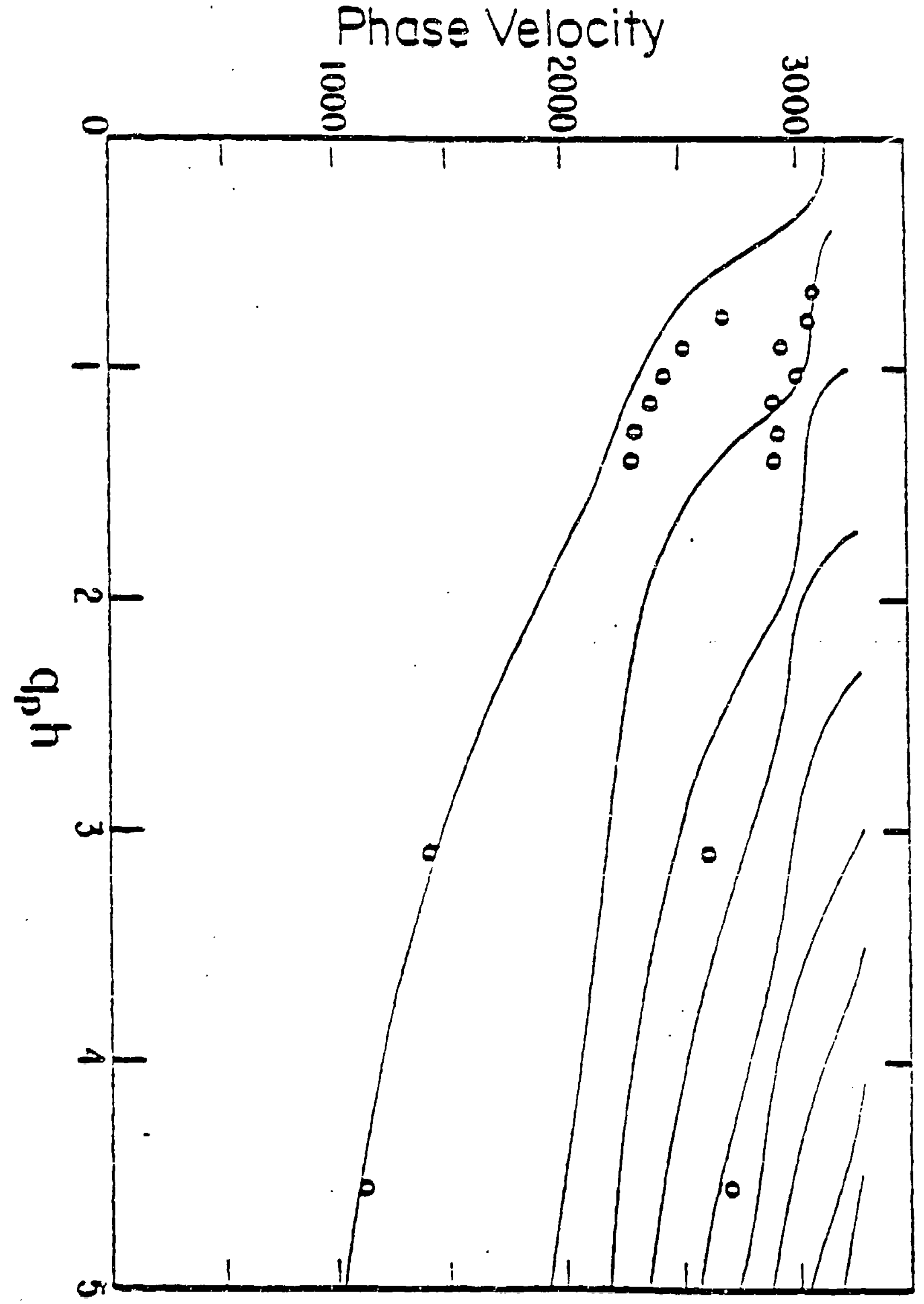

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