The CECOM Center for Night Vision and Electro-Optics

OPTOELECTRONIC WORKSHOPS

XXV

LIQUID CRYSTAL MATERIALS AND DEVICES FOR OPTO-ELECTRONIC APPLICATIONS

December 5, 1990

sponsored jointly by

ARO-URI Center for Opto-Electronic Systems Research
The Institute of Optics, University of Rochester

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Stephen Jacobs (UR) and James Miller (CCNVEO)

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13. ABSTRACT (*Maximum 200 words*)

This workshop on "Liquid Crystal Materials and Devices for Opto-Electronic Applications" represents the twenty-fifth of a series of intensive academic / government interactions in the field of advanced electro-optics, as part of the Army sponsored University Research Initiative. By documenting the associated technology status and dialogue it is hoped that this baseline will serve all interested parties towards providing a solution to high priority Army requirements. Responsible for program and program execution are Dr. Nicholas George, University of Rochester (ARO-URI), and Dr. Rudolf Buser, CCNVEO.

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1. INTRODUCTION

This workshop on "Liquid Crystal Materials and Devices for Opto-Electronic Applications" represents the twenty-fifth of a series of intensive academic / government interactions in the field of advanced electro-optics, as part of the Army sponsored University Research Initiative. By documenting the associated technology status and dialogue it is hoped that this baseline will serve all interested parties towards providing a solution to high priority Army requirements. Responsible for program and program execution are Dr. Nicholas George, University of Rochester (ARO-URI), and Dr. Rudolf Buser, CCNVEO.

OPTOELECTRONIC WORKSHOP

ON

LIQUID CRYSTAL MATERIALS AND

DEVICES FOR OPTO-ELECTRONIC APPLICATIONS

Organizer: ARO-URI -University of Rochester
and CECOM Center for Night Vision and Electro-Optics

1. INTRODUCTION

2. SUMMARY -- INCLUDING FOLLOW-UP

3. VIEWGRAPH PRESENTATIONS

CECOM Center for Night Vision and Electro-Optics
Organizer -- James E. Miller

ARO-URI Center for Opto-Electronic Systems Research
Organizer -- Kenneth L. Marshall

Introduction
James Miller, CCNVEO

An IR Chopper for the 8-12 µm Region Employing the
TLSM Effect in Ferrcelectric Liquid Crystals
Kenneth L. Marshall, ARO-URI

An Overview of Optical Power Limiting Materials,
Devices, and Sponsored Programs
Gary L. Wood, CCNVEO

Third-Order Nonlinear Susceptibility of Liquid Crystals
at 1053 nm by Chirped-Pulse Nonresonant CARS
Ansgar Schmid, ARO-URI

Optical Power Limiting Employing Laser Speckle in
Liquid Crystal Guest-Host Systems: A Time-Resolved Study
Mark Guardalben, ARO-URI

Liquid Crystal Beam Switching/Beam-Steering Concepts--
Are There Potential CCNVEO Applications?
Kenneth L. Marshall

4. LIST OF ATTENDEES

2. SUMMARY AND FOLLOW-UP

The workshop was opened by a brief review by J. Miller of the device requirements for an electro-optic element to replace a mechanical chopper for uncooled IR detector arrays. K. Marshall then reviewed the liquid crystal TLSM/IR chopper project and presented recent results. Key highlights presented included the following:

(1.) A TLSM cell driven by a programmable waveform generator designed and built at UR/LLE was shown to be capable of generating a square-wave optical response with rise and decay times of 500 μs;

(2.) A modulation depth of 40% in the 8-12 μ region of the infrared was demonstrated in an FTIR experiment using a prototype TLSM/IR chopper;

(3.) The design and synthesis of a new ferroelectric liquid crystal with the potential for improved transmission in the 8-12 μ region was described ;

(4.) A functional prototype TLSM/IR chopper and programmable waveform generator were delivered to C^2NVEO for further characterization and experimentation.

All participants agreed that the only major unresolved issues for practical implementation of the TLSM/IR chopper were IR transmission and modulation depth. It was agreed that every effort must be made to minimize IR losses in future prototypes by (1) employing thinner substrates and infrared AR coatings, and (2) emphasizing continued development and synthesis of new IR transparent ferrroelectric liquid crystals with increased birefringence to reduce interaction pathlength requirements and increase modulation depth.

The following three presentations concentrated on optical power limiting. G. Wood reviewed current Army performance requirements for power limiter devices, and pointed out that the current emphasis is on wavelength agility with more emphasis on the nanosecond response regime as opposed to picosecond response. Nonlinear phenomena which showed the greatest potential for power limiting were identified, and data on modeling efforts of ideal device performance were presented. A review of funded liquid crystal research efforts at Kent State, Penn State, and Optical Shields, LTD was also given. A. Schmid discussed a novel technique for the determination of purely electronic contributions to the X3 of nonlinear materials, and presented data correlating molecular structure to the magnitude of X3 in several new liquid crystal compounds synthesized at UR/LLE. M. Guardalben described a series of time-resolved measurements designed to elucidate the mechanism of laser-induced scattering in a homeotropically aligned smectic liquid crystal cell with spatially varying anchoring strength.

The workshop was concluded with a brief overview by K. Marshall on a new project involving liquid crystals for electro-optical beam switching /beam steering applications and a discussion of potential applications, followed by a demonstration of a prototype infrared imaging system using uncooled detectors by C^2NVEO personnel.

As part of the University Research Initiative collaboration between the U.S. Army Center for Night Vision and Electro-Optics and the University of Rochester, the following items were delivered to C^2NVEO, Fort Belvoir, today:

- One IR chopper TLSM cell.
- One electronic driver for the TLSM cell.
- One DRV-II parallel interface card for computer control of the electronic driver.
- One folder of user documentation for the above, including one 8-in. floppy disk with driver software.

5 December 1990

Stephen D. Jacobs
University of Rochester

J. E. Miller
C^2NVEO

WORKSHOP

Liquid Crystal Materials and Devices for Opto-Electronic Applications

Center for Night Vision and Electro-Optics
Fort Belvoir, VA

5 December, 1990

University of Rochester
Organizer

K. L. Marshall
(716)-275-5101

Center for Night Vision and Electro-Optics
Organizer

J. E. Miller
(703)-664-1585

AGENDA

10:30 AM	Introduction	(5)	J. Miller (C^2NVEO)
	An IR Chopper for the 8-12 μm Region Employing the TLSM Effect in Ferroelectric Liquid Crystals	(30)	K. Marshall (LLE)
	An Overview of Optical Power Limiting Materials, Devices, and Sponsored Programs	(45)	G. Wood (C^2NVEO)
	Third-Order Nonlinear Susceptibility of Liquid Crystals at 1053 nm by Chirped-Pulse Nonresonant CARS	(20)	A. Schmid (LLE)
	Optical Power Limiting Employing Laser Speckle in Liquid Crystal Guest-Host Systems: A Time-Resolved Study	(20)	M. Guardalben (LLE)
12:30 pm	Lunch		
1:30 pm	Liquid Crystal Beam Switching/Beam-Steering Concepts -Are There Potential C^2NVEO Applications?	(10)	K. Marshall (LLE)
1:45 pm	Discussions		
2:30 pm	C^2NVEO Demonstration -IR Imaging Device using Uncooled Detectors		
3:00 pm	Adjourn		

CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH
AN IR CHOPPER FOR THE 8-12 μM REGION EMPLOYMENT THE TLSM EFFECT IN FERROELECTRIC LIQUID CRYSTALS

An IR Chopper for the 8-12 μm Region Employing The TLSM Effect In Ferroelectric Liquid Crystals

UR LLE

Kenneth L. Marshall

Laboratory for Laser Energetics
University of Rochester

Workshop
"Liquid Crystal Materials and Devices for Opto-electronic Applications"
Center For Night Vision and Electro-optics
Fort Belvoir, VA
5 December, 1990

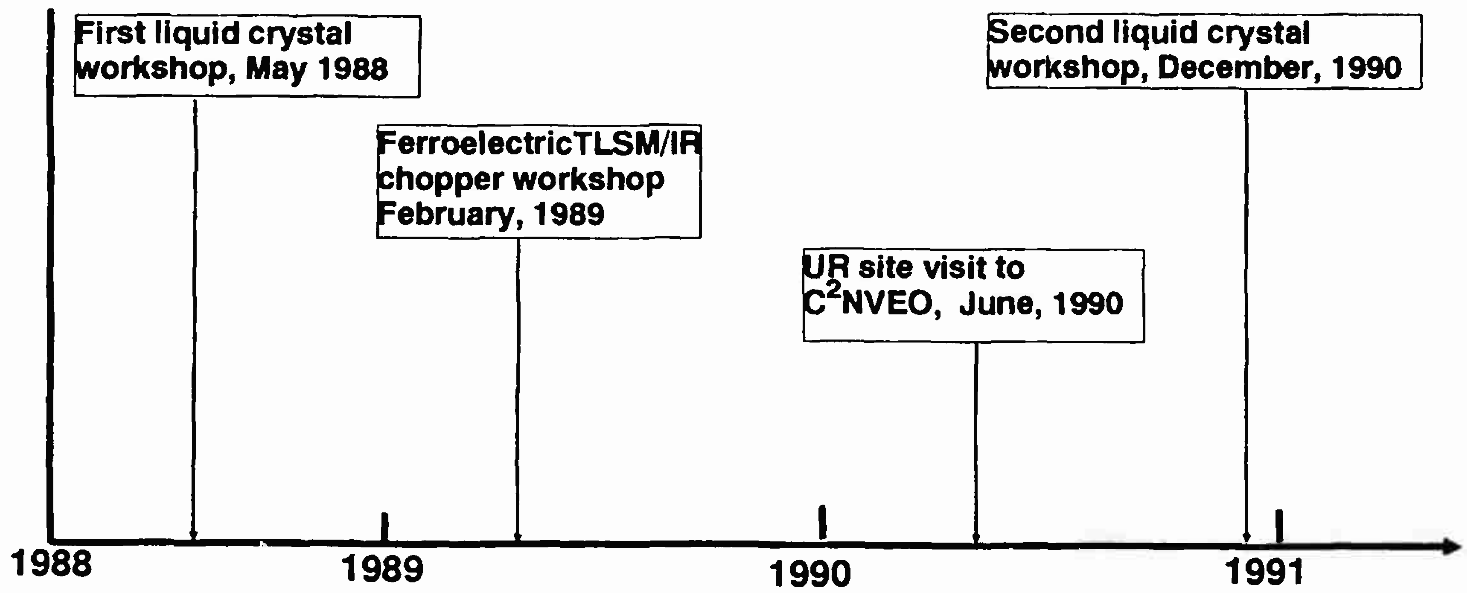
Outline

UR LLE

- Background and motivation
- Identification of key issues
- Description of research activities:
  - Cell fabrication and testing
  - Device driver electronics
  - LC materials design and synthesis
- IR modulation experiments
- Summary

Background and motivation for UR/C^2NVEO interaction

Need for a solid state device to replace a mechanical chopper for infrared detector arrays (8-12 μm region)*



*Army URI/Institute of Optics Workshop: "Liquid Crystals for Laser Applications", Night Vision and Electro-Optics Center, Ft. Belvoir, VA; 11 May 1988; Dr. James E. Miller, IRT-UDDT

A number of materials technologies have been previously investigated for mid-IR modulation

- Ferroelectric ceramics
  - TsTSL
- Inorganic crystals
  - KDP, $LiNbO_3$, GaAs, CdTe, ZnSe
- Liquid crystals
  - Dynamic scattering in nematics*

* I. C Khoo, Dept. of Electrical Engineering, Penn State University

The liquid crystal line scan chopper concept is the most desirable approach for uncooled detector arrays

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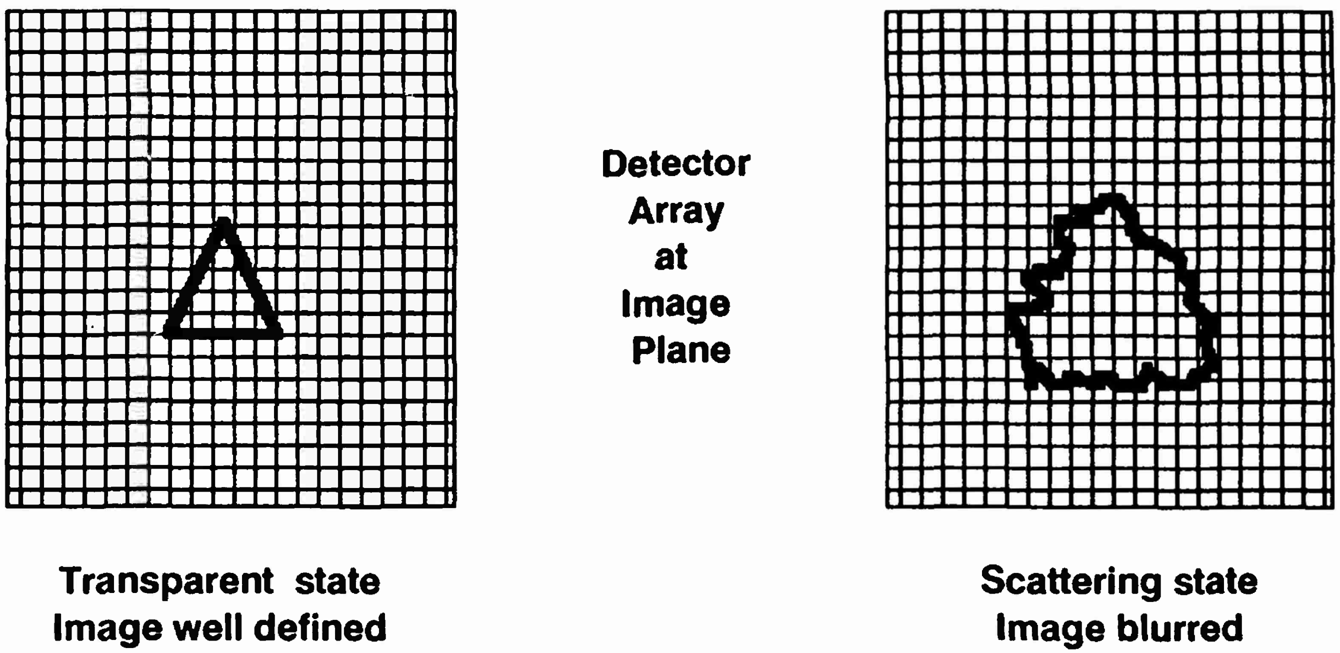
- Operates by forward scattering, not transmission reduction
- Blurring or defocussing of image on detector plane



Dynamic scattering in nematics satisfies most performance requirements except for switching speed

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Device performance requirements:

- **Response time:** $<$ 1 ms rise, $<$1 ms decay
- **Acceptance angle:** 40^{o}
- **Transmission:** $>$ 80% (8-12 μm region)

Dynamic scattering response time:

- **Rise time:** 1 ms
- **Decay time:** 100 ms

Decay time is two orders of magnitude too slow for a practical device

Ferroelectric liquid crystal technology provides a solution to the response time problem

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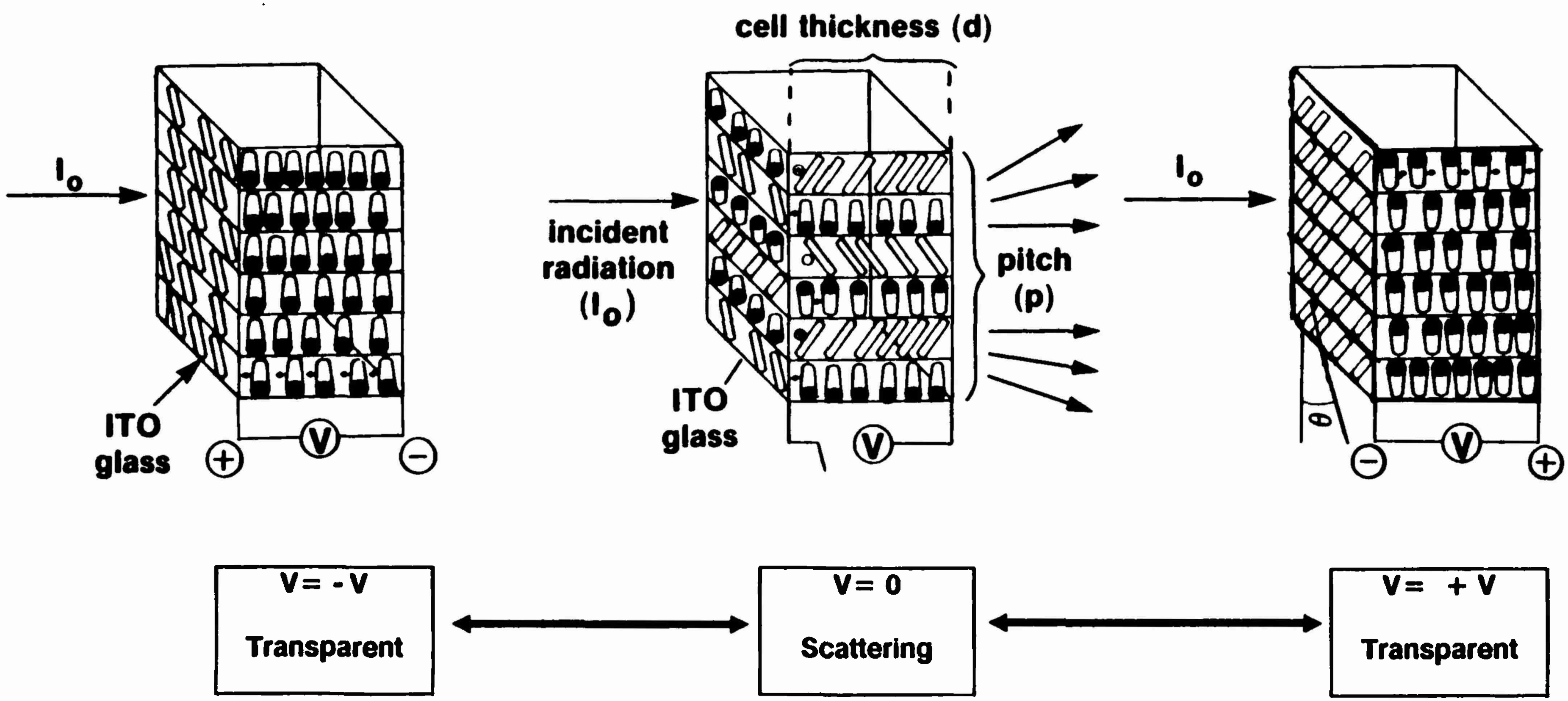
Ferroelectric liquid crystals are capable of :

- Response times in the microsecond regime
- Field-driven reversibility of optic axis orientation

Possible optical effects include:

- Polarization rotation
  - SSFLC
- Field-induced scattering
  - TLSM

The Transient-Light-Scattering Mode (TLSM) in Ferroelectric Liquid Crystals



- Reversal of dc field polarity through zero voltage state produces transient scattering effect

Three key issues must be resolved in order to validate the TLSM / IR chopper device concept

UR LLE

Issue 1:

- Rise and decay time of TLSM effect

Issue 2:

- Driving waveforms required to control the duration of the scattering effect

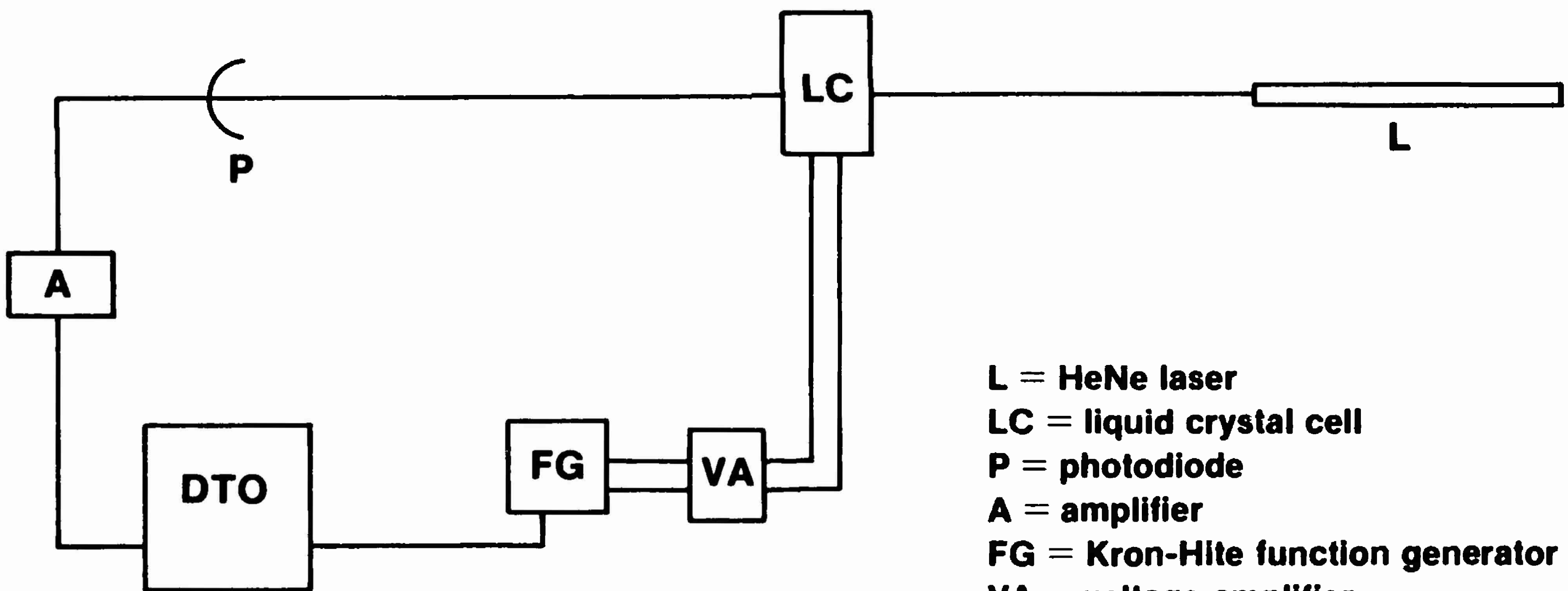
Issue 3:

- IR transmission characteristics of ferroelectric mesogens and device components in the 8-12 μm region

Issue 1: Electro-optic Response of TLSM Mode

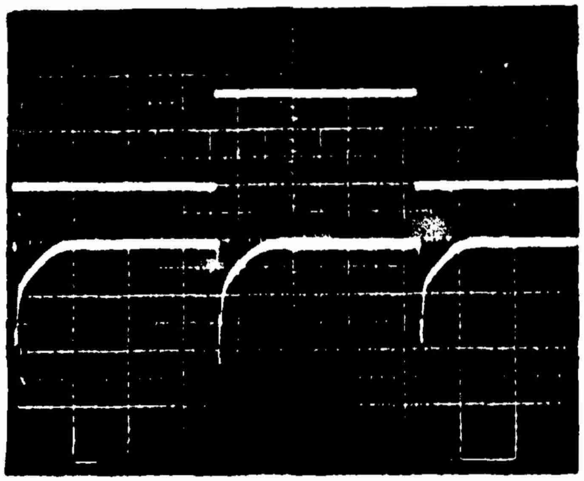
- Response time measurements conducted in the visible for experimental simplicity and reduced cost

TLSM Response Time Setup



L = HeNe laser
LC = liquid crystal cell
P = photodiode
A = amplifier
FG = Kron-Hite function generator
VA = voltage amplifier
DTO = dual-trace oscilloscope

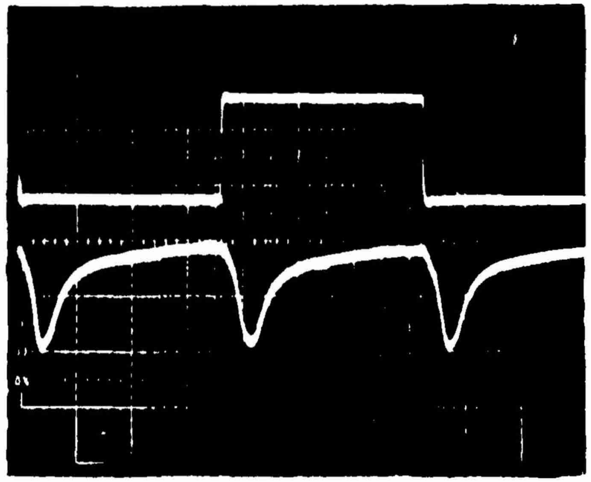
TLSM Response of Ferroelectric LC Mixture ZLI 4003



2 ms/div

cell path length: 25 μm

drive voltage: $\pm$200V
(square wave)



200 μs/div

rise time: 80-100 μs

decay time: 600 μs

- Issue 1 has been successfully resolved

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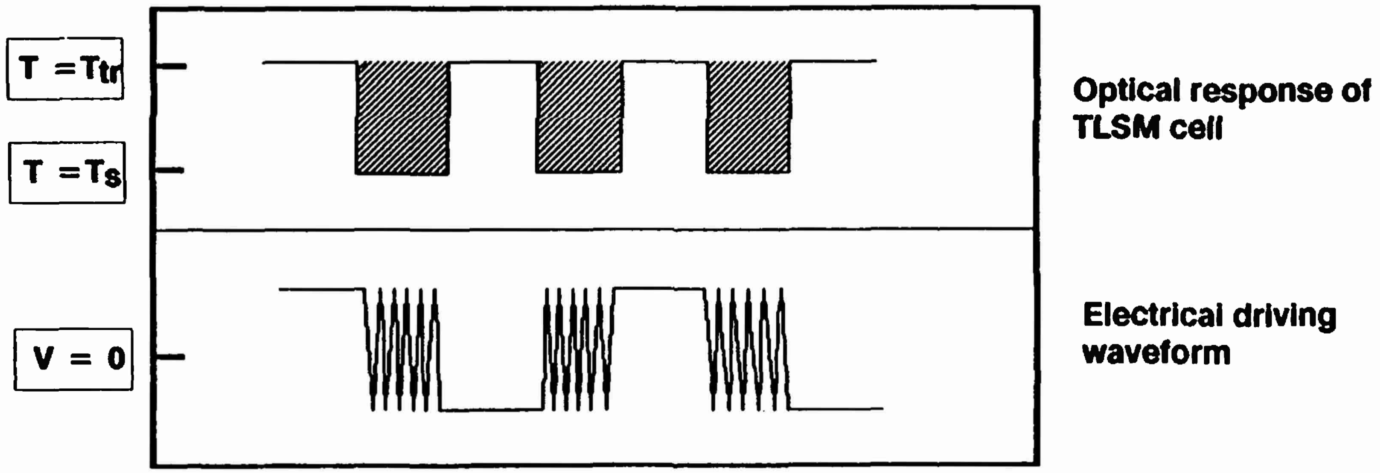
Issue 2: Driver for TLSM /IR Chopper

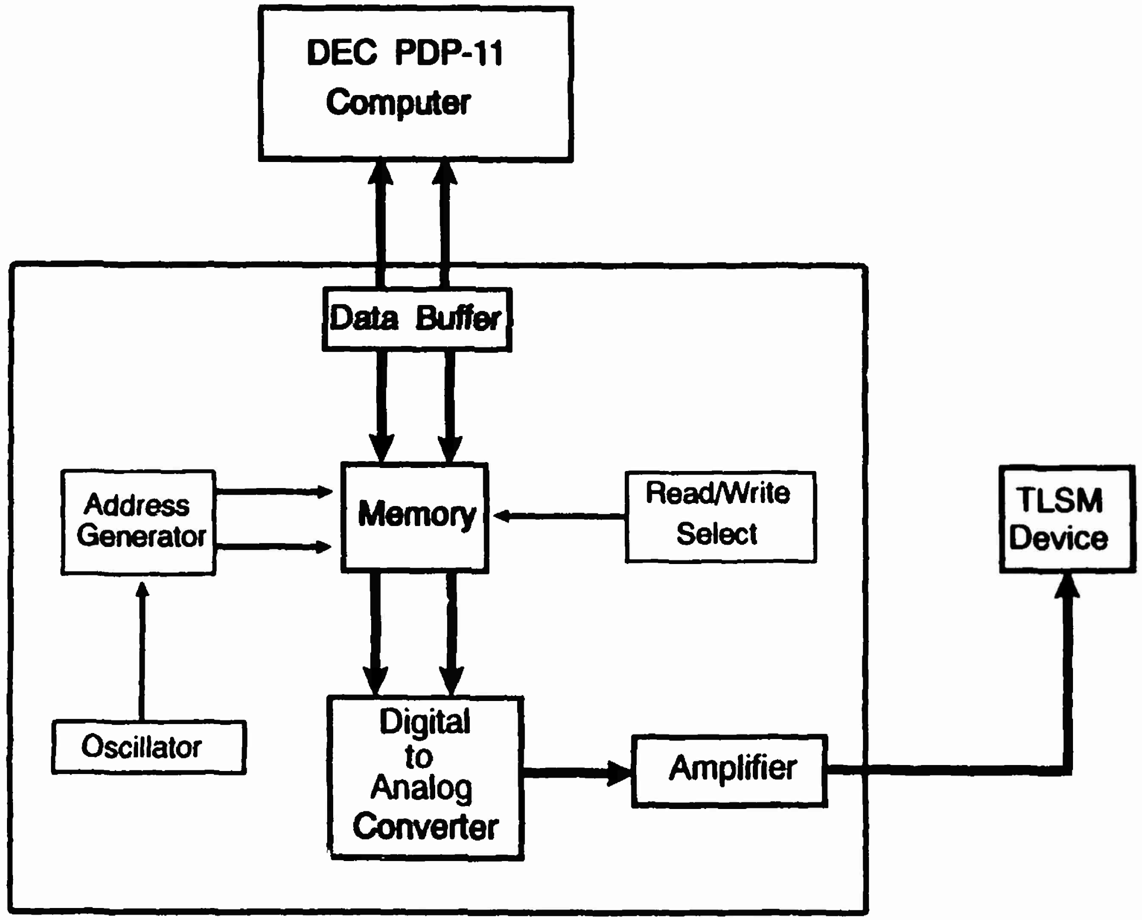
- **Requirements:**
  - 200 V peak-to-peak output
  - Ability to deliver program waveforms to TLSM cell which will simulate square-wave optical response



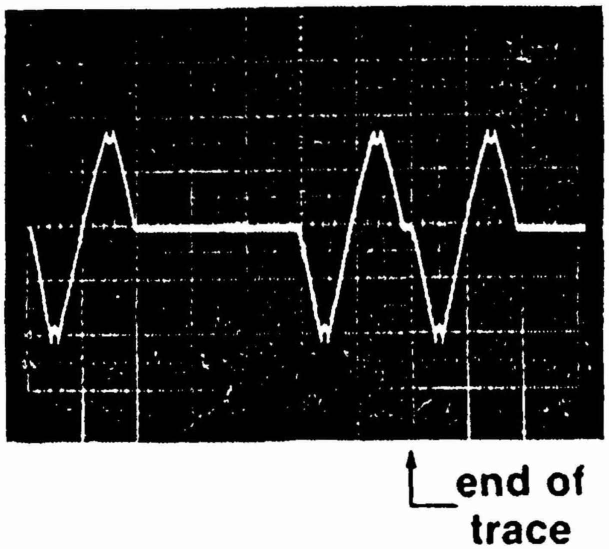
  - TLSM cutoff frequency for ZLI 4003 = 20 KHz

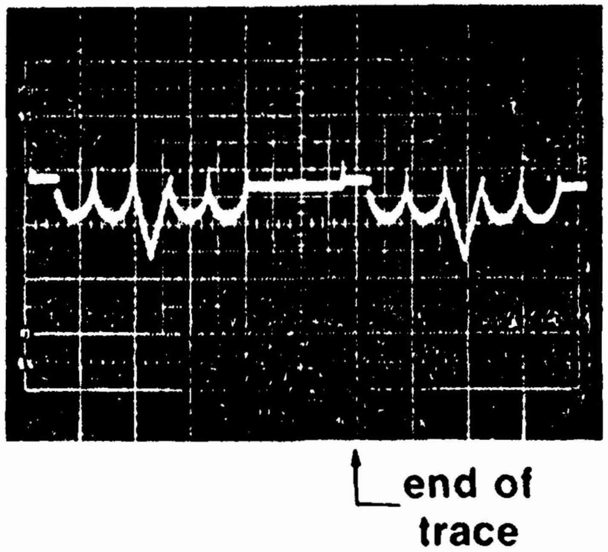
Programmable waveform generator combines maximum flexibility with simplicity of design

UR LLE



Two Computer-Generated Waveforms Unattainable by Standard Analog Instruments





- Maximum amplitude: ±100 V
- 50 μs/division timescale
- Oscilloscope triggered by address-generator synched pulse
- Single-trace option available

G2420

Issue 3: Mid-Infrared Transparency of Materials

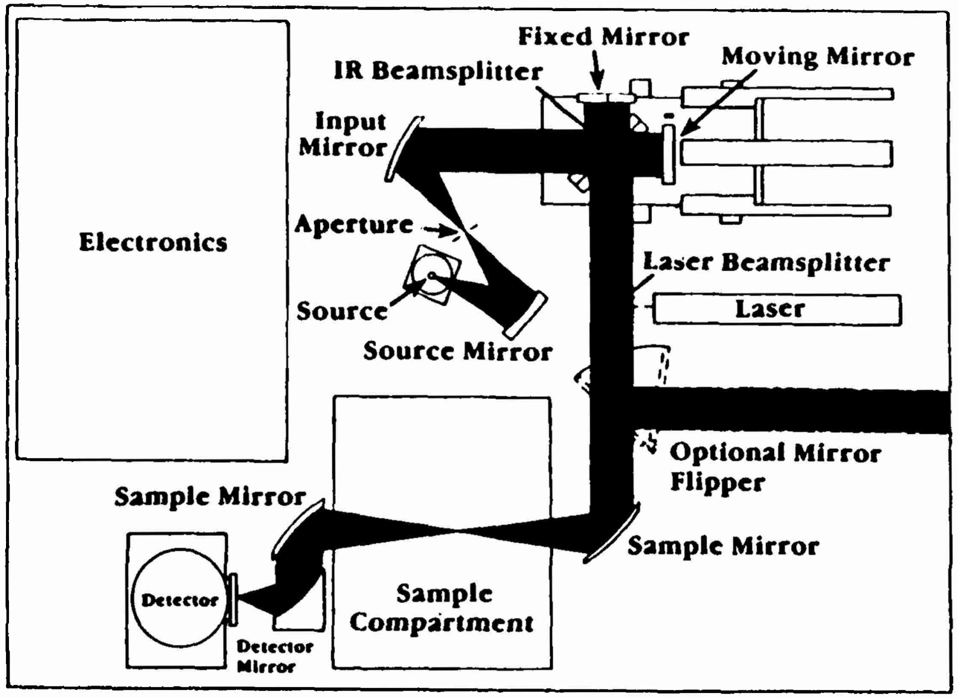
UR LLE

Materials issues under consideration:

- Ferroelectric liquid crystals
- ITO and alignment coatings
- Substrates

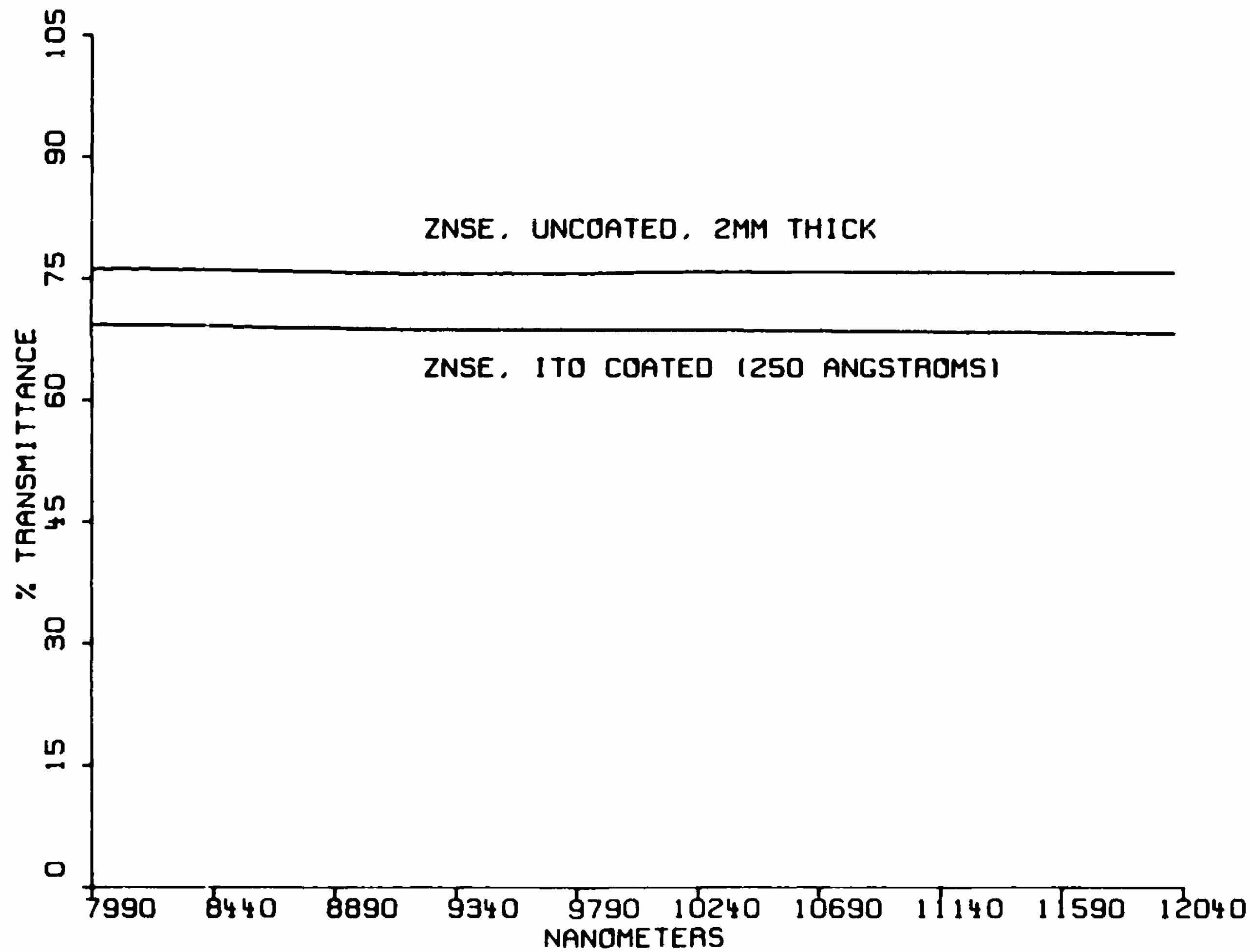
Fourier transform infrared spectrometry yields transmission information over the entire mid-infrared region

Nicolet 20SXC FTIR spectrometer optical diagram

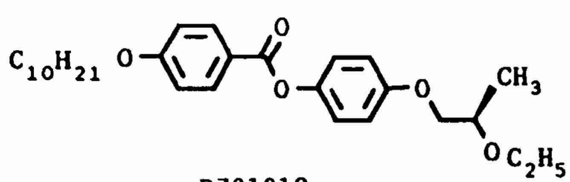


Range:	7000 - 400 cm^{-1}
Resolution:	0.2 cm^{-1}
Maximum scan rate:	20 scans /sec
Signal/noise:	850 : 1

Thin film alignment and conductive coatings make the smallest contribution to IR transmission losses

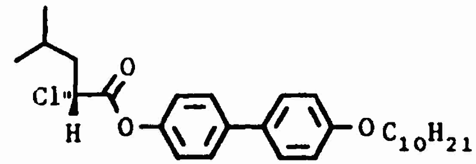


Molecular structure has a strong influence on the mid-infrared transparency of liquid crystal compounds



D781812

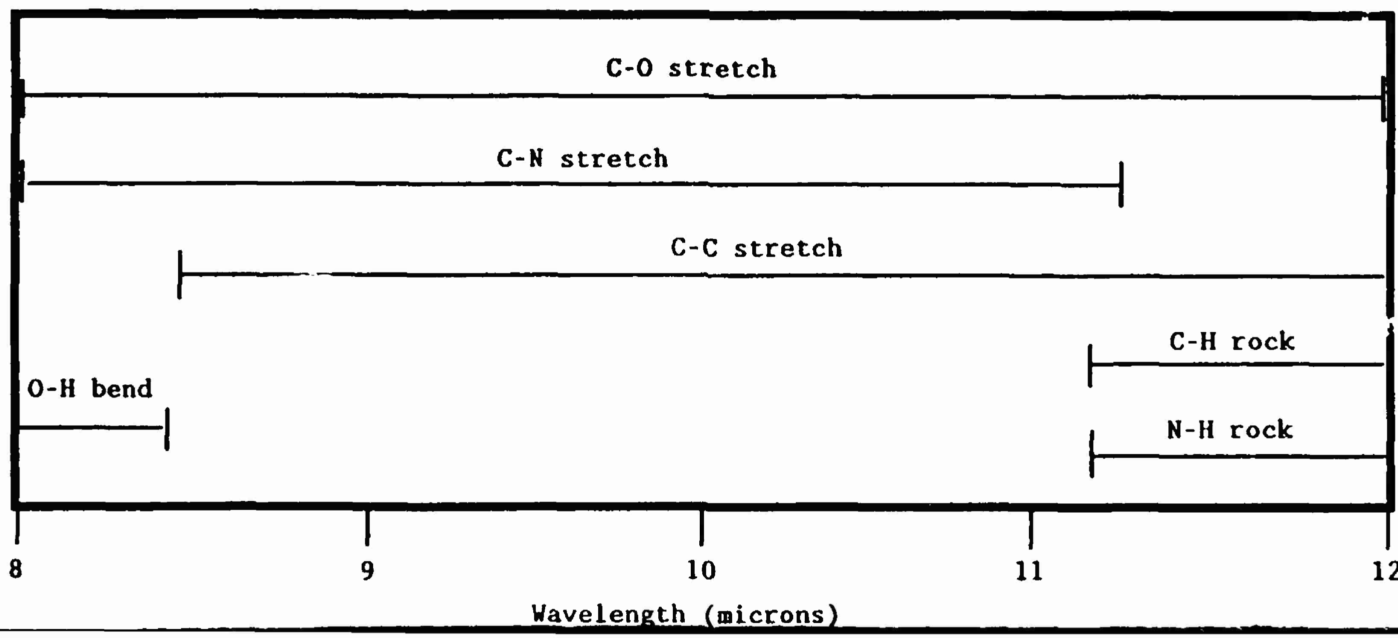
(Commercial ferroelectric)



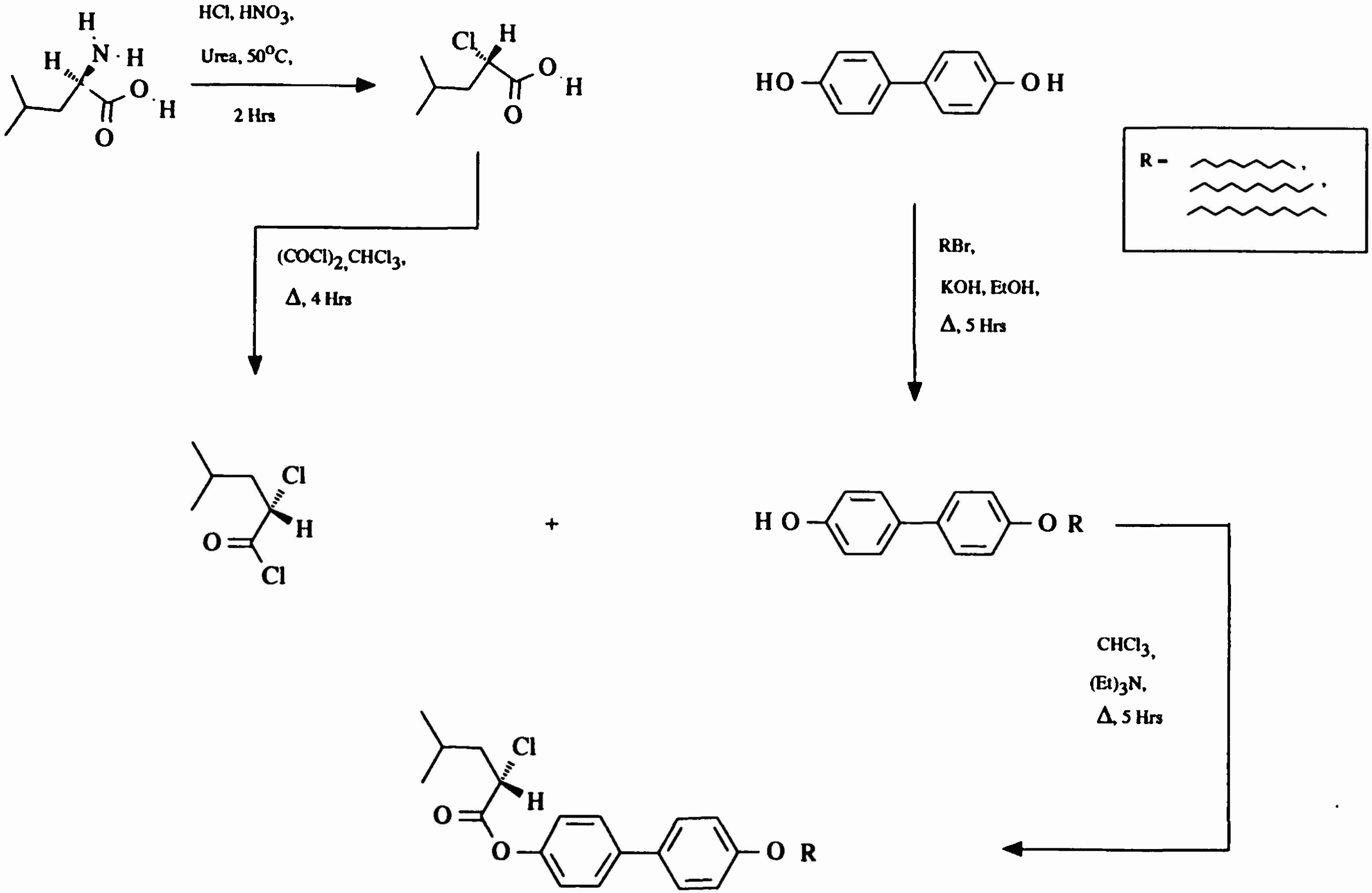
B-4

(In-house ferroelectric)

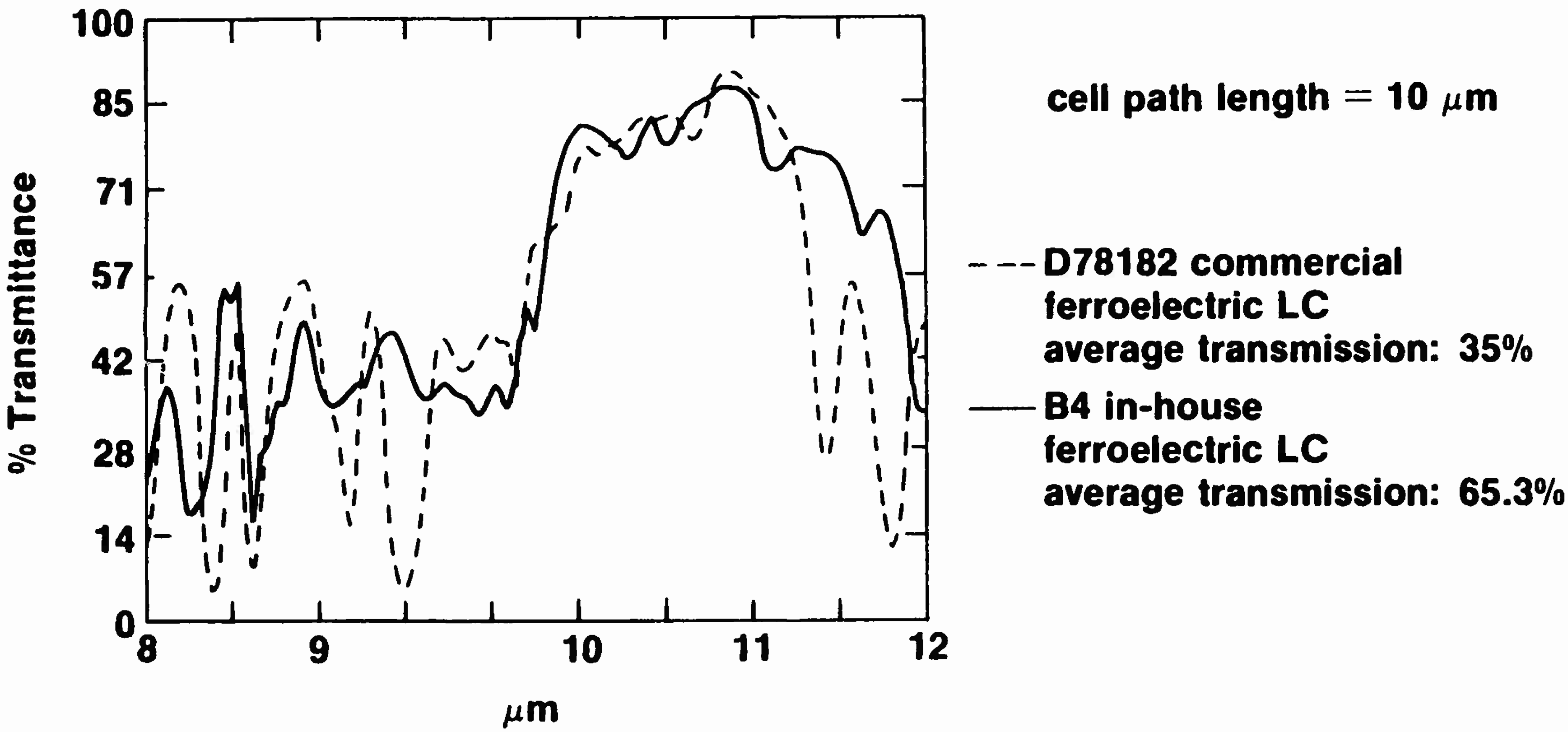
Characteristic Functional Group Absorptions



Synthesis Method for Biphenyl Esters with Highly Polar Chiral Centers



Careful attention to molecular design issues results in improved mid-infrared transmission

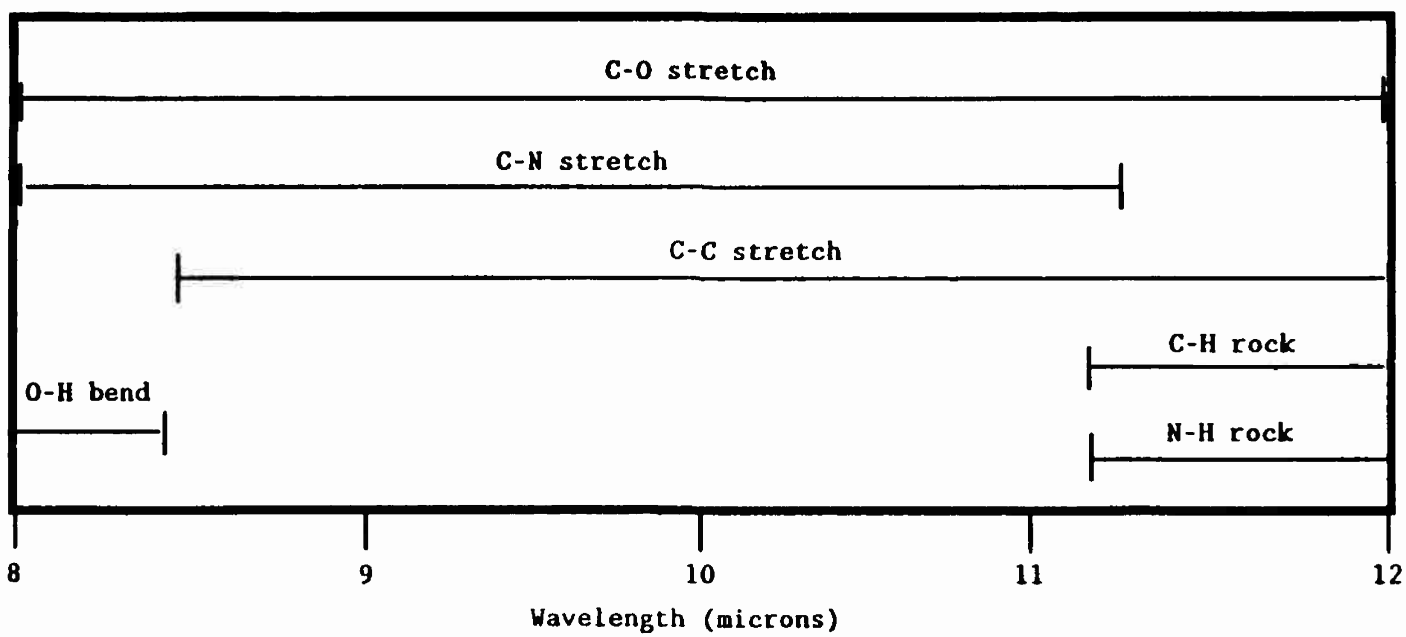


- New ferroelectric LC materials recently synthesized in-house show an improvement in transparency over 8- to 12-μm region.

G2829

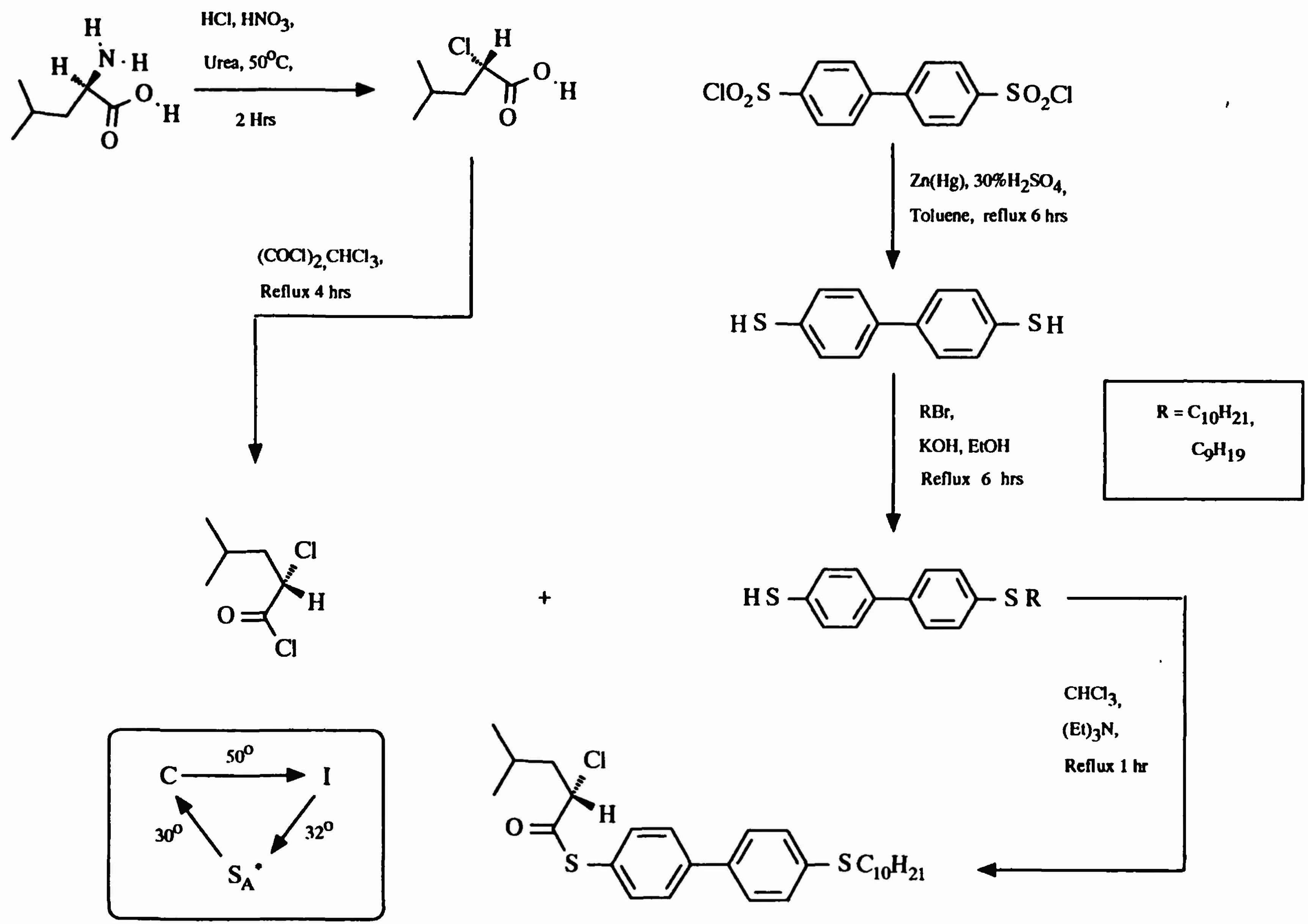
Replacement of 8-12 μm chromophores with non-absorbing functional groups is essential for further IR transmission gains

Characteristic Functional Group Absorptions



- Substitution of sulfur for oxygen in C-O linkages is the best short-term approach for improving IR transparency

Alkylthio-substituted bipheny thioesters are key to improved IR transmittance in TLSM devices



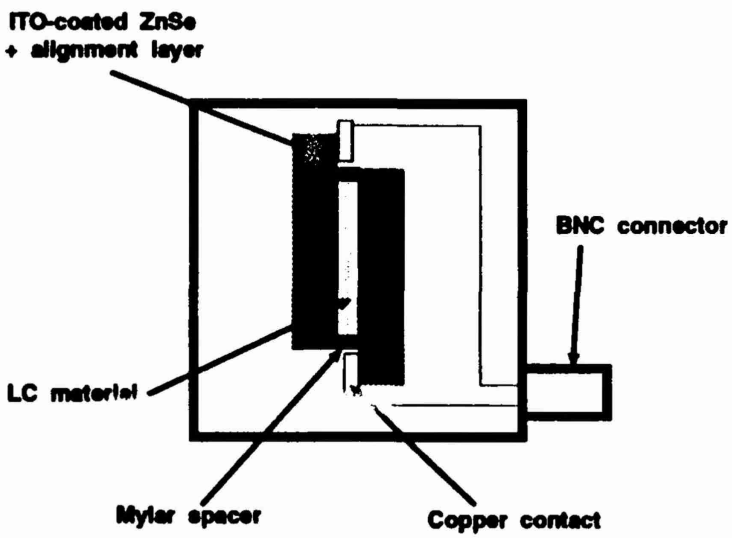
Preliminary characterization of the first functional prototype TLSM/IR chopper

UR LLE

Purpose:

- Verify ability to modulate IR radiation
- Study effect of basic waveform shape on modulation depth

TLSM/IR chopper assembly



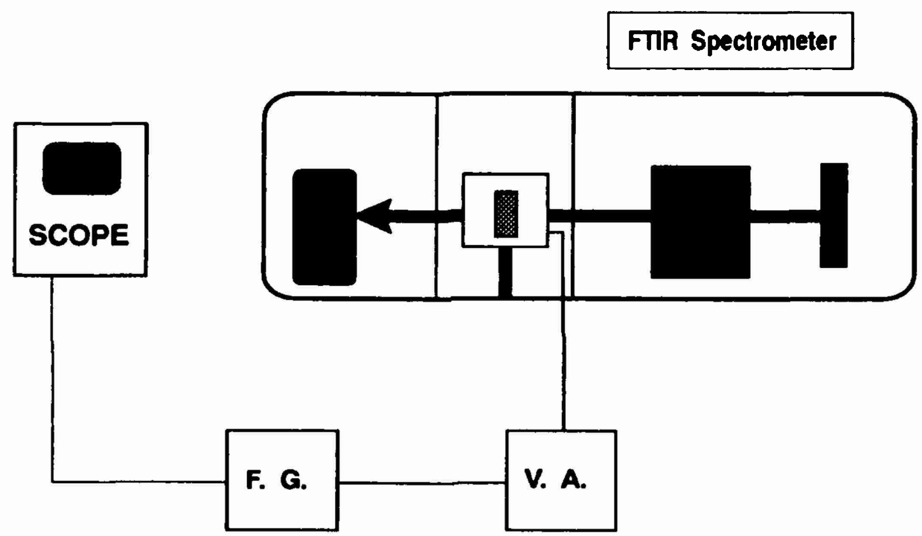
Cell parameters:

Ferroelectric LC material:	Merck ZLI-4003
Substrates:	ZnSe, 2 mm thick
Conductive coating:	ITO (250 Å)
Alignment coating:	Buffed PBT (500 Å)
LC layer thickness:	25 μm

No AR coatings on outer surfaces

A simple FTIR experiment is used to evaluate device performance

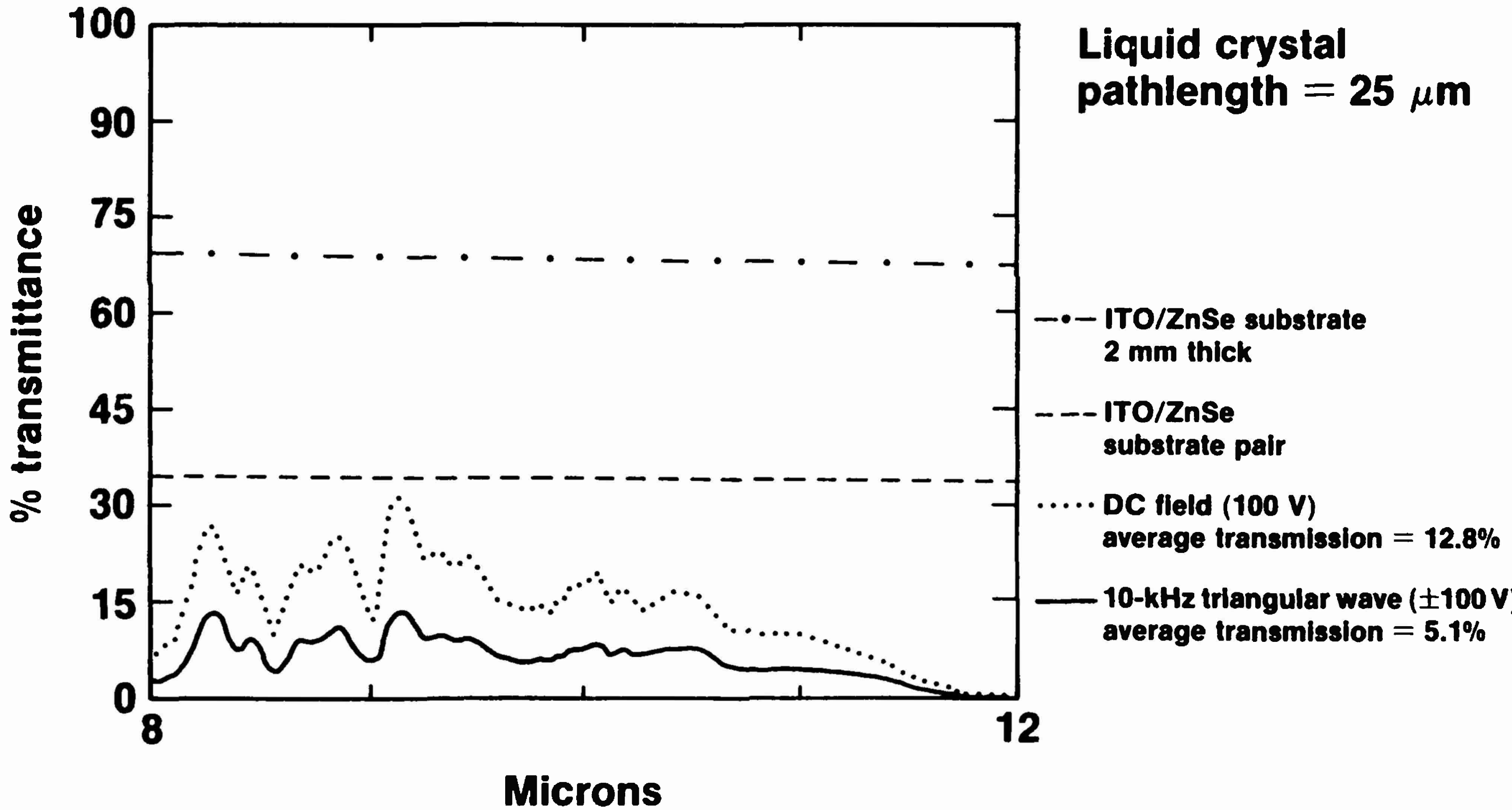
UR LLE



Cell drive waveforms employed for transmission measurements:

- Scattering state:
  - Sine, square, and triangular waves at various frequencies
- Transparent state:
  - Fixed 100V dc field

The TLSM/IR chopper demonstrates a 40% modulation of 8-12 μm radiation in an unoptimized device geometry



G3028

Summary

UR LLE

- TLSM /IR chopper proof of concept has been demonstrated in a prototype device
- Substantial performance improvements can be realized with additional refinements in cell construction parameters
- Several device physics issues, including IR polarization effects and distribution of scattered radiation, remain to be investigated
- Future research emphasis must be placed on LC materials development to reduce both mid-IR absorbance <u>and</u> interaction pathlength requirements
- Continued UR/C^2NVEO interaction is vital for further progress toward applications goals

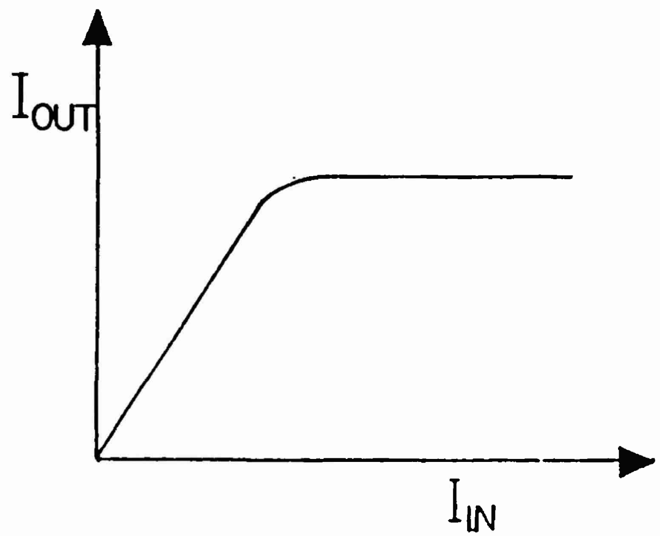
CECOM CENTER FOR NIGHT VISION AND ELECTRO-OPTICS
AN OVERVIEW OF OPTICAL POWER LIMITED MATERIALS, DEVICES, AND SPONSORED PROGRAMS

OPTICAL LIMITERS UTILIZING NONLINEAR MATERIALS

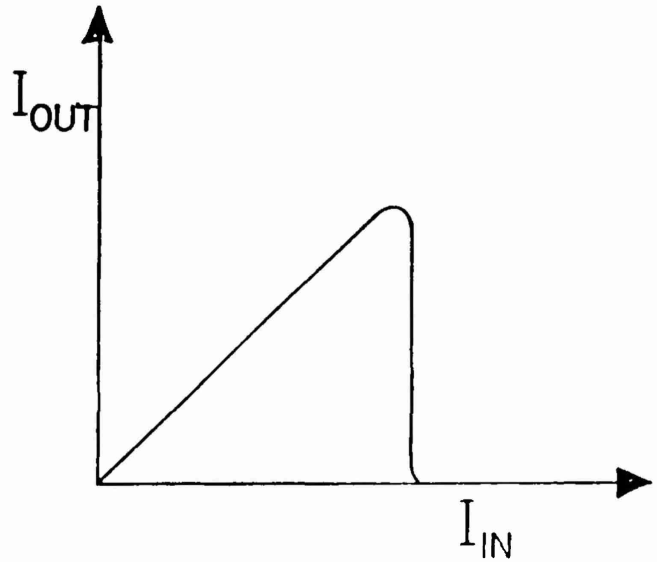
Gary L. Wood, William W. Clark III,
Edward J. Sharp, and Mary J. Miller

Center for Night Vision & Electro-Optics
Fort Belvoir, Virginia 2206-5677

IDEAL LIMITER & SWITCH



(a) OPTICAL LIMITER



(b) OPTICAL SWITCH

Broadband, some FOV

TYPES OF LIMITERS & SWITCHES

ACTIVE: example--mechanical shutter

PASSIVE: example--photochromic eyeglasses

	ACTIVE	PASSIVE
GOOD FEATURES	large OD & broadband relatively easy to make	simple design can be very fast
BAD FEATURES	may be complex $\tau_p > 10$ microseconds	difficult to make fast and broadband with large OD

PASSIVE LIMITER/ SWITCH CHARACTERISTICS

- BROADBAND ($\Delta\lambda$)
- DYNAMIC RANGE (Low NL threshold, high damage threshold)
- FIELD OF VIEW
- ALL TIME DOMAINS (Pulsed to CW)
- CHEMICAL STABILITY
- NON-HAZARDOUS
- REPETITIVE PULSES (fast recovery)
- LOW INSERTION LOSS
- GOOD MTF

NONLINEAR OPTICS

ANHARMONIC RESPONSE OF MATERIAL TO APPLIED ELECTRIC FIELD RESULTS IN A DIPOLE RESPONSE AS:

$$P_i^{\omega} = \chi_{ij}^{(1)} E_j^{\omega_o} + \chi_{ijk}^{(2)} E_j^{\omega_o} E_k^{\omega'} + \chi_{ijkl}^{(3)} E_j^{\omega_o} E_k^{\omega'} E_l^{\omega''} + \cdots$$

PASSIVE NL DEVICE RESTRICTS $P_i^{\omega} \longrightarrow P_i^{\omega_o}$ AND

$$P_i^{\omega_o} = \chi_{ij}^{(1)} E_j^{\omega_o} + \chi_{ijk}^{(2)} E_j^{\omega_o} E_k^{0} + \chi_{ijkl}^{(3)} E_j^{\omega_o} E_k^{0} E_l^{0} + 3\chi_{ijkl}^{(3)} E_j^{\omega_o} E_k^{\omega_o} E_l^{-\omega_o}$$

NOTE $E^{\omega_o} E^{-\omega_o} \propto I$

NONLINEAR PHENOMENA (SELF-INDUCED EFFECTS)

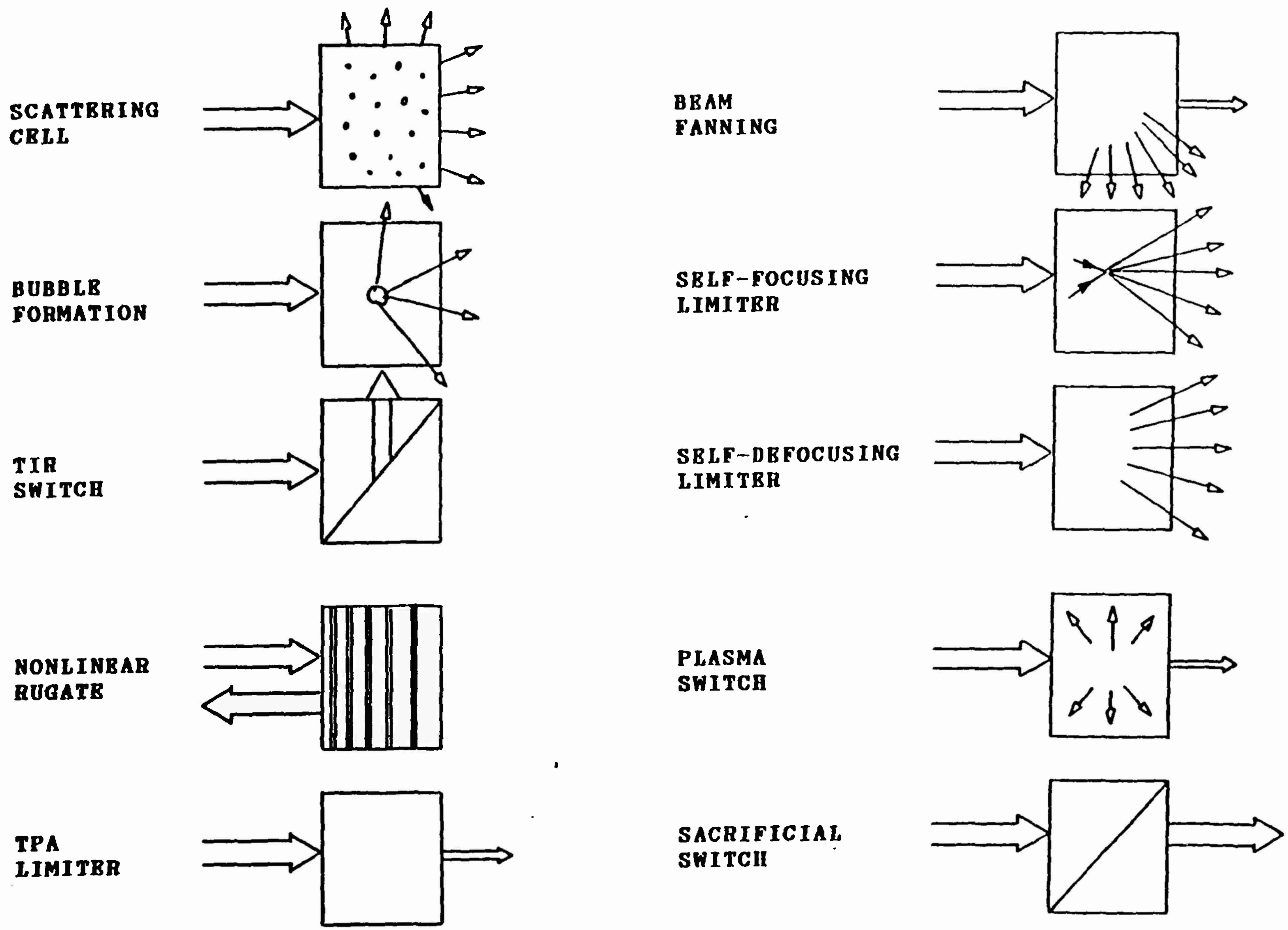
Third-Harmonic Generation	THG	Diag.	$X^{(3)}(-3w,w,w,w)$
Four-Wave Mixing: Nonlinear Refraction (n_2)			
Self-Focusing	SF	Diag., NT	$X^{(3)}_{Re}(-w,w,w,-w)$
Self-Defocusing	SD	"	$-X^{(3)}_{Re}(-w,w,w,-w)$
Degenerate Four-Wave Mixing	DFWM	Diag.	$X^{(3)}_{Re}(-w,w,w,-w)$
: Nonlinear Absorption (β)			
Two-Photon Absorption	TPA	Diag., NT	$X^{(3)}_{IM}(-w,w,w,-w)$
Excited-State Absorption	ESA	"	effective $X^{(3)}_{IM}(-w,w,w,-w)$
Stimulated Scattering*			
Stimulated Raman Scattering	SRS	Diag., NT	$X^{(3)}_{IM}(-w_S,w_L,-w_L,w_S)$, where $w_L > w_S$
Stimulated Brillouin Scattering	SBS	"	$X^{(3)}_{IM}(-w_S,w_L,-w_L,w_S)$, with $w_L \sim w_S$
Stokes-Anti-Stokes Coupling+	S-AS	Diag.	

* Scattering can induce nonlinear refraction for the incident beam with significant depletion.

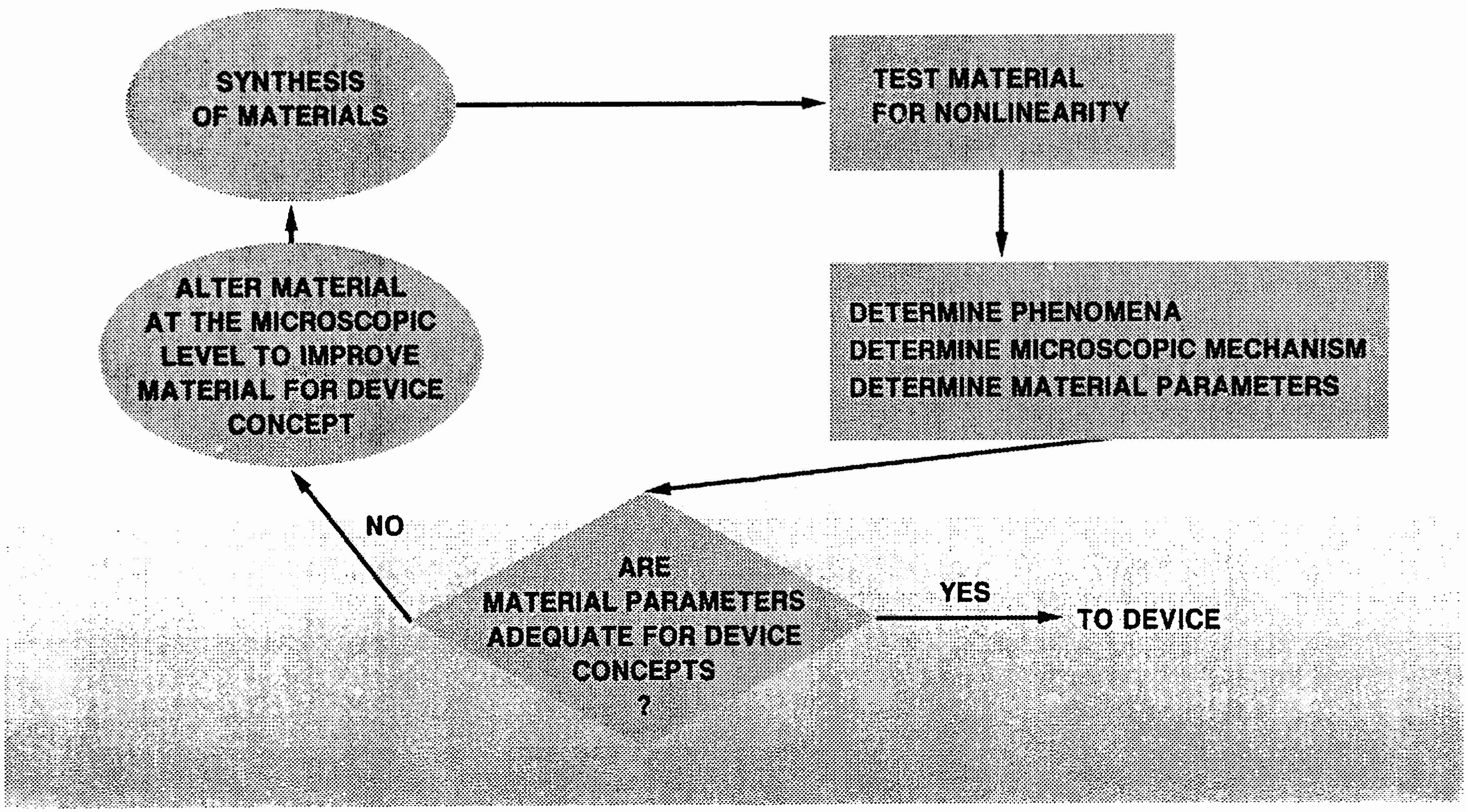
+ Involves generation of $w_{AS} > w_L$ and the effect of this frequency on the generation of w_S and w_L. Generation of w_{AS} from, $X^{(3)}(-w_{AS},w_L,w_L,-w_S)$ and $X^{(3)}(-w_{AS},w_L,-w_L,w_{AS})$.

TABLE 1

OPTICAL LIMITING/ SWITCHING CONCEPTS

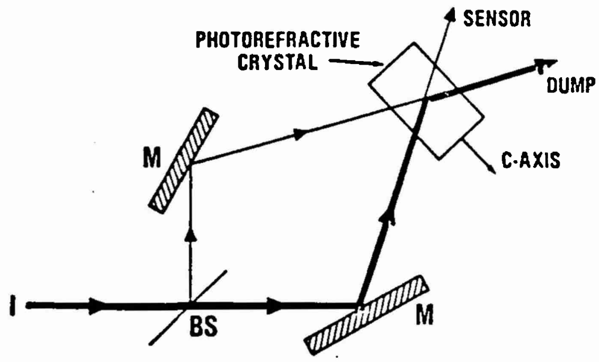


NONLINEAR OPTICAL MATERIALS EFFORT

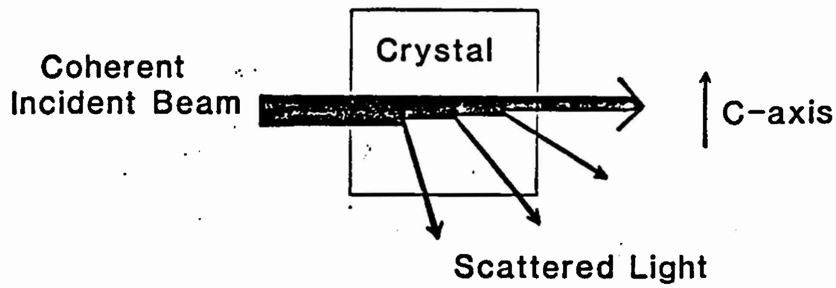


PHOTOREFRACTIVE DEVICES

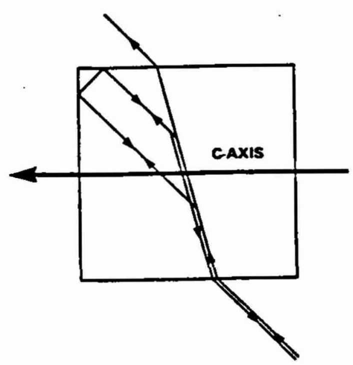
Two-Beam Coupling



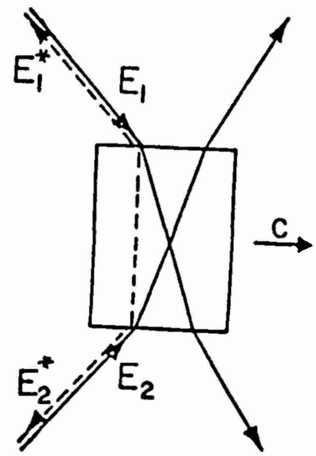
BEAM FANNING



Self-Pumped Phase Conjugation



Double Phase Conjugation



CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH
THIRD-ORDER NONLINEAR SUSCEPTIBILITY OF LIQUID CRYSTALS AT 1053 NM BY CHIRPED-PULSE NONRESONANT CARS

Third-Order Nonlinear Susceptibility of Liquid Crystals at 1053 nm by Chirped-Pulse Nonresonant CARS

UR LLE

Kenneth Marshall, Ansgar Schmid, and Mark Guardalben

Laboratory for Laser Energetics
University of Rochester

Center for Night Vision and Electro-Optics
Fort Belvoir, VA
5 December 1990

Outline

- Objective
- Material Selection
- Experimental Approach
- Results

We Set Out to Meet Two Objectives

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1. Establish hyperpolarizability trend within a class of similar compounds, as result of substituent and linkage effects.
2. Prepare in-house $\chi^{(3)}$ measurement capability for cross checking literature values.

Only nonresonant $\chi^{(3)}$ values are of practical importance

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Photochemical stability *disfavors* resonant-effect devices

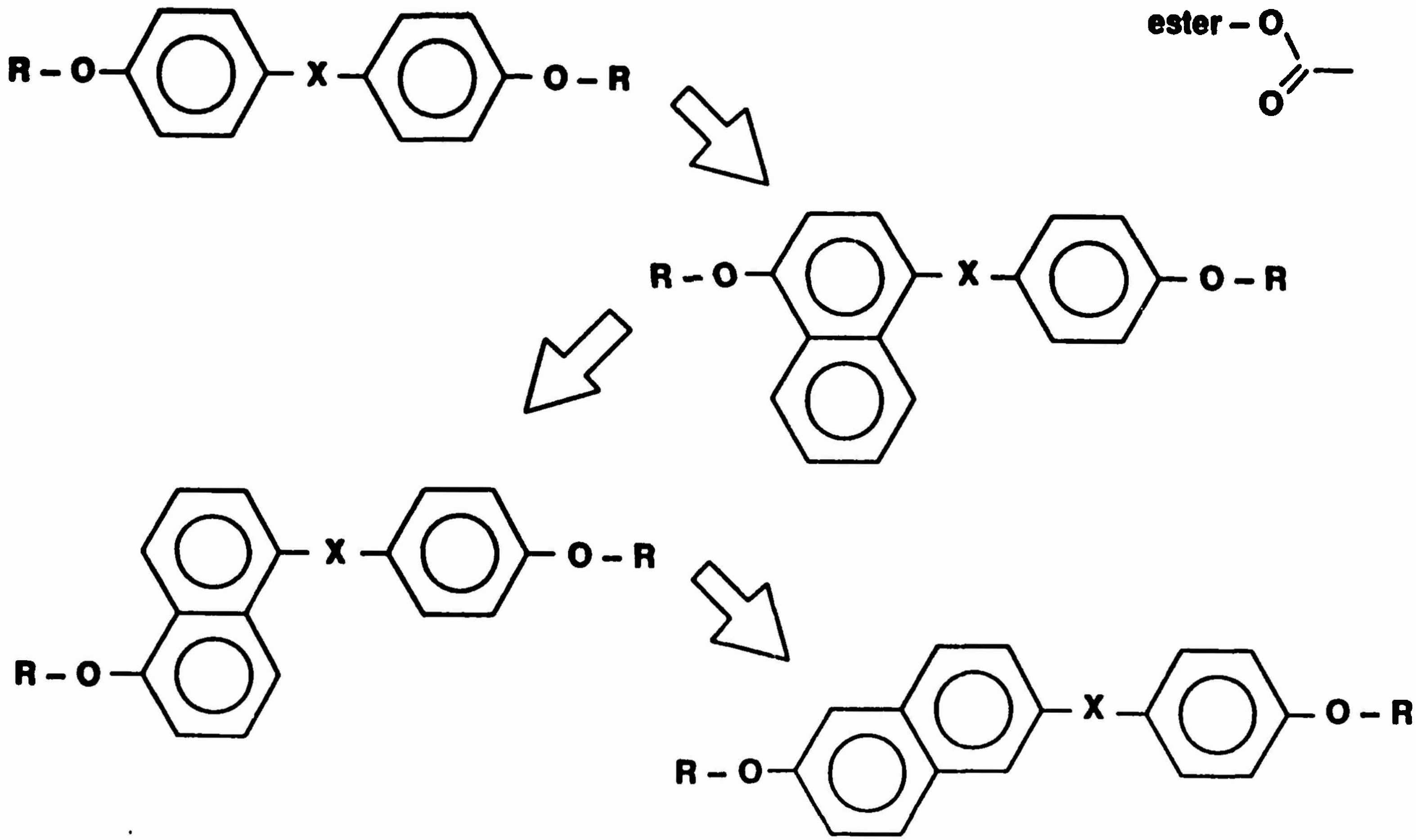
- You want large nonresonat $\chi^{(3)}$
- We eliminate potential resonant contributions

Test: Molecular hyperpolarizability $\chi^{(3)}$ as a function of π-electron delocalization

All compounds are thermotropic liquid crystals

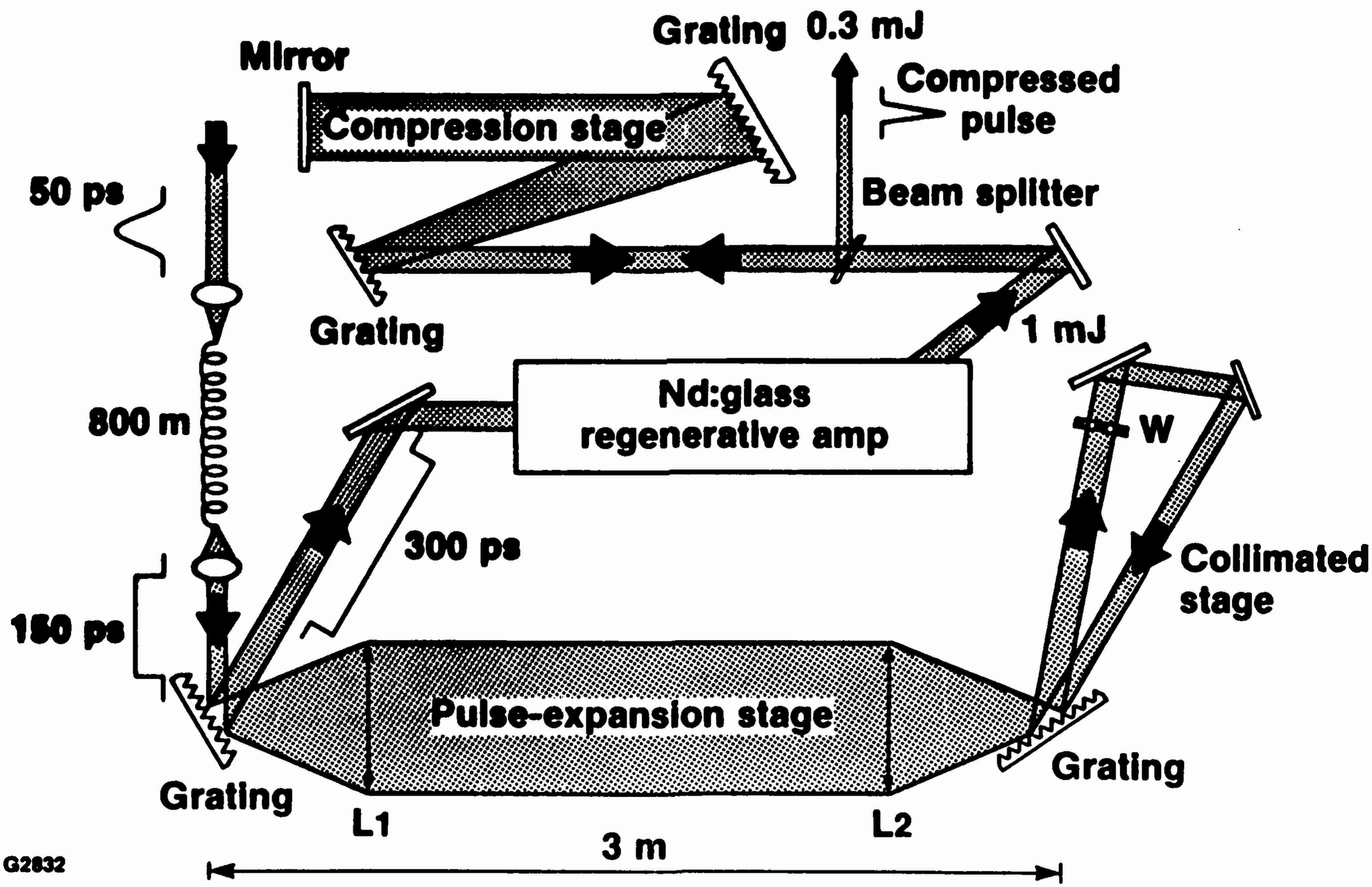
X = acetylene – C ≡ C –

ester – O–C(=O)–



G2952

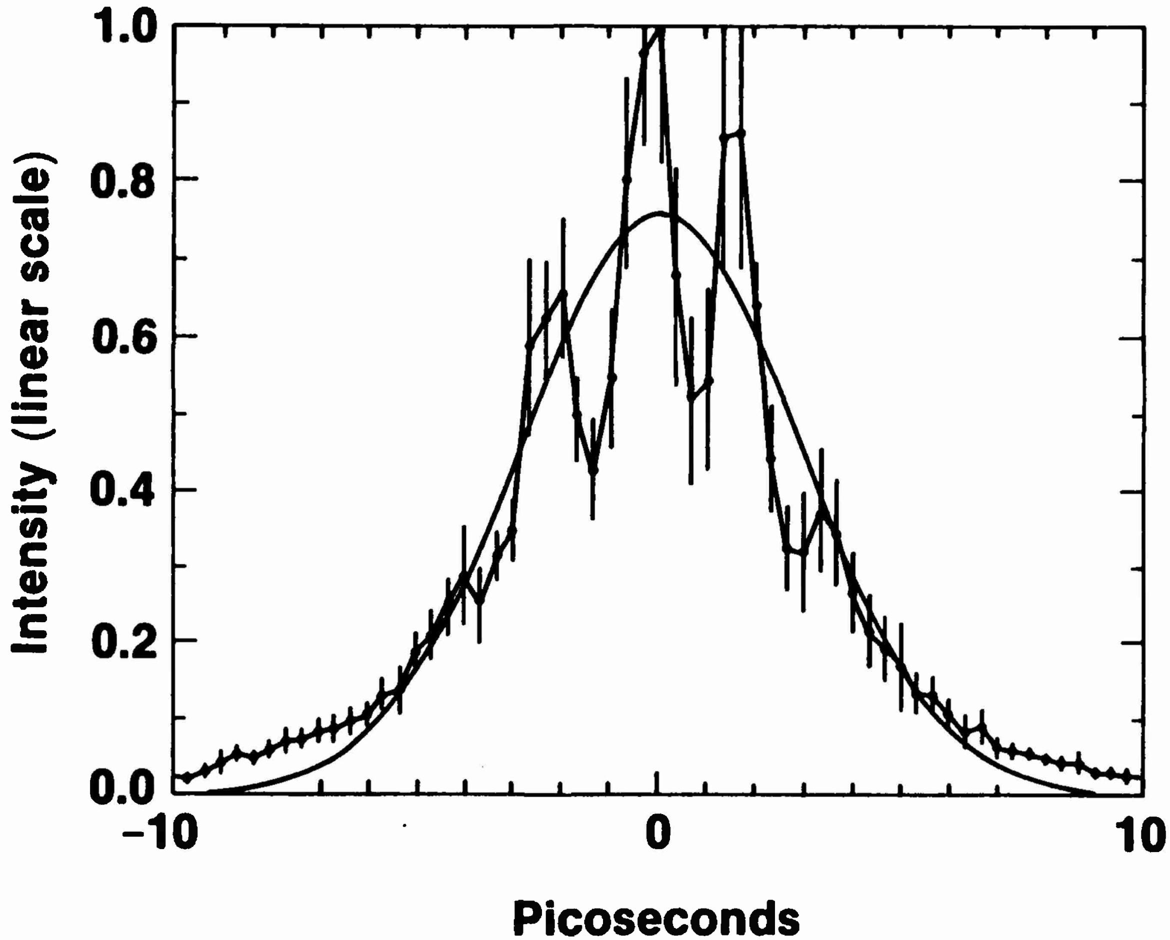
All-solid-state approach provides efficient CARS driver source



G2832

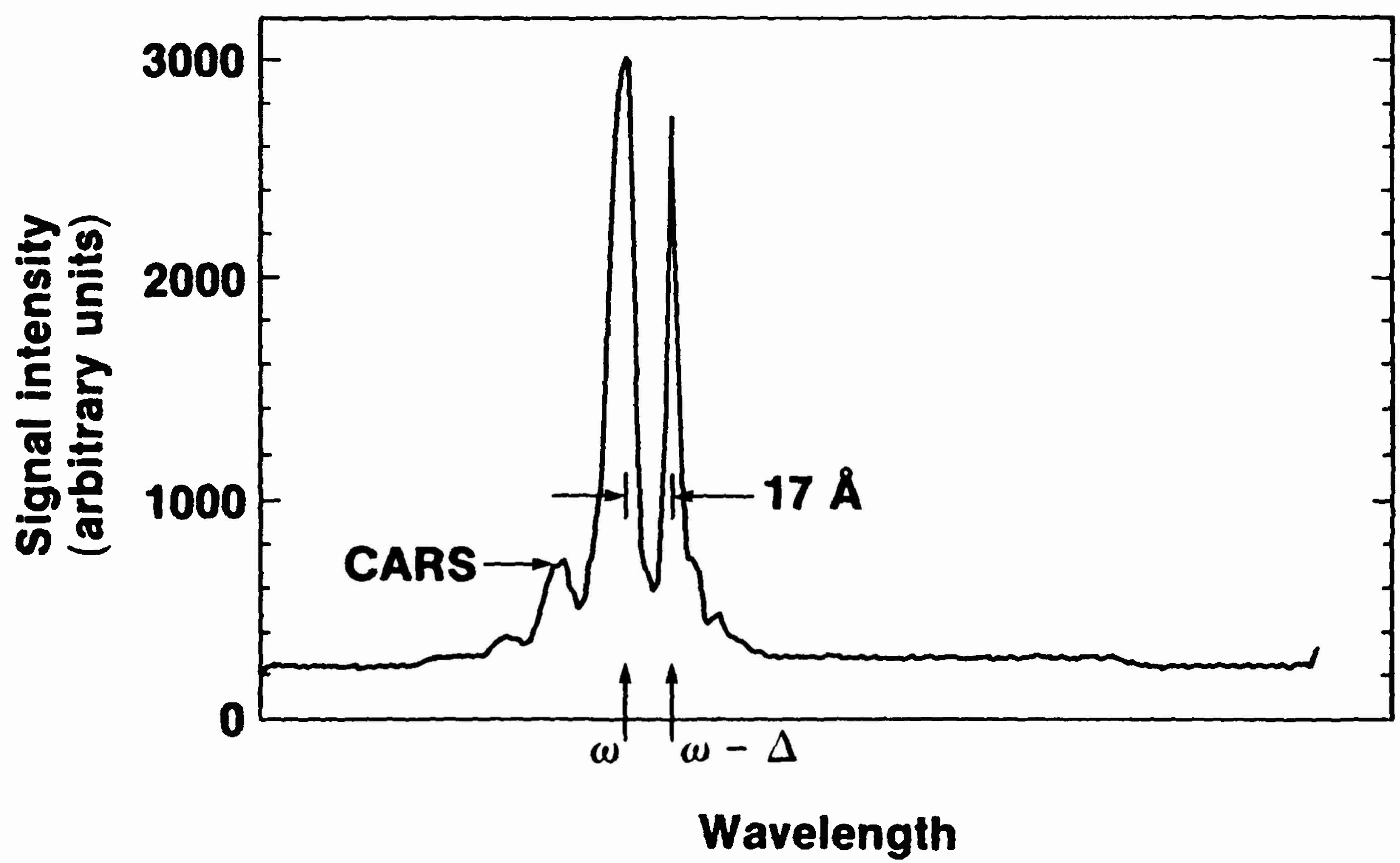
SH autocorrelation trace of CARS input pulse

Data points: 10-shot averages



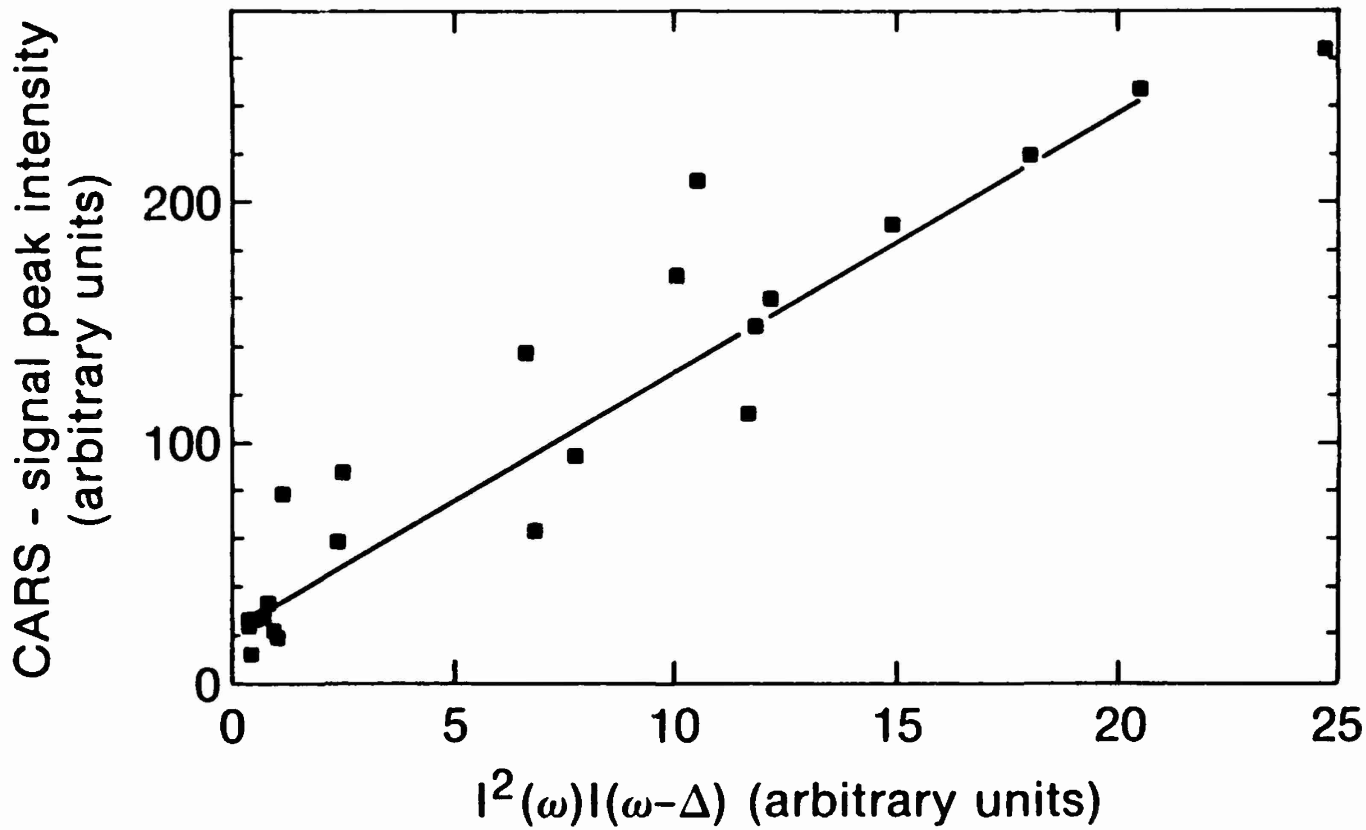
G2894

Single-shot, Stokes, anti-Stokes spectrum from CS_2



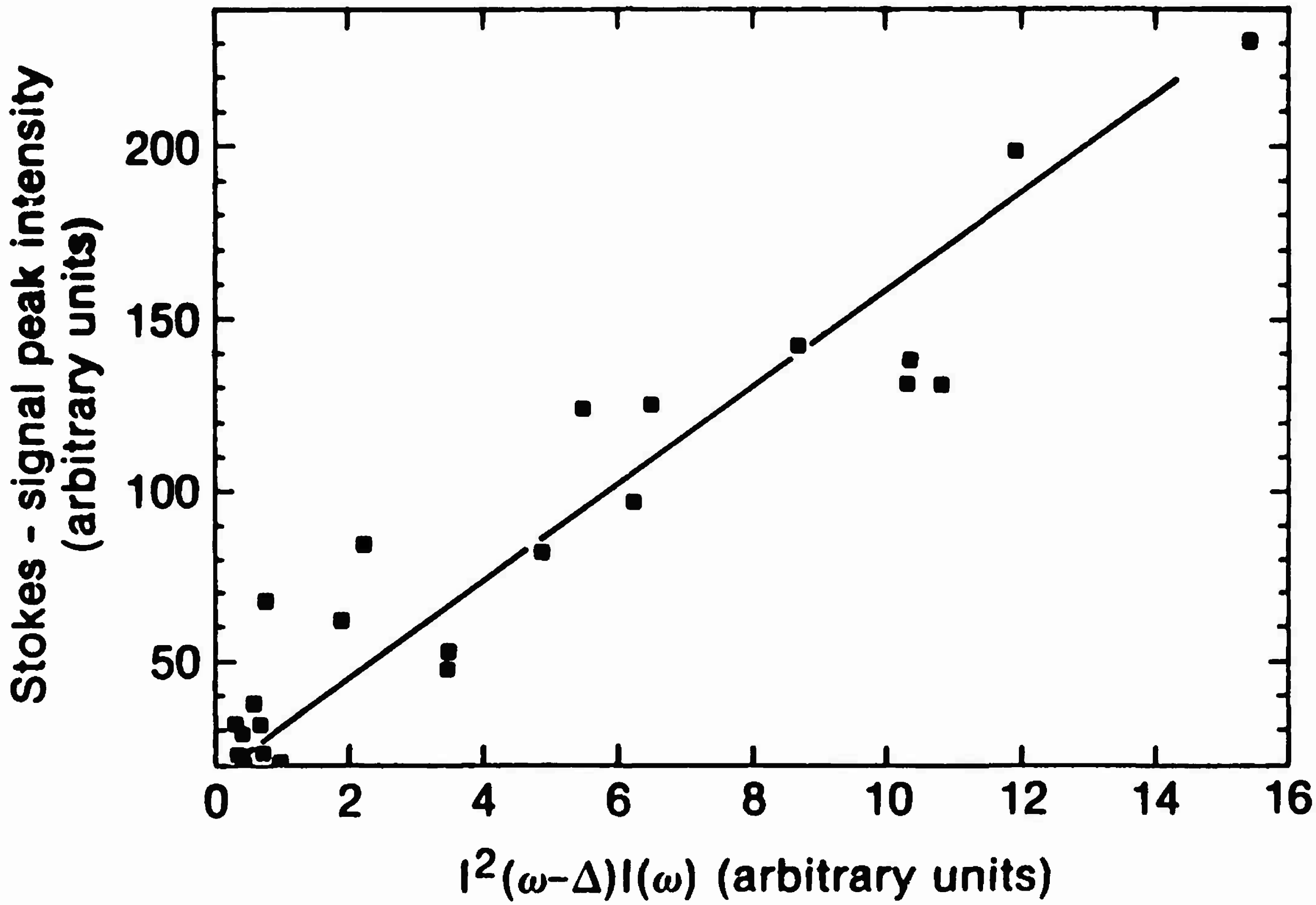
G2896

Intensity scaling of CS_2 nearly degenerate CARS signal



G2897

Intensity scaling of nearly degenerate coherent Stokes scattering from CS_2



G2895

In picosecond range pros outweigh cons

Pros

- Background—free measurement
- "Damage friendly"—sample must not sweep through a focus
- Only electronic contribution to $\chi^{(3)}$ counts
- Source compatibility

Cons

- Complex apparatus—cost
- Limited wavelength activity of our source
- Does not measure:
  - reorientation contribution to $\chi^{(3)}$
  - thermal contribution to $\chi^{(3)}$

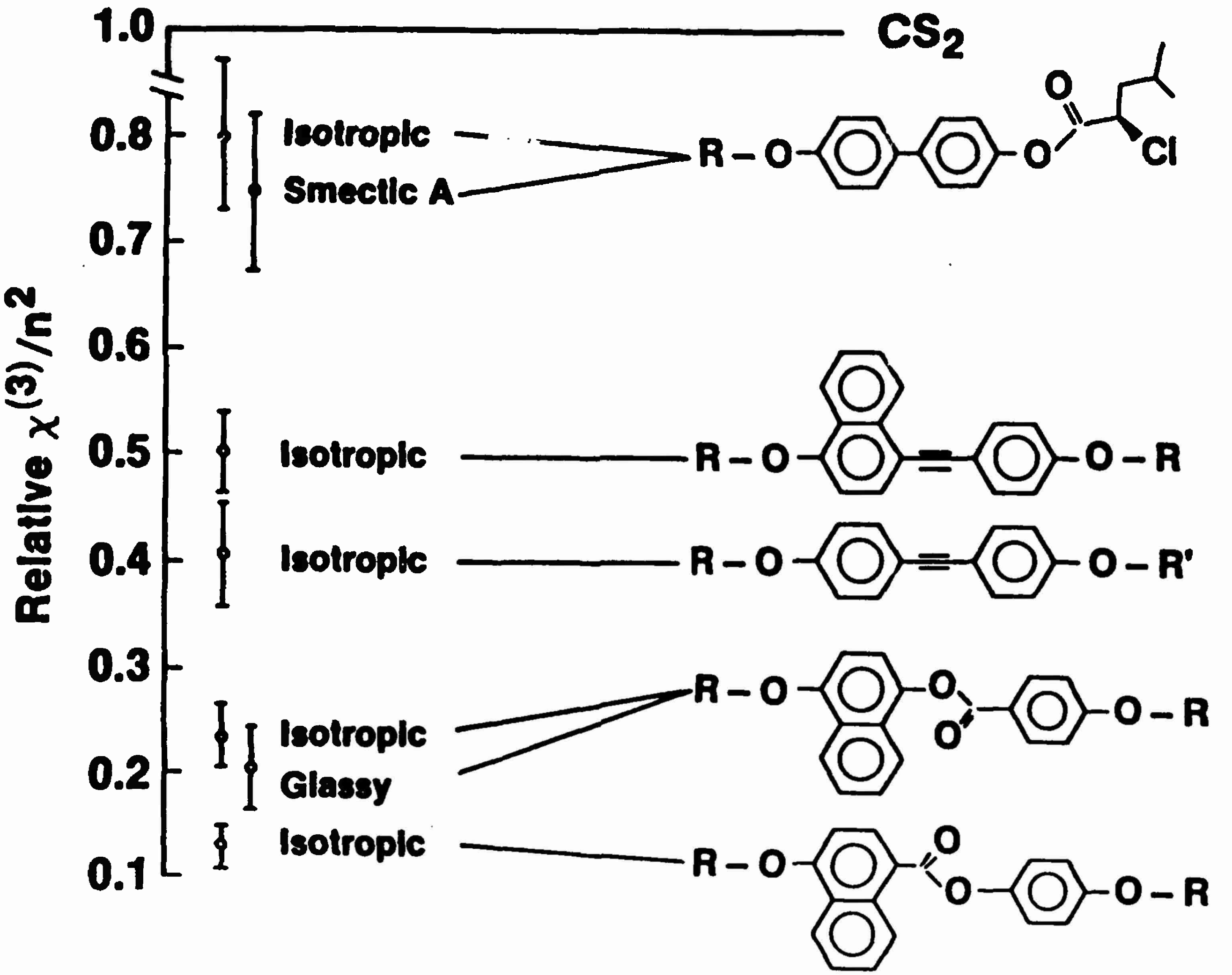
All materials were measured in 500-μm path-length cells

Cell Preparation	Phase Control	Relative $\chi^{(3)}$
• Alignment coating: poly-butyleneterephthalate • Dip coated in 1% solution of p-chlorophenol • Coating mechanically buffed	• Cells mounted in Mettler hot stage • $\chi^{(3)}$ measured in isotropic and LC mesophase	• The anti-Stokes signal is compared with that from a 500-μm cell of CS_2

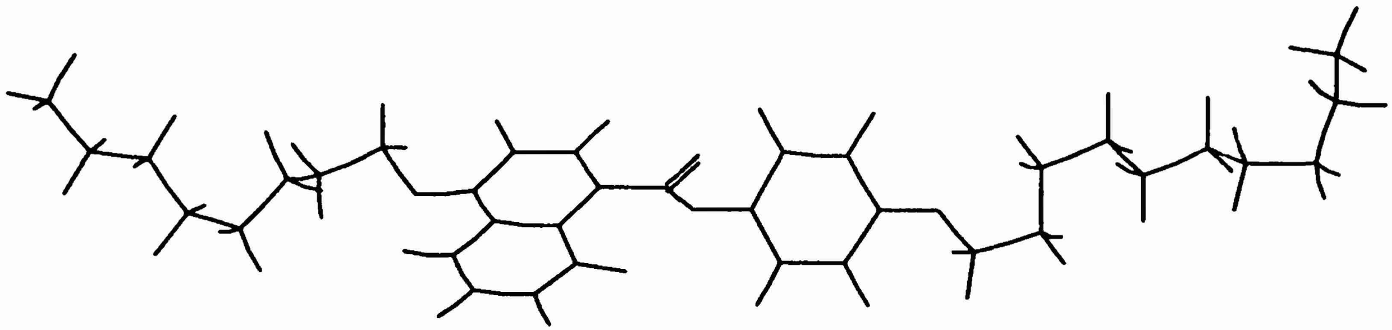
- The LC linear refractive index is measured on a temperature-controlled Abbé refractometer.

G2951

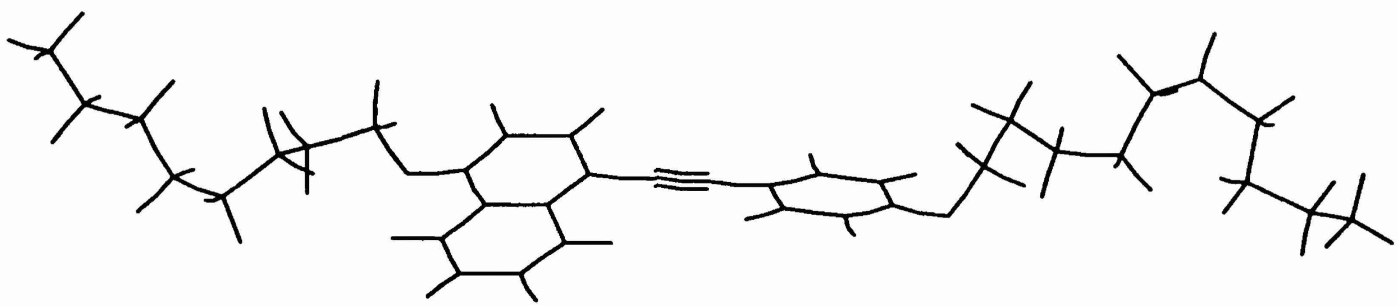
Relative $\chi^{(3)}$ measurements reveal clear distinction between molecular linkages and substituents



G2953



Naphthalene ester-ring torsion angle= 51.8 °



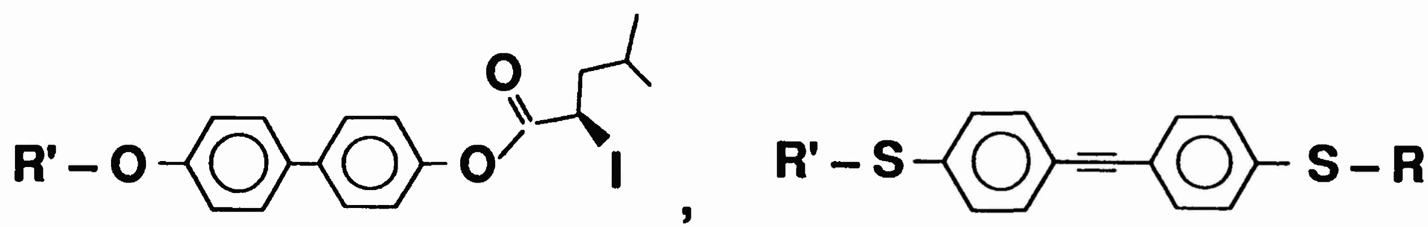
Naphthalene tolane-ring torsion angle= 18.6°

Alchemy II
TRIPOS Associates
St. Louis, Mo.

In chemistry terms, there are several preliminary conclusions

- Tolane linkages enhance $\chi^{(3)}$ over ester linkages.
- Push-pull substituents enhance nonlinearities.
- Liquid-crystal mesophases differ only slightly from isotropic condition in third-order response

Still to come:



CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH
OPTICAL POWER LIMITING EMPLOYING LASER SPECKLE IN
LIQUID CRYSTAL GUEST-HOST SYSTEMS: A TIME-RESOLVED STUDY

Time-Resolved Study of Smectic-A Guest-Host System Response to 488-nm Pulsed Excitation Using Laser Speckle

UR LLE

Mark Guardalben, Shen-Ge Wang,* Joseph Landry,
and Nicholas George*

Laboratory for Laser Energetics
and
*Institute of Optics
University of Rochester

Optical Society of America
1990 Annual Meeting
Boston, MA
4–9 November 1990

Motivation

- Passive power-limiting device
  - onset time for scattering < 1 μs
  - no external restoring field needed
  - large extinction (OD 1–2)

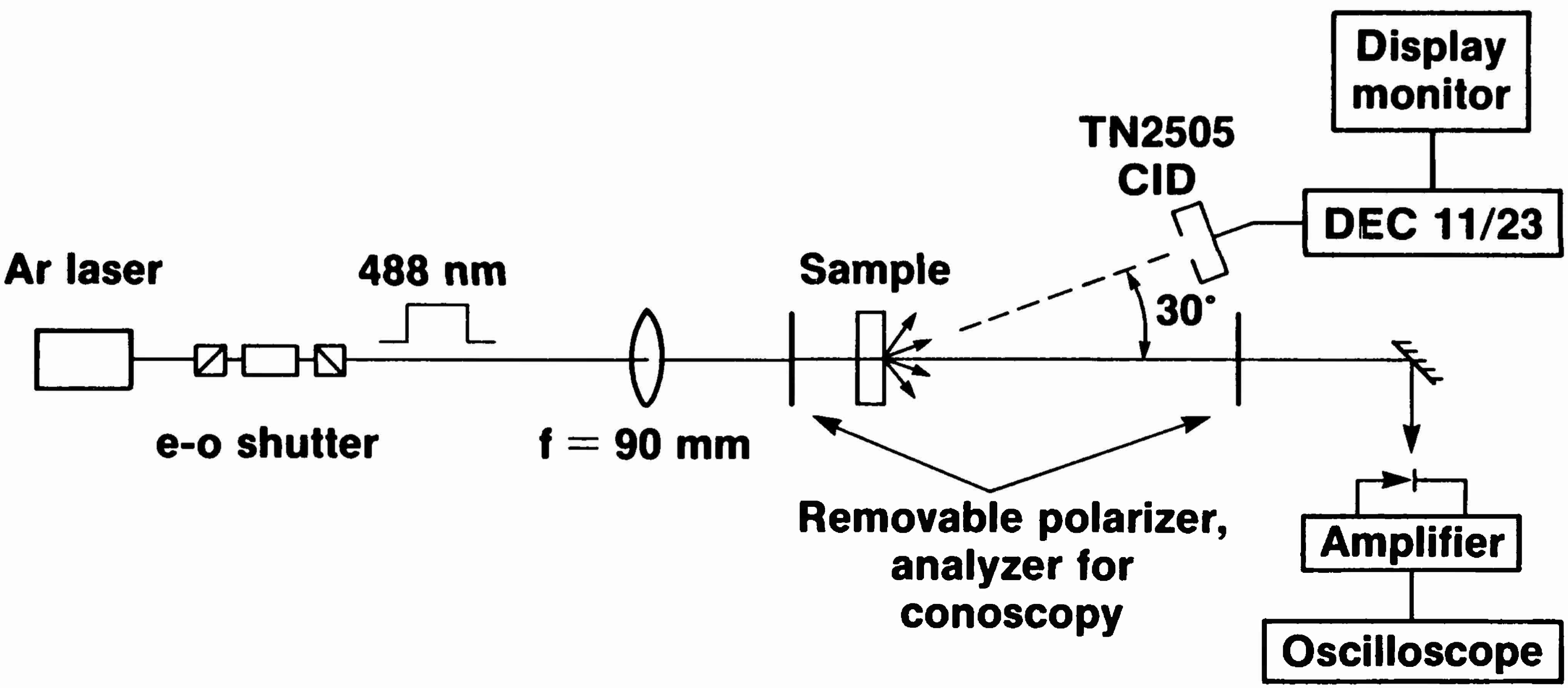
Goal: Elucidate mechanism of power-limiting effect by modeling irradiated region as a time-dependent transmission function.

Outline

UR LLE

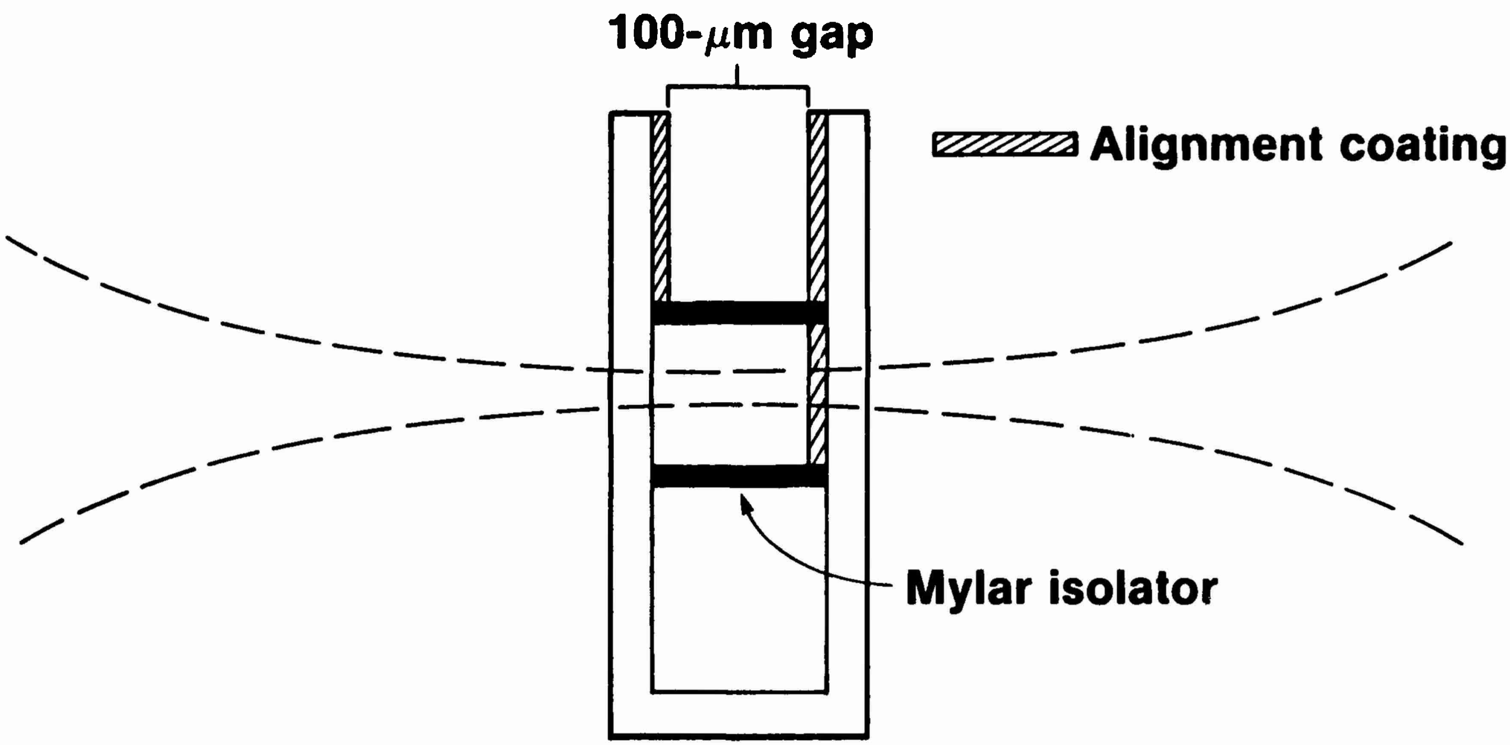
- Guest-host smectic-A can be modeled as transient diffuser (speckle) with lens-like features
  - Material: 0.1% w/w D2 in smectic-A K24
- Temporal measurements of speckle pattern provide new information about guest-host dynamics.

Pulsed Ar laser used as both pump and probe to characterize the spatio-temporal evolution of the scattered field



G2993

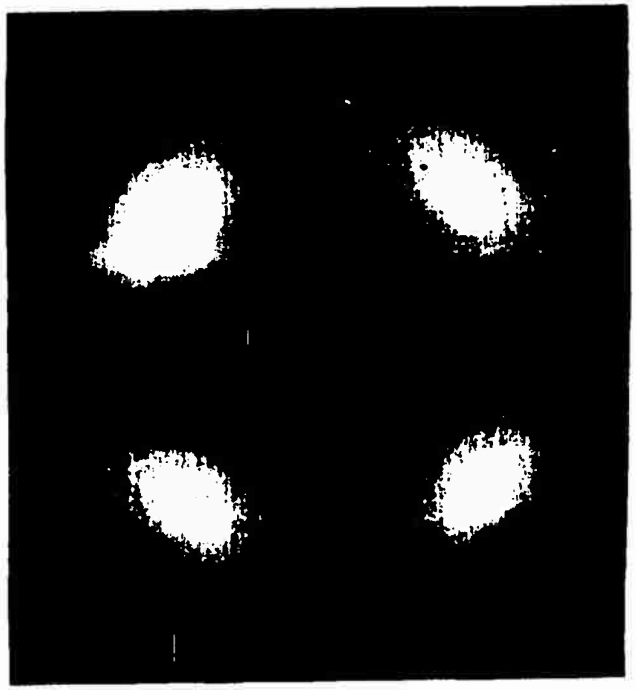
Segregated quartz cell permits investigation of different molecular anchoring conditions



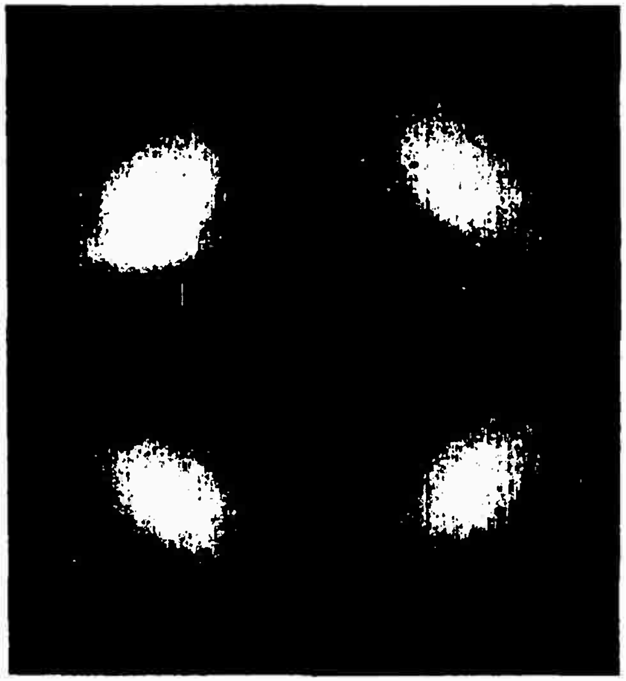
Identical focal conditions in each region

G2994

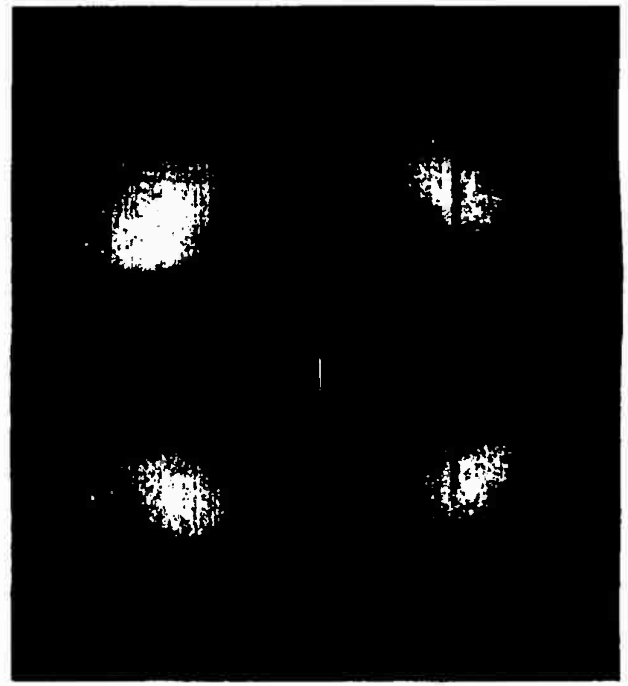
Conoscopic isogyres reveal identical uniaxial alignment in each irradiated region



Alignment coating on both surfaces



Alignment coating on one surface



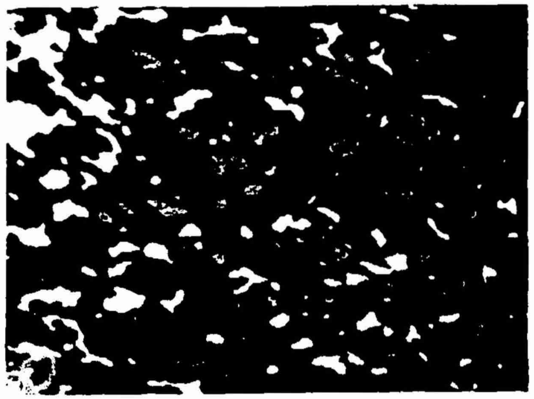
No alignment coating

G3016

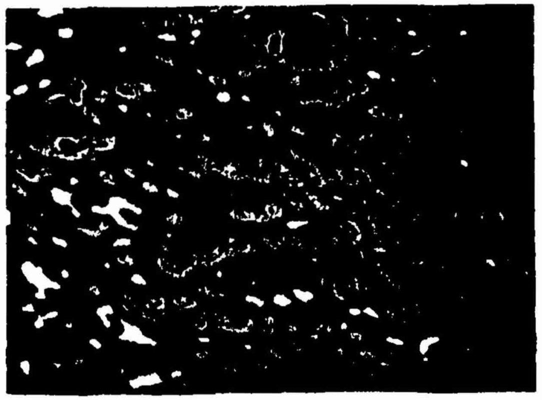
Scattered light from liquid crystal shows distinctive features of speckle

UR LLE

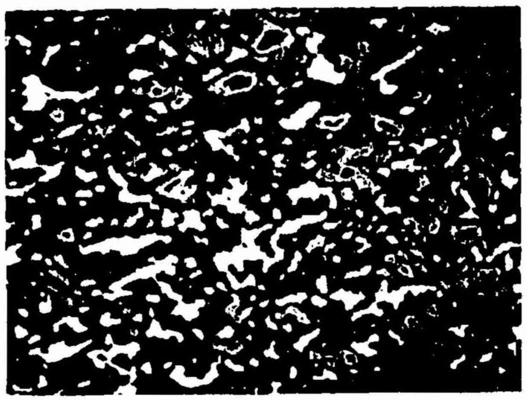
Liquid Crystal Speckle



Early ($\Delta t = 100$ ms)



Late ($\Delta t = 1.5$ s)

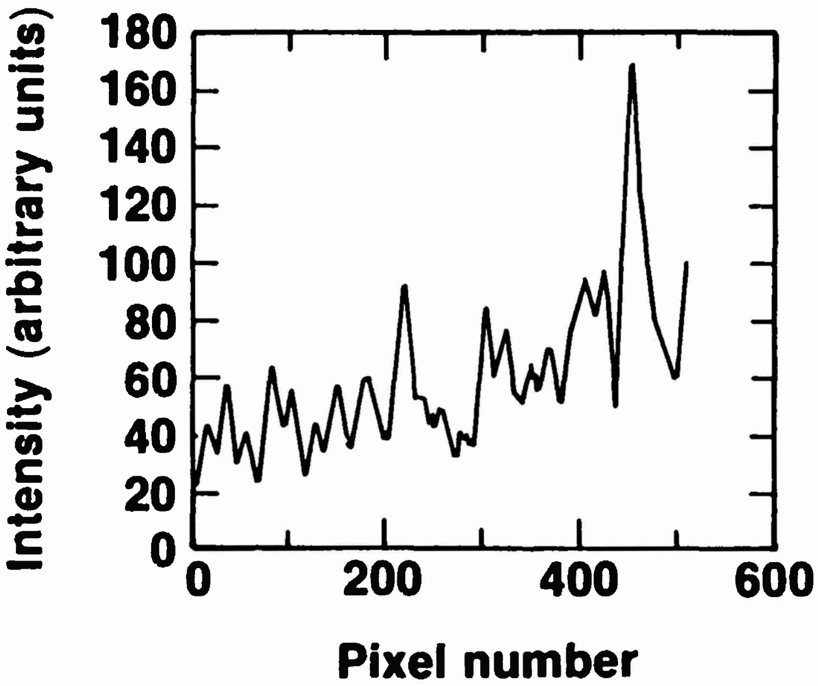


Etched-glass diffuser

G3022

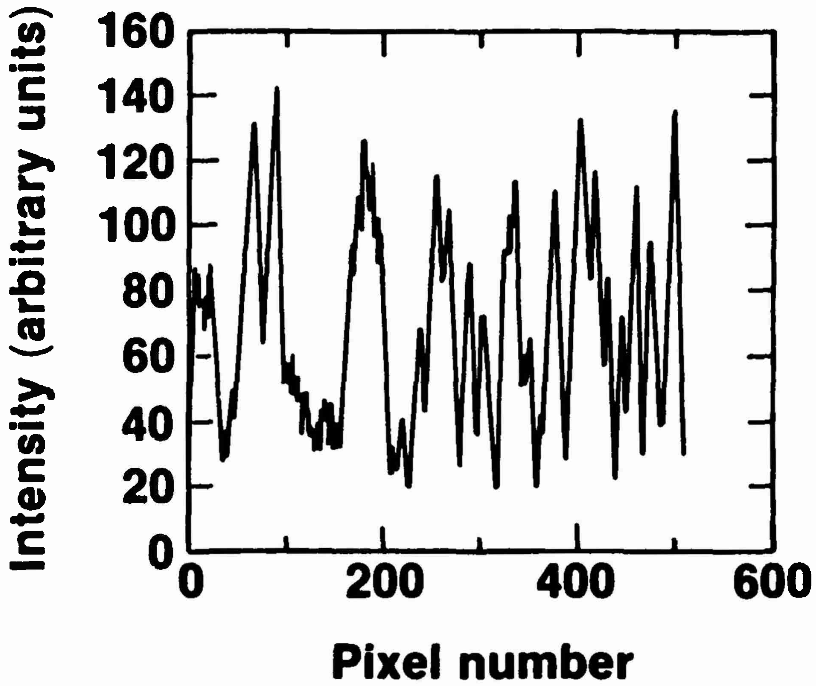
Liquid crystal speckle shows lens-like features

Liquid crystal



Strong-background, low-contrast speckle

Mildly etched diffuser



High-contrast, well-developed speckle

E3019

Statistical theory of speckle gives liquid crystal rms refractive index variation

	Polarized				Unpolarized
	$\frac{R_u(0)}{R_u(\infty)}$	C_R	h_σ		$\frac{R_u(0)}{R_u(\infty)}$
Theory	2.00	1.00			0.707
Reference cited* Measured ground glass	1.88	0.94			
Current data Mild etch glass	1.33	0.58	0.28 μm		
Liquid crystal (No coating, Δt = 50 ms)	1.15	0.384	0.21 μm ⇒	$(\Delta n)_{rms} \approx 0.0021$	

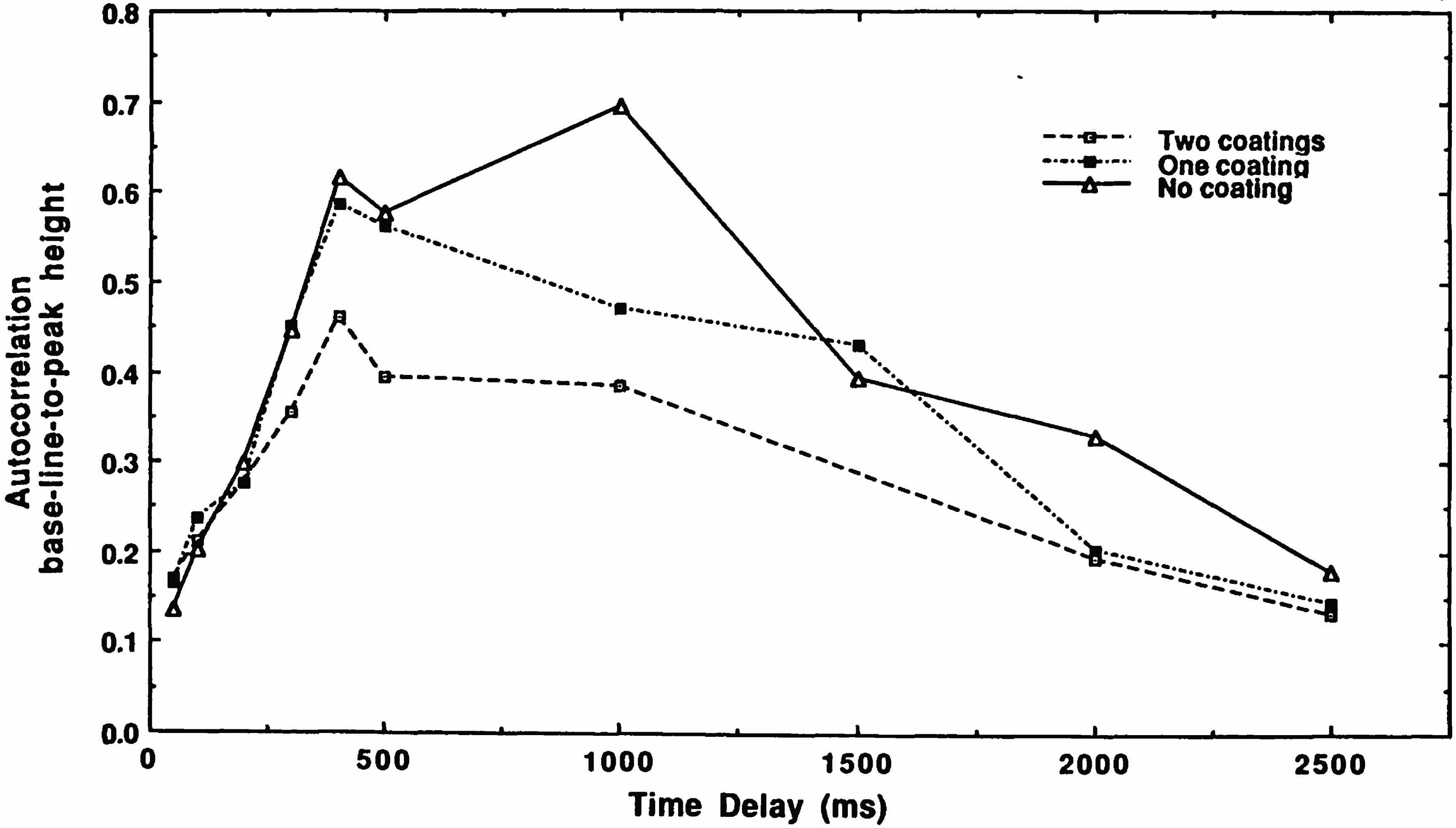
$$C_R = \sigma / \langle u \rangle$$

$$C_R = \left[\frac{R(0)}{R(\infty)} - 1 \right]^{1/2}$$

*N. George, A. Jain, and R. D. S. Melville, *Appl. Phys.* 7, 157–169 (1975).

G3020

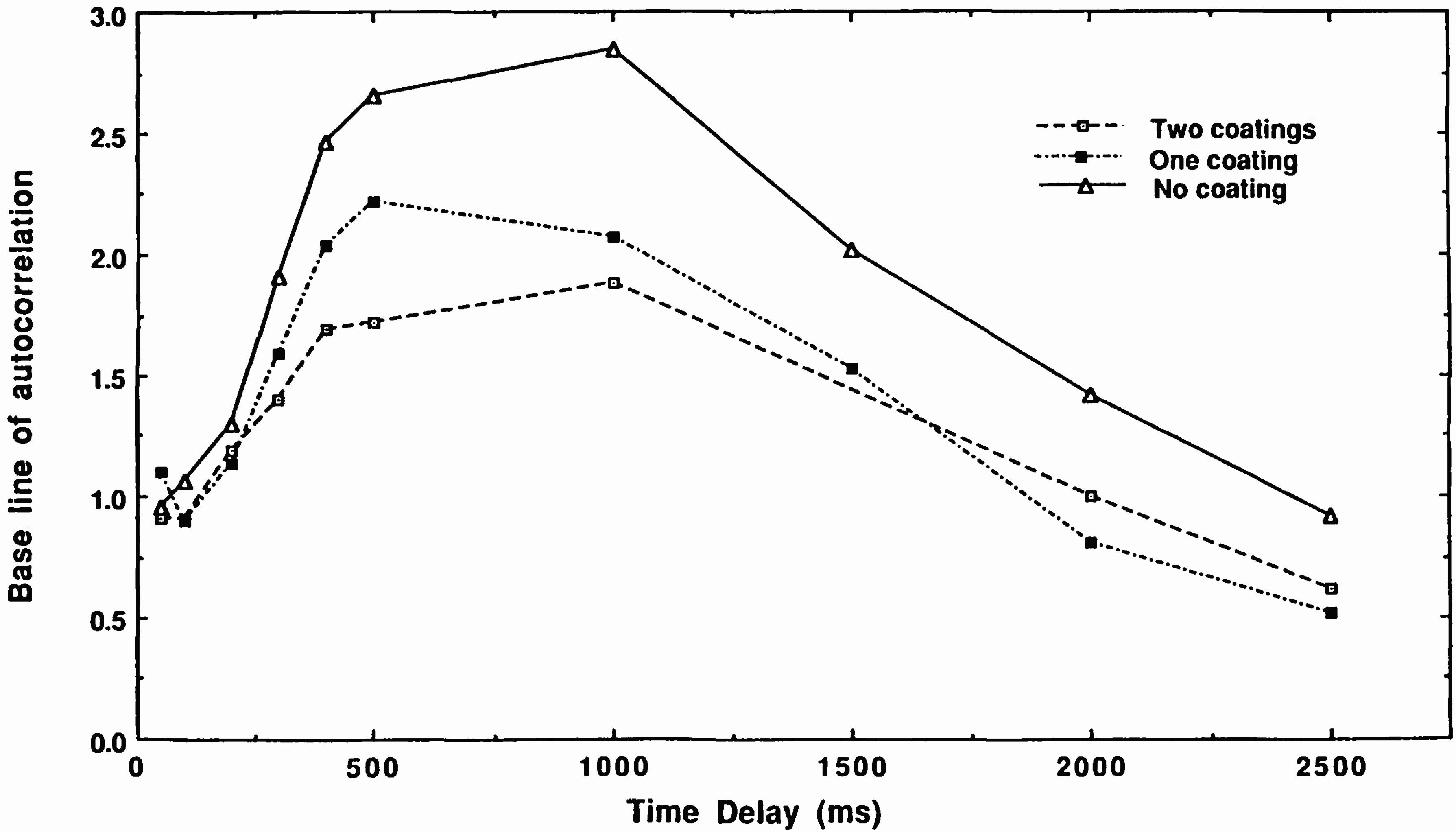
Random molecular orientation is greater for weaker anchoring



Speckle component of autocorrelation versus time delay

G3023

Temporal variation of lens-like component is a function of anchoring strength



Base line of autocorrelation versus time delay

G3021

Summary

- Compared with guest-host nematic (time-varying lens)*, guest-host smectic-A can be modeled as time-varying diffuser with lens-like features.
- From diffuser model, $(\Delta n)_{rms} \approx 0.0021$.
- Temporal dependence of scatter is function of molecular anchoring.
- Further study of guest-host dynamics required.

*I. Jánossy and A. D. Lloyd, 13th International Liquid Crystal Conference, 22–27 July 1990.

G3027

CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH
LIQUID CRYSTAL BEAM SWITCHING / BEAM-STEERING CONCEPTS:
ARE THERE POTENTIAL CCNVEO APPLICATIONS?

Liquid Crystal Beam Switching/Beam Steering Concepts- Are there Potential C^2NVEO Applications?

Kenneth L. Marshall

Laboratory for Laser Energetics
University of Rochester

Workshop
"Liquid Crystal Materials and Devices for Opto-electronic Applications"
Center For Night Vision and Electro-optics
Fort Belvoir, VA
5 December, 1990

Outline

UR LLE

Concept 1:

- A TIR beam switch using the SSFLC effect in ferroelectric liquid crystals

Concept 2:

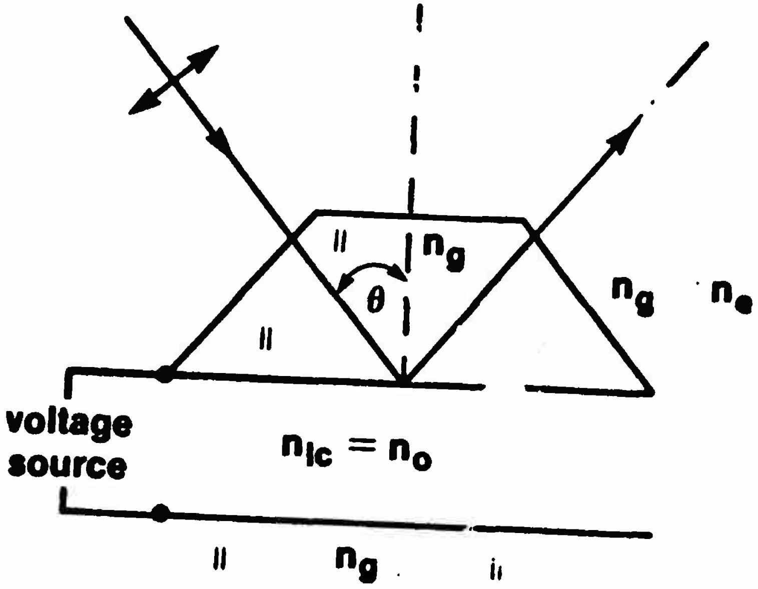
- A linearly variable beam deflector based on the electroclinic effect in chiral smectic A materials

Concept 3:

- Liquid crystal gradient index beam switching/steering devices

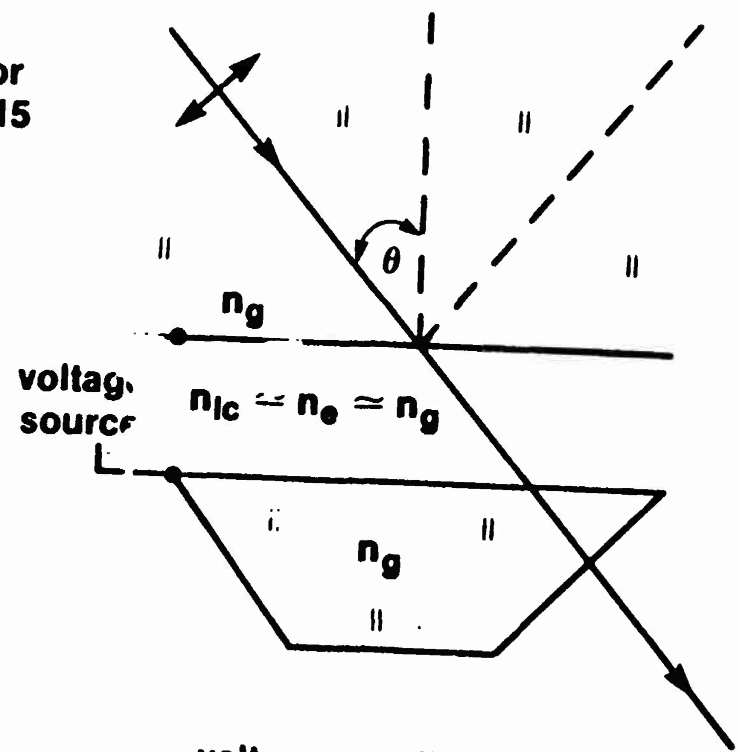
Two-Position Beam Deflector Concept

- Based on frustrated total internal reflection - bistable operation



(a) $n_{lc} = n_o < n_g \longrightarrow$ TIR

$\theta \simeq 70°$ for
$\Delta n_{lc} = 0.15$

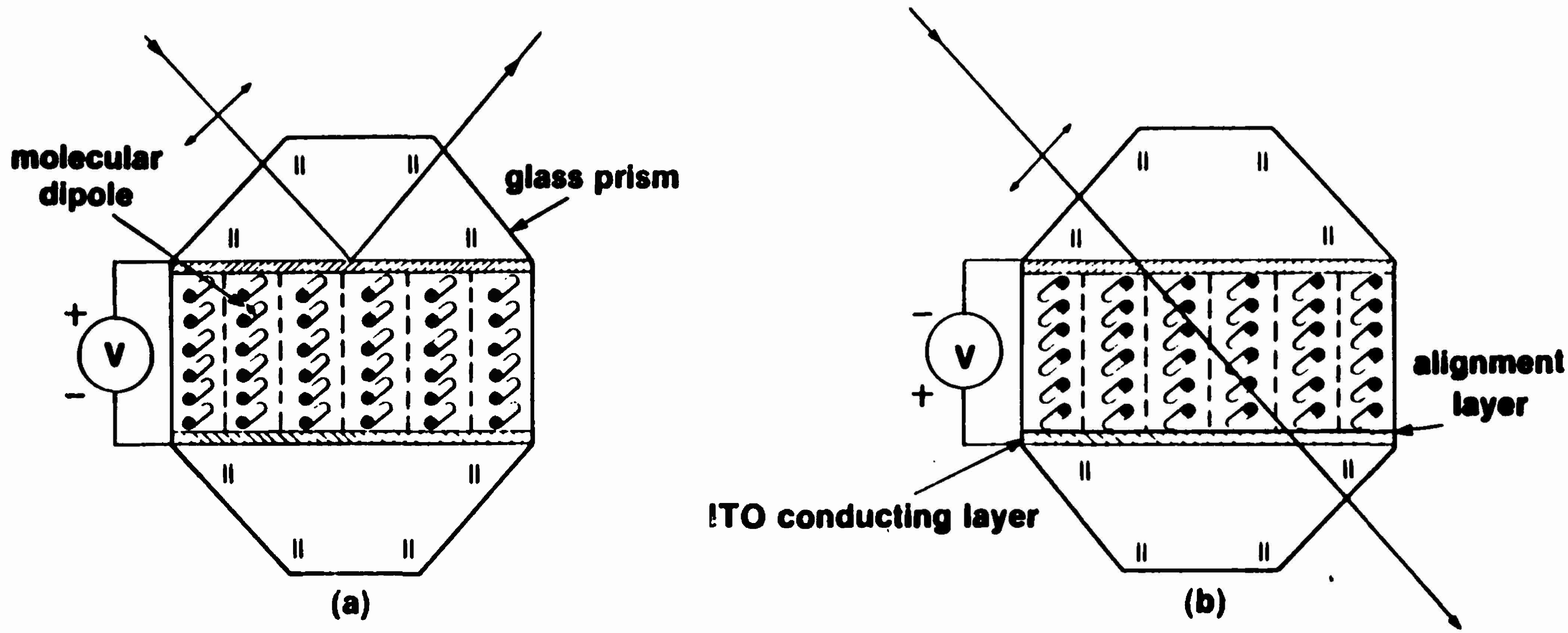


(b) $n_{lc} \simeq n_e \simeq n_g \longrightarrow$ transmission (frustrated TIR)

G1952

Two-Position Bistable Beam Deflection Device Using fTIR in Ferroelectric Chiral Smectic C Mesogens

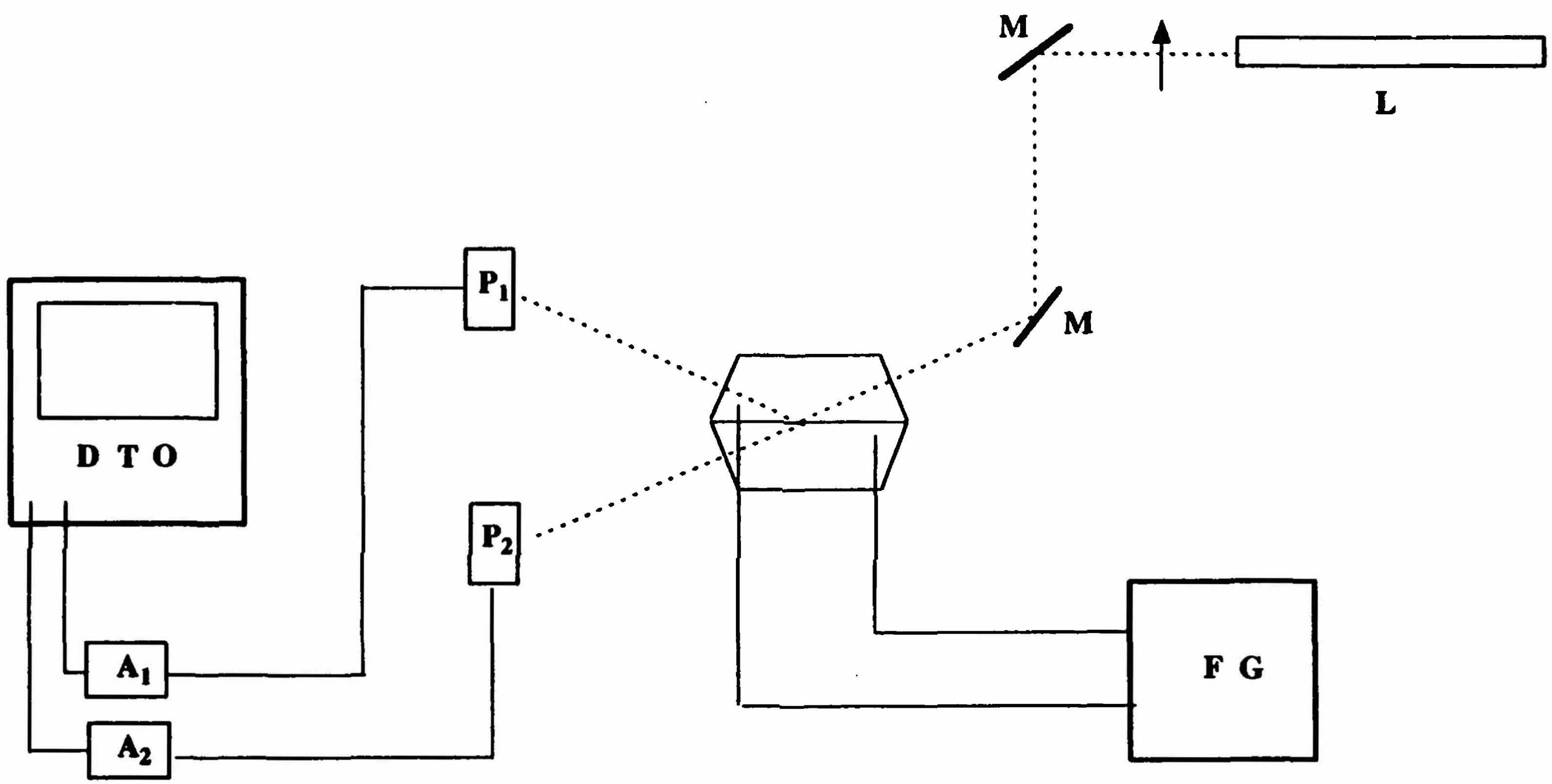
Incident Polarization Orientation (45° out of plane of drawing)



(a) Incident radiation experiences n_o, allowing TIR. (b) Reversal of field polarity causes incident radiation to experience n_e, resulting in fTIR.

G1953

Electro-optic Test Setup for Beam Switch



DTO - Dual Trace Oscilloscope

P_1, P_2 - Photodiode

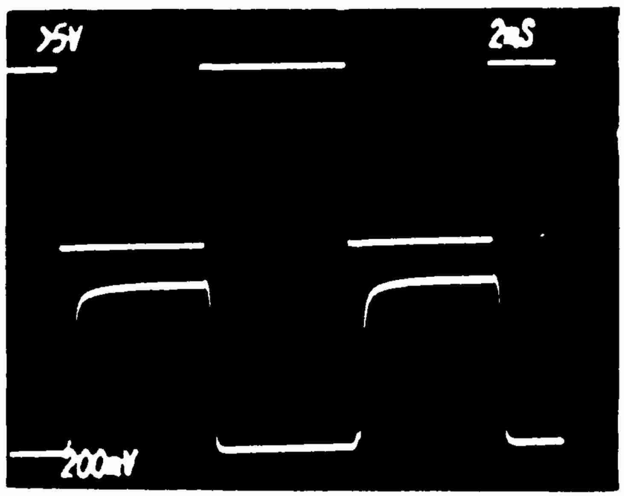
A_1,A_2 - Photodiode Amplifier

FG - Kron-Hite Function Generator

L - Laser

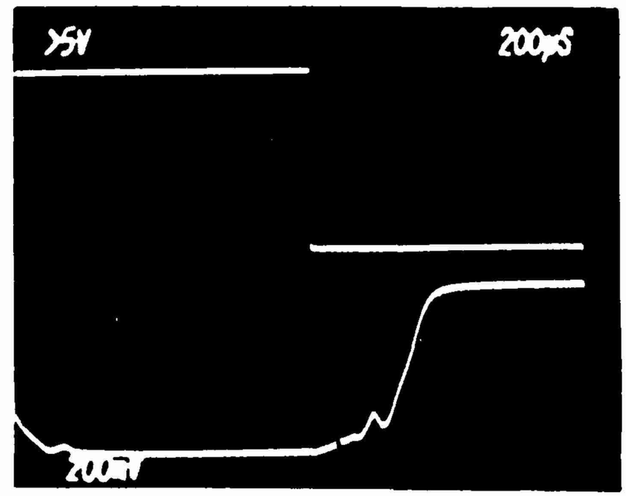
M - Mirror

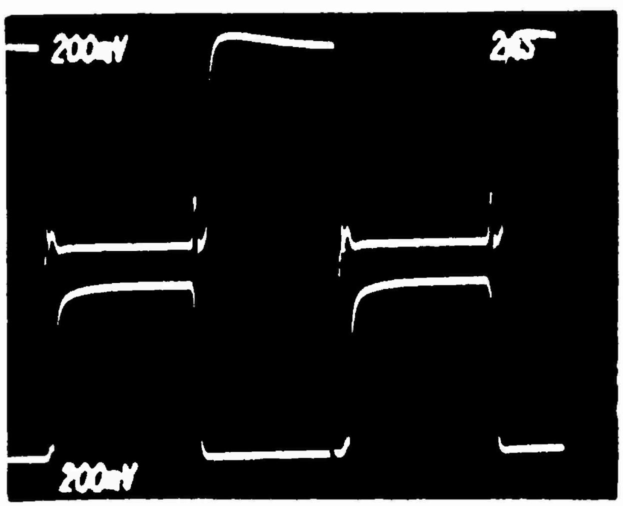
Electro-optic Switching Performance of Ferroelectric LC Beam Switch using ZLI 4139



Top Trace: Drive Voltage (10 V/Div)

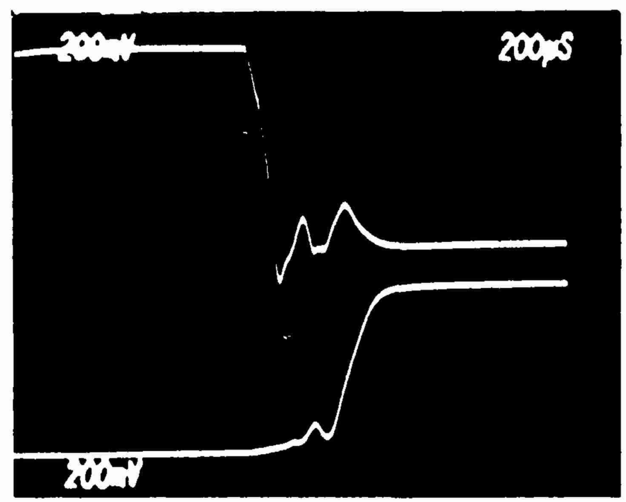
Bottom Trace: Photodiode Response (Transmitted Beam)





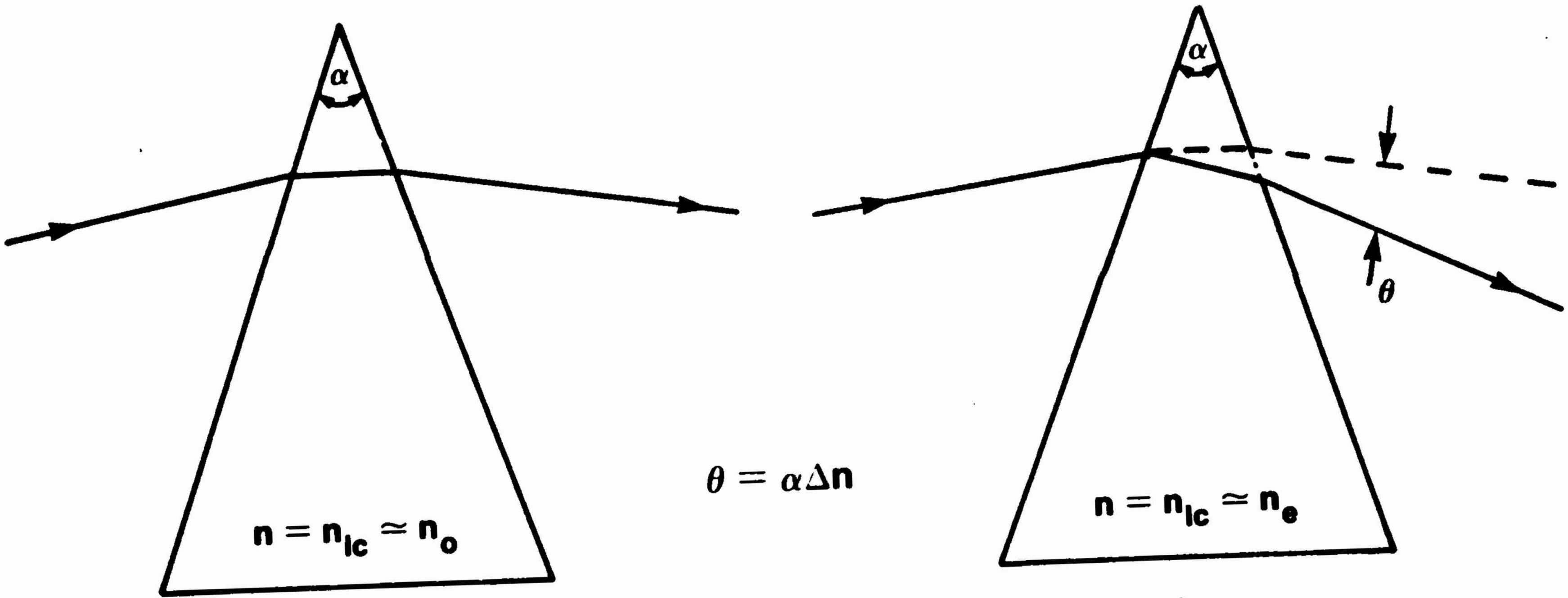
Top Trace: Reflected Beam

Bottom Trace: Transmitted Beam



Multiposition Beam Deflector Concept

- Several possible modes of operation
  - bistable
  - bistable with tunable birefringence around two bistable positions
  - nonbistable

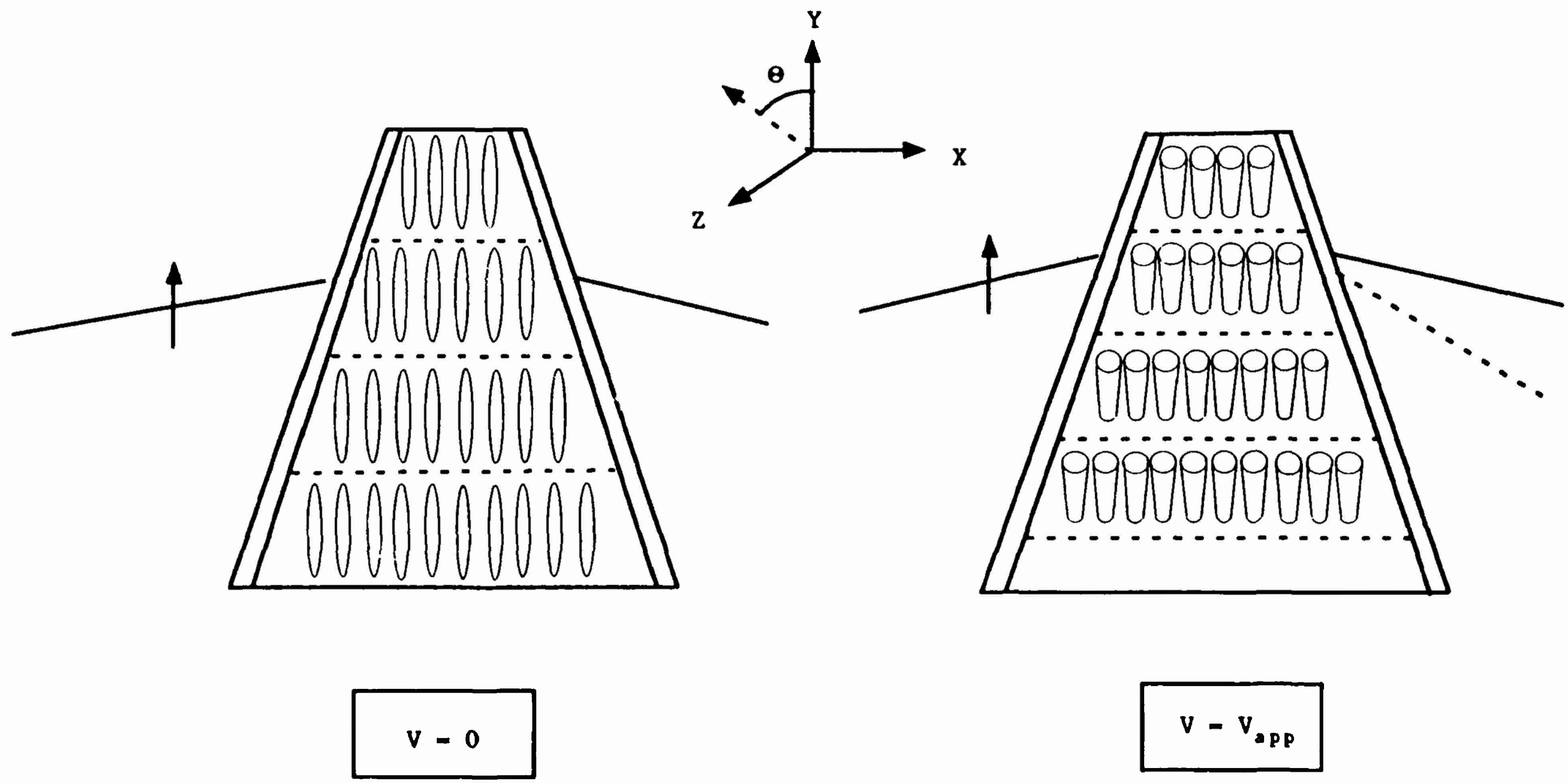


$$\theta = \alpha \Delta n$$

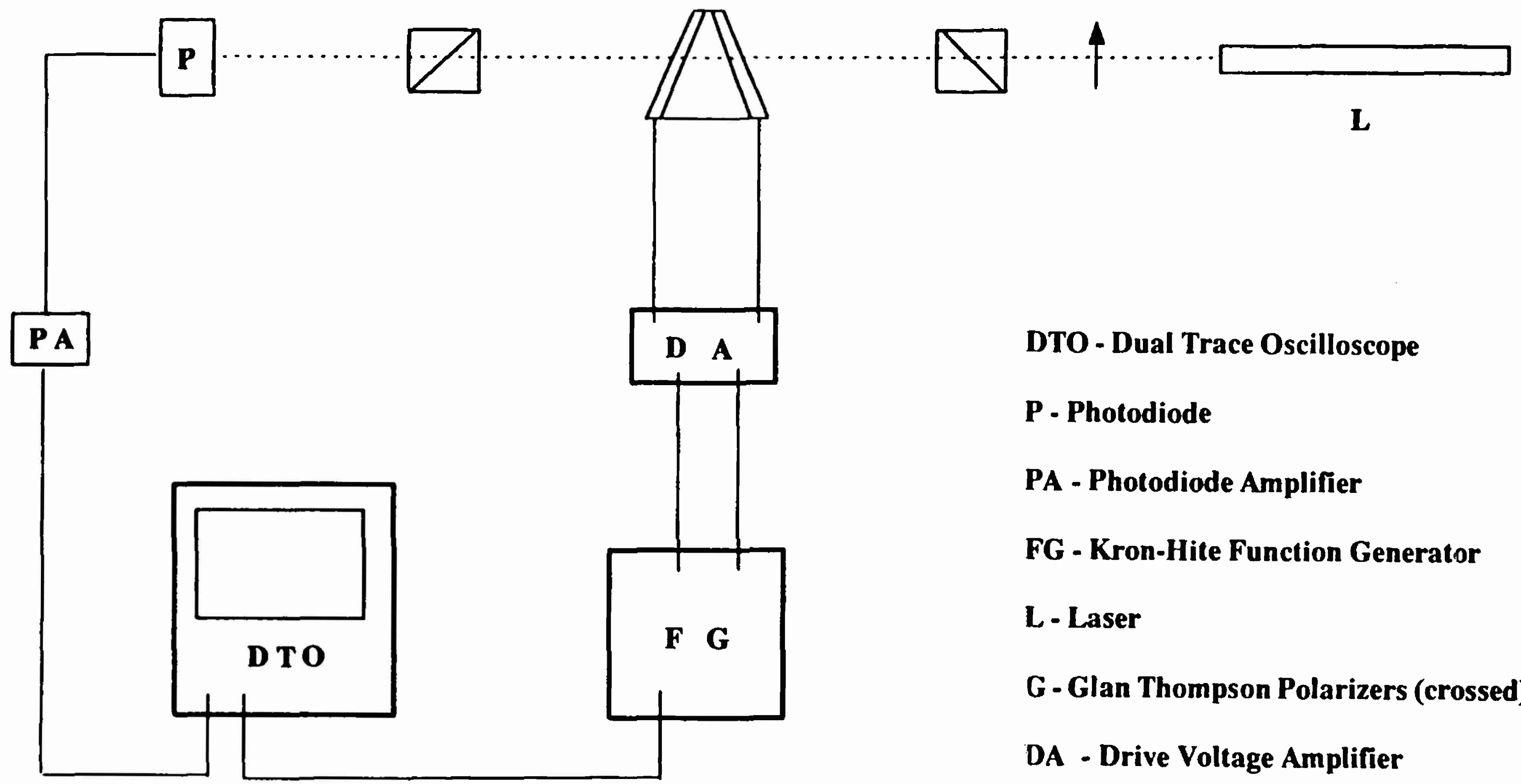
where θ = deflection angle (several tenths of a degree)
α = cell wedge angle (0.1–1.0 degrees)
Δn = change in refractive index due to field-induced director reorientation (as large as 0.2)

G1954

Variable Beam Deflector Employing the Electroclinic Effect in Chiral Smectic A Materials



Electro-optic Test Setup for Evaluation of Wedged Smectic A Cells



DTO - Dual Trace Oscilloscope

P - Photodiode

PA - Photodiode Amplifier

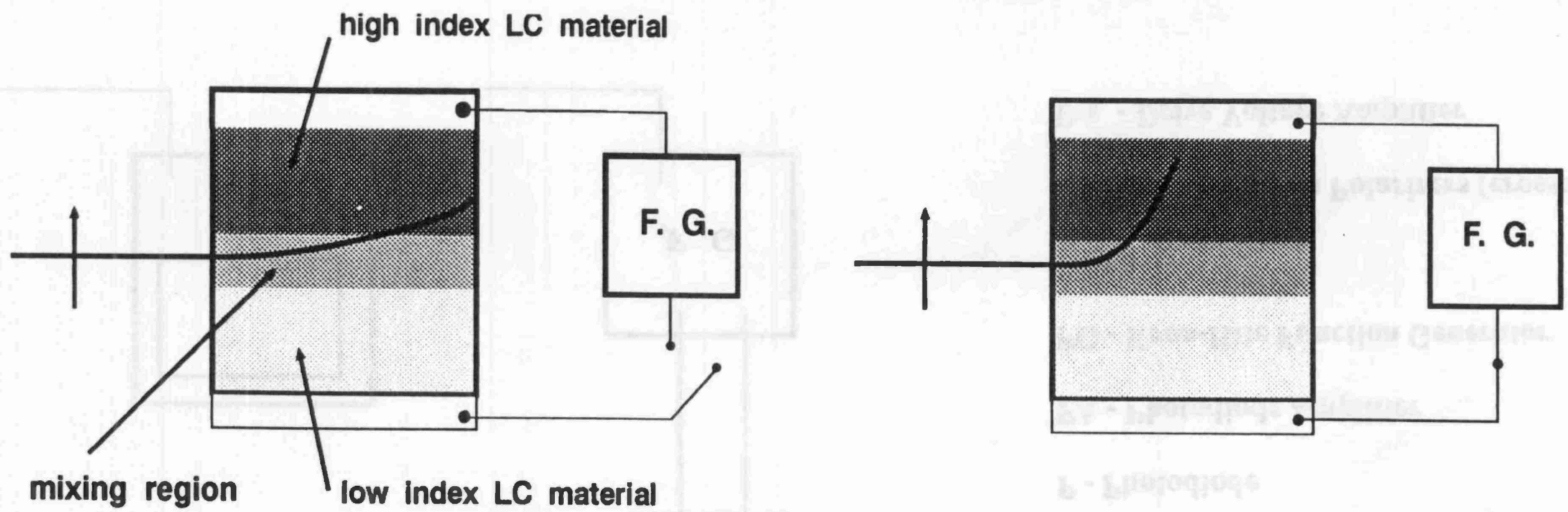
FG - Kron-Hite Function Generator

L - Laser

G - Glan Thompson Polarizers (crossed)

DA - Drive Voltage Amplifier

Liquid crystal gradient index beam switching/beam steering devices



- **Deflection angle is determined by**

$$\theta = L(\Delta n/W)$$

θ = deflection angle
L = propagation length
W = width of mixing region
Δn = difference in n_e of LC materials

LIST OF ATTENDEES

WORKSHOP

Liquid Crystal Materials and Devices for Opto-Electronic Applications

Center for Night Vision and Electro-Optics
Fort Belvoir, VA

5 December, 1990

LIST OF ATTENDEES

C^2NVEO

James E. Miller*	IRT-UDDT	703-664-1585
Robert. E. Flannery	IRT-UDDT	703-664-1585
Mary Jo Miller	L-LRT	703-664-1432
Don Nichols	IRT-UDDT	703-664-1585
Andy Mott	L-LRT	703-664-1432
Gary L. Wood	L-LRT	703-664-1432
Byong Ahn	L-LRT	703-664-5364
Edward J. Sharp	L-LRT	703-664-5767

University of Rochester

Kenneth L. Marshall*	LLE	716-275-5101
Stephen D. Jacobs	LLE	716-275-5101
Ansgar W. Schmid	LLE	716-275-5101
Mark Guardalben	LLE	716-275-5101
Don Schertler	Optics	716-275-6195
Bryan Stassel	Optics	716-275-6195

*Workshop Organizers

IRT = Infrared Technology Division
L = Laser Division
LRT = Laser Research Team
UDDT = Uncoded Devices Development Team