Center for Research in Electro-Optics and Lasers
University of Central Florida

AFFILIATES' DAY

January 13, 1992

Speakers' Presentations

CREOL
12424 Research Parkway, Suite 400
Orlando, Florida 32826
(407) 658-6800
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CREOL
(Center for Research in Electro-Optics and Lasers)

Established 1986
University of Central Florida, Orlando,
Director:  M J Soileau
Assistant Director:  C M Stickley

Objective:
* Establish a Center of Excellence at UCF in optics and laser research and education
* To assist in the development of Florida's High Tech industries

Description:
CREOL is an interdisciplinary center involving faculty and students from a variety of academic units including Physics, Electrical Engineering, Mechanical Engineering, Mathematics and Computer Science

University of Central Florida Research Park
Research Pavilion
Suite 400
CREOL FACULTY PROFILES

- 50% hold rank of fellow in major national and international professional societies.

- CREOL faculty are on boards of governors of 3 out of 4 major professional societies dealing with lasers and optics.

- 50% have chaired, co-chaired or served on organizing committees of major national and international conferences dealing with this research specialty in the past year.

- Over 150 professional publications and presentations in AY 90/91.

Conclusion: CREOL faculty are judged by their peers to be among the top people in their research fields.
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FACULTY
OPTICS COURSES

EEL-4440 Optical Engineering
EEL-5441 Introduction to Wave Optics
EEL-5446 Optical Systems Design
EEL-5450C Thin Film Optics
EEL-5451L Electro-Optics Laboratory
EEL-5563 Fiber Optics Communication
EEL-6443 Electro-optics
EEL-6457 Advanced Topics in Electro-Optics
EEL-6560 Laser Engineering
EEL-6561 Fourier Optics
EEL-6562 Diode Pumped Lasers
EEL-6564 Optical Communication Theory
EEL-6565 Infrared Technology

PHY-4424 Optics
PHY-5446 Laser Principles
PHY-5431 Optical Properties of Materials
PHY-5938 Introduction to Crystal Growth
PHY-6434 Nonlinear Optics
PHY-6448 Laser Systems
PHY-6424 Optical Properties of Solids
PHY-6204 Atomic Spectroscopy
PHY-6400 Physics of Free Electrons
PHY-6410 Modern X-Ray Science
PHY-6447 Laser Physics

Center for Research in Electro-Optics and Lasers
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<tr>
<td>• SL Laboratories</td>
<td>• 76,000 sq ft CREOL Building Planned (ground breaking Sep 92)</td>
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<td>• 85,000 sq ft Office and Labs (Research Pavilion)</td>
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CREOL Industrial Affiliates Program

Membership Requirements

Sustaining Member:
Participate in Eminent Scholar Program

Senior Member:
Annual Donation of $10,000

Member:
1. Gross sales greater than $10,000,000: $5,000 annual donation
2. Gross sales greater than $1,000,000: $2,500 annual donation
3. Gross sales less than $1,000,000: $1,000 annual donation

Membership in this special category is restricted to small business as defined by the U.S. Government
CREOL Industrial Affiliates Program

Membership Benefits*

- Establishes a formal relationship between the company and CREOL
- The *Highlights* newsletter of the Center for Research in Electro-Optics and Lasers
- Copies of any unrestricted publications, upon request arising from research carried out by the Center
- The CREOL Director's reports on the status of ongoing research, prospective programs and other activities
- A directory of the graduate students involved in CREOL-related programs
- Participation in the Annual Corporate Affiliates Meeting
- Influence direction of CREOL research
- Senior members are given a seat of the CREOL Industrial Advisory Board

*The honest truth is that CREOL is the primary beneficiary of this program because it supplies us with our only source of unrestricted funds.
CREOL
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University of Central Florida Research Park
Research Pavilion
Suite 400
SENSOR PROTECTION

Faculty:
E.W. Van Stryland
M.J. Soileau
D.J. Hagan
A. Miller

PhD Scientists:
D. Hutchings
M. Sheik-Bahae
A.A. Said

Students:
Tai Wei, Richard DeSalvo, Jiangwei Wang, Zho Wang, T. Xia and Mike Hasselbeck

Two of the PI's (MJS and EVS) hold security clearances. This helps in communicating research results to company scientists working with classified military systems (eg. Martin Marietta).
Funding Received:

US CNVEO/DARPA (1988–92) .................. $1,200,000
"Passive Spatial Beam Control" with M.J. Soileau
This was a direct match to the FHTIC funding.

SBIR Funded with Schwartz E-O (we split award) .......... $49,992

Battelle Columbus Laboratories (1987–88) ............. $25,000
"Measurement of Nonlinear Optical Properties
of Materials", with M.J. Soileau and D.J. Hagan

General Dynamics (1987–88) ........................ $44,731
"Laser Damage and Limiting", with M.J. Soileau

"Pulse Laser Test", with M.J. Soileau

Jet Propulsion Laboratory (1988–89) ............... $50,000
"Cascaded Optical Limiter"
with M.J. Soileau and D.J. Hagan

Army Research Office (1990) ................... $75,000
"Optical Limiting"
with D.J. Hagan and M.J. Soileau

McDonnell Douglas (1990) .................... $22,293
"Limiting Test"
with M.J. Soileau

National Science Foundation (1987–90) ............. $248,000
"Engineering of Two-Photon Nonlinearities in Bulk and
Artificially Structured Semiconductors"
with M.J. Soileau, and D.J. Hagan

Battelle Columbus Laboratories (1992) .............. $75,000

National Science Foundation (1992–95) ............. $252,000
"Dispersion of Optical Nonlinearities in Solids"
with M.J. Soileau, D.J. Hagan and M. Sheik-Bahae

Florida High Technology and Industrial Council (1991)  $21,161
"Passive Optical Switching"
with D.J. Hagan and M.J. Soileau
DISSECTATIONS

The research funded by the Florida High Technology and industrial Council the past year has resulted in the completion of the following doctoral dissertations.


APPROACH

1. develop techniques and facilities for the nonlinear optical characterization of materials
2. work with the materials people to optimize the nonlinear optical properties based on the results of our studies
3. implement these materials in the design and construction of optical limiting devices for sensor protection.

This last step is to be accomplished in collaboration with industry and government laboratories (eg. Martin Marietta, Shwartz E-O, JPL, CNVEO).

We organized three topical meetings of the SPIE held in Orlando entitled "Materials for Optical Switches, Isolators, and Limiters". This conference brought to Florida the primary researchers from around the U.S. working in this field. We presented several talks each year.
History

- original OPL patent M.J. Soileau ............... 1978
- screening test for OPL ...................... 1980
- semiconductor limiter (2PA) ................. 1985
- Patent; "OPL Based on Two-Photon Absorption" .................. 1988
- designed and built MONOPOL ................ 1988
  self-protecting semiconductor limiter
  10 nJ (300 W) limiting for psec 0.53μm pulses
  1 μJ (80 W) limiting with nsec 0.53μm pulses
- developed Z-scan .......................... 1988
- limiting in carbon suspensions .............. 1989
- developed psec DFWM (1 and 0.5 μm) ........ 1989
- developed method to model thick limiters .... 1989
  can optimize focusing geometry ......... 1990
- related n₂ to β the 2PA coefficient via nonlinear Kramers-Kronig ............... 1990
COLLABORATIONS:

- with RSRE Malvern, England
  - modified liquids, $V_xO_y$, liquid crystals
- with Jet Propulsion Lab on organics
- with Westinghouse on TAS at 10 $\mu$m (Singh)
  - also AgGaSe from Stanford (R. Route)
  - also AgGaS from Martin Marietta
- with DuPont on $n_2$ of KTP (Vanherzeele)
- with McDonnell Douglas for screening materials
- with Battelle Columbus for screening materials
- with LLNL (R. Adair, L. Chase)
  - $n_2$ of a series of materials at several $\lambda$
  - they have interest in $n_2$ at 355 and 266 nm
- with Bruce Chai (CREOL)
  - $n_2$ of LiCaAlF (of interest to LLNL)
- with Wright Patt. (C. Lee, Spire)
  - $n_2$ of organic thin films (in plastic host)
- with University of Florida (Joe Simmons)
  - DFWM, $n_2$, Darkening of semiconductor doped glass
- with Kent State Liquid Crystal Institute on organics
- with U. of Iowa (A.L. Smirl) semiconductor doping
- with Oklahoma State Univ. (R.C. Powell)
- with CNVEO for;
  - help in setting up in-house experiments
Ideal Optical Limiter Response

Fluence or Irradiance Output

Ultradfast Response

Power or Energy Input

High Linear

Broad Band

variable

$180^\circ$

$\leftarrow \rightarrow$

variable

fast rise
In the case of Kerr liquids such as CS$_2$, you can get exactly the shape desired and have high linear transmission. Also the screening test can be used to calculate the critical power and obtain an

You can get a very large dynamic range with CS$_2$, since liquids self-heal, and you can vary the cutoff power— but only to higher values. You do this by diluting it. That's the only thing wrong
Semiconductor Limiter

ZnSe or ZnS

\( \lambda = 532 \text{nm} \)

Transmitted on-axis fluence (arb. units)

Incident energy (\( \mu \text{J} \))

10 ns psec, \( >10^4 \) DR
300 W

1 mJ nsec, 10' DR
100 W

Combine with ZnN2 material
(Joint with JPL)

Grad student
Nonlinear Scattering in a Carbon Black Suspension

\( \lambda = 532 \text{ nm} \)

\( t_p = 14 \text{ nsec} \)

(a) Low Intensity

Front of the Cell \( \leftarrow \) 1 CM \( \rightarrow \) Back of the Cell

High Intensity

(b)
LIMITING BY THERMAL EXPANSION FOR NSEC PULSES

$L = 1 \text{ cm}$
$f = 10.2 \text{ cm}$
$\tau_p = 24^\circ \text{ ns}$

\[ \frac{dn}{dT} \text{ for Acetone } = 50 \times 10^{-5} \text{ per } ^{\circ}\text{K} \]
For a 2 inch input lens and a 1/4 inch iris opening, the energy in the limiting medium is $\approx 70$ times the energy entering the eye in the linear regime.

- An F/4 Objective with Identical Eye Lens constitutes Afocal System
- Non-linear Material is positioned at Prime focus of Objective Lens
- Stop at Objective Lens is reimaged by Field Lens to produce Exit Pupil at Eye
- Spherical Aberration designed in to dominate Coma and Astigmatism (controls image size and makes it uniform over 30° field)
- Erecting Prism (not shown) to be between Field Lens and Eye Lens
Nonlinear and Electro-Optic Materials for Optical Switching

Announcement and Call for Papers

2nd International Symposium

and Exhibition on Optical Engineering and Photonics

4-24 April 1992

Marriott’s Orlando World Center Resort and Convention Center

Orlando, Florida USA

Conference Chairman: M. J. Salehian, CREOL/Univ. of Central Florida


Eric W. Stavland, CREOL/Univ. of Central Florida

This conference will emphasize materials concepts and basic sciences

relevant to optical switching. Of particular interest are papers

dealing with materials and physical mechanisms that are relevant to

optical applications, papers on nonlinear optical phenomena that can be

used to fabricate optical switches are also welcome. Topics include:

- broadband fast optical modulators
- liquid crystals
- nonlinear properties of organic
- photorefractive materials
- photorefractive materials
- application absorption, reflection, and scattering
- sensor detecting

Abstract Due Date: 23 September 1991
Manuscript Due Date: 23 March 1992
CHARACTERIZATION OF NONLINEAR OPTICAL MATERIALS

Personnel

Faculty:

D. J. Hagan
E.W. Van Stryland
M.J. Soileau
M. Sheik-Bahae

Postdoctoral:

D.C. Hutchings (Theory)
A.A. Said

Students:

P. Buck, T. Xia, J. Wang, Z. Wang
R. DeSalvo, M. Hasselbeck, T.H. Wei
Nonlinear Refraction and Absorption:

\[ n = n_0 + n_2 |E|^2 + n_4 |E|^4 + \ldots \]

\[ \alpha = \alpha_0 + \beta I + \ldots \]

more generally:

\[ n \rightarrow n(I) \]

\[ \alpha \rightarrow \alpha(I) \]

- Strong light propagating in a medium can alter its optical properties.
Self-Focussing: \( n_2 > 0 \)

1/ Regular lens

plane wave

spherical wave: \(-ikr^2/2\)

2/ Nonlinear Medium: \( n = n_0 + n_2 |E|^2 \)

\[ I(r) \propto |E|^2 e^{-2r^2/(w_0^2)} \]

Plane-Gaussian Wave

Gaussian Wave - Grouts

- effective focal length

\[ f_{eff} = \frac{W^2}{n_2 |E|^2 L} \]
Measurement Techniques

Nonlinear Transmission
Optical Limiting
Beam Distortion
Excite-Probe
Degenerate Four-Wave Mixing
Z-Scan*
Exite-Probe Z-Scan*

(* Developed at CREOL)
Z-Scan Set-up

Best form lens

D2

D1
\[ \Delta T_{p,v} = p |\Delta \Phi^{NL}| \]

where \( p = 0.36 \) for a 40\% aperture

The NL phase shift is defined as:

\[ \Delta \Phi^{NL} = k n_2 I L \]

- \( k \) is the wave vector
- \( I \) is the peak irradiance
- \( L \) is the sample length
- \( n_2 \) is the nonlinear refractive index
LABS & FACILITIES

10-Hz Picosecond Nd:YAG lab
- Excite-Probe Z-scan & DFWM

10-Hz Picosecond Nd:YAG / Dye laser lab
- Z-Scans in IR, Visible & UV.

Picosecond/Nanosecond CO₂ lab
- Characterization in the mid-IR
  (9-11 micron band)

Single mode Nanosecond Nd:Yag lab
- Streak camera/vidicon for study of nsec limiting.
- nsec Z-Scans in IR and Visible

Picosecond Cr:LiSrAlF₆ laser lab
- Tuneable 50 psec 850 nm laser with 100 microjoule output.

* Femtosecond Ti:Sapphire/Cr:LiSrAlF regenerative amplifier system
  - 200 fsec, millijoule energy pulses
  - fsec broadband continuum source

Picosecond Nd:YLF laser
- Electro-Optic Sampling
Development of New Lasers and NLO Materials

Bruce H.T. Chai

CREOL
(Center for Research in Electro-Optics and Lasers)
University of Central Florida
12424 Research Parkway
Orlando, Florida 32826

Tel: (407) 658 - 6847
Fax: (407) 658 - 6880

January 13, 1992

* This work is supported by DARPA, FHTIC
§ Introduction:

⇒ Objectives:

◊ Establish a state-of-art crystal growth center in a university environment for

  » Research
  » Education

◊ Developing high optical quality crystals

  » Solid state laser hosts
  » Nonlinear optical devices
  » Substrates

◊ Supply materials internally and externally for R & D

◊ Technology transfer

  » from abroad to CREOL
  » from CREOL to industry and government laboratories
§ Crystal Growth Facilities at CREOL:

◊ The Crystal Growth Laboratory is established under AMMP (the Advanced Microelectronics and Materials Program) funded by both DARPA and the State of Florida.

◊ Laboratory planning started in March 1989.

◊ Installation of power, water and utilities started in July 1989.

◊ Testing first crystal puller at the end of September, 1989.

◊ Current Facilities:

Five stations fully optional, four to be completed. They include

3 RF heated pullers (two 30KW and one 50KW)
2 resistant heating fluoride pullers
3 TSSG furnaces (flux growth)
1 Cambridge pressurized puller

◊ Low temperature solution growth stations

⇒ nonlinear organic compounds.

◊ A fiber puller is under construction ⇒ with J. Dixon

◊ Optical fabrication laboratory.

◊ Most completed bulk crystal growth facility in U.S. universities.
§ Crystal Growth Stations at CREOL:

Fig. 2, Induction heated Czochralski station

Fig. 3, Resistance heated Czochralski station
§ Czochralski Pulling:

- Pulling crystals directly from melt
- Best developed growth technique because it can produce large, dislocation free crystals in a reasonable time.
- Produces highest optical quality crystal
- Require smooth rotation and pull movement
- Crystal diameter depends on temperature and pull rate.
- Free standing crystal after growth
- Can tolerate to some degree of nonstoichiometry and peritectic melting

- Two types of pullers used

  (1) RF heated → for oxide crystals,
      - high melting point (up to 2200°C)
      - Iridium metal containers

  (2) Resistant heated → for fluorides
      - low melting point (up to 1100°C)
      - Platinum metal containers
§ Current Research Programs:

(A) New Laser Materials Research
   - Oxides
   - Fluorides

(B) Nonlinear Optical Crystals
   - Borates
   - Niobates
§ Selection of Laser Materials:

- Selection of host crystals
  transparent
  robust
  high thermal conductivity
  low refractive indices

  Cline's rule – High Al and Be for good laser materials

- Selection of dopants
  rare earth elements – intrinsic transition
  transitional metals – extrinsic transition
  codoping – energy transfer

- Matching crystal to dopants
  ionic size
  coordination number
  chemical stability

- Site distortions
  fluorescence lifetime
  nonradiative absorption
  excited state absorption

- Crystal growth

* Crystal defects
  scattering, smoke
  stress
  inclusions, voids, solid particles, Ir, etc.
  inhomogeneity
§ Current Laser Materials Research

◊ Oxides:
  • Cr$^{4+}$ doped laser materials
    -- Mg$_2$SiO$_4$, YAG, CAS, CGS, CAO, YSO, FAP
    -- Cr$^{4+}$ doped YSO has been successfully lased
  • Rare earth doped laser materials
    -- YAG, YAP, YSO, FAP, CaYAlO$_4$

◊ Fluorides:
  • Cr$^{3+}$ doped laser materials
    -- LiSAF, LiCAF, LiSCAF, LiSCrF
  • Rare earth doped laser materials
    -- YLF, KYF, BYF
    -- First demonstration of TSSG of KYF
§ Current Nonlinear Optical Materials Research

◊ Borates:

- BTO, SNB, KNB
- KNB – a new potential useful crystal

◊ Niobates:

- LiNbO$_3$, KLN, SBN
- Rare earth doped NLO materials
  - LiNbO$_3$, SBN,
  - Self frequency doubling
- Periodical structures for quasi-phase matching
  - LiNbO$_3$, LiTaO$_3$, BNN,
NEW SOLID STATE LASERS

Presented by Dr. Michael Bass

Industrial Affiliates' Day

Monday, January 13, 1992
Losses in Cr:LiSAF

Loss [% / cm]

Time

Jan  Apr  Jul Aug  Oct
Laser performance of Cr:LiSAF at different repetition rates

Rear mirror: HR 2m
Output coupler: R=43% flat

Maximum output power:
10 Watts

Center for Research in Electro-Optics and Lasers
Input output energies for 2%Cr:LiSCAF

Output Energy [mJ]

Input Energy [J]

- R=95%
- R=80%
- R=69%
- R=43%
Lifetime [$\mu$s]

Temperature [K]

LiBAF
LiSAF
LiCAF

Lifetimes of Cr$^{3+}$ in LiBAF, LiSAF, and LiCAF
Free-running Laser Spectrum of Cr:Y$_2$SiO$_5$ at 77K
SOLID STATE LASERS AND LASER SPECTROSCOPY

Faculty:
  Jin J. Kim, Professor of Physics and Electrical Engineering
  Bruce H.T. Chai, Professor of Physics and Mechanical Engineering

Postdoctoral:
  Chil-Min Kim

Students:
  Jim Scheid
  Kijun Park
  Ron Raike
Solid State Lasers and Laser Spectroscopy

Jin J. Kim and Bruce H. T. Chai

Center for Research in Electro-Optics and Lasers

University of Central Florida

Orlando, FL 32826

Study the Physical Properties of Tunable Laser Host Materials such as Cr$^{3+}$:LiSAF, LiCAF, LiSCAF, and Pr$^{3+}$:YLF for Diode Laser Pumping

---measurements of thermal expansion coefficients and the indices of refraction
---excited state absorption cross sections
---transition properties
---laser gain


Set up CW Diode Laser Pumping of Pr$^{3+}$:YLF Laser
Pump at 640 nm
Signal at 520 nm
Excited State Absorption Measurements

Fig. 3

J. J. Kin, et al.
Cr-doped LiSAF Laser Pumped by a Pulsed Dye Laser

(a) 10% Cr Concentration

(b) 3% Cr Concentration

Input Energy (mJ)

Output Energy (mJ)
Fig. 2

J. J. Kim, et al.

Cr^{3+} : LiSAF
We have expertise in spectroscopic studies of materials and laser research and development. We also have expertise in applications of pulsed power technology to laser research and development.
SOLID-STATE LASERS
DIODE-LASER-PUMPED
GROUP PERSONNEL
DIODE-PUMPED CG:LiSbF LASER

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<td>ADVANTAGES</td>
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**PROS**
- Low output power
- High efficiency

**CONS**
- Lifetime
- Cost
- Size
- Efficiency

**COMPARISON**
- New wavelengths
- Energy storage
- Spatial coherence
- Spectral coherence
- Amplitude stability

**COMPARABLE TO FLASHPLANNING**
- Nonlinear Optical Materials
- External Resonant Processes
- Intracavity Processes
- Frequency Conversion
- Develop Techniques for Nonlinear
- Novel Ways to Use Old Diodes
- New Diodes
- Develop Pumping Techniques
- Investigate New Laser Materials
- Primary Group Objectives
GROUP PERSONNEL

ZHANG - STUDENT

HEIKE VÖSS - STUDENT

ERIC GRAN - STUDENT

JERRY CUTHBERTSON - STUDENT

DR. PETER N. KEAN - POSTDOCTORAL FELLOW

DR. DIVINDEE SAINI - POSTDOCTORAL FELLOW
NEW MATERIALS

1. CRYSTAL

2. SPECTROSCOPY LAB

3. SPECTRUM

4. SINGLE CRYSTAL FIBER CRYSTAL
PUMPING TECHNIQUES

1. Inter cavity pumping
2. Resonant pumping
3. Close coupled pumping
4. 670-mm pumping
SOLID-STATE LASER
RESONANTLY-PUMPED
2. DOUBLE RESONANT HARMONIC GENERATION

1. RESONANTLY-PLUMED SIGNAL GENERATION

CONVERSION

NONLINEAR FREQUENCY
PUMP-RESONANT SUM FREQUENCY LASER
Plasmas produced from laser

- Advanced solid
- Development
- State laser

Microscopy
Pulsed X-ray

- Lithography
- Projection
- Soft X-ray

Interactions
Laser pulse
Short pulse

- Optic X-ray
- Electro-optic
- Electro-optic technology

New optical designs
Ultrasound techniques
New focusing techniques

Novel target geometries
Special channeling techniques

Improved fabrication techniques
Improved techniques
COMPACT

Laboratory-size footprint, low cost, clean vacuum environment, high repetition rate.

PULSED EMISSION

Pulsed duration from millisecond to picosecond.

FLASH AND TIME-RESOLVED STUDIES.

TARGET DEPENDENT.

MULTI-COMPONENT SPECTRUM, STRONG LINE EMISSION.

Variable spectrum.

BRIGHTNESS

Isotropic or directional.

High conversion efficiency to continuum and line emission.

UNIQUE PROPERTIES OF LASER PLASMA X-RAY SOURCES.

STABLE TO MICRONS IN POSITION.

MICRON-SIZE POINT SOURCE.
Impact Areas of X-ray Microscopy

- Structures as thick as 50 microns may be possible.
- Thick specimens. The larger depth of field permits thicker structures to be imaged.

Location of specific elements in color-sensitive images.

- Laser-plasma source provide picosecond (even less) time resolution.
- Dynamic studies of subcellular structure. Pulsed x-rays, say from a laser-plasma source provide picosecond (even less) time resolution.

- Provide high contrast images.
- In vivo studies of live specimens. Soft x-rays are the only radiation which can penetrate several microns thick of biological stuff and which can penetrate several microns thick of biological stuff and
High Resolution Image of *in-vitro* Human Chromosome
Relatively simple laser - plasma experimental set-up

Technique is non-specific to specimens studied

Advantages

- Microscopy
  - Replication & TEM
  - Isomorphic
  - Image Replication by PMMA resist

We have demonstrated a robust, reliable technique which permits the rapid application of x-ray microscopy to many biological and life science issues.
Schwarzschild Microscope at 44A
A multi-media laser system

- Beam focusing
- Beam transport
- Pulse compression
  and Passive FourPass Amplifier
  CR: LISA/ LICAF Power Amplifier

- Waveshot Imaging
  CR: LISA/ Regenerative Amplifier with chirped pulse

- Pulse stretcher
  mode-locked L: Sapphire
  AR ion laser pumped 100fs front end
Small signal gain measurements of LISAF
XUVFEL and FIRFEL (X-Ray/Vacuum-UV and Far-Infrared FEL)

Accelerator and Electron Beam Layout

- 8 MV Tandem Accelerator
- 2 MV Electron Collector
- 2 MV Electron Gun

Average Power: 1-3 kW

Wavelength Range

- Phase I: Mid-Infrared Region
  \[ \lambda = 10 - 80 \text{ microns} \]

- Phase II: Vacuum-Ultraviolet/Soft X-Ray
  \[ \lambda = 0.04-0.4 \text{ microns} \]
BASIC COMPONENTS OF
A FREE ELECTRON LASER
UCSB - QUANTUM INSTITUTE
**CFELI** (Compact Free-Electron Laser)

**CFELI** is presently under construction.

**Average Power:** 1 kW

**Wavelength Range:** 120 - 800 micrometers
LiSAF regenerative amplifier for chirped 100fs pulses
Future Work

**Improved laser plasma x-ray sources**
- Reduced effects of plasma and particulate debris
- Higher x-ray conversion efficiency
- High repetition rate

**High resolution x-ray optics**
- Further experiments with contact and reflection microscopes
- Active image magnification and registration
- Applications to biology and life sciences

**High intensity lasers**
- Amplifier studies
- Experiments at ultra-high focused intensities
CREOL FEL PROJECT

**Major Objectives:**

- Develop continuously tunable sources in regions of the electromagnetic spectrum where conventional sources do not exist.
- Make the laser sources available to science and industry through a state funded user's facility.

**Scientific and Technical Staff:**

Luis Elias, Professor of Physics, Director of CREOL FEL
Isidoro Kimel, Theoretical Senior Physicist
Huabei Jiang, Postdoctoral Researcher
Muffit Tecimer, Postdoctoral Trainee
Kent Hopkins, Junior Physicist, FEL Laboratory Manager
Eduardo Ugaz, Visiting Physicist
Paul Tesch, Graduate Student
3 Undergraduate Students

**Administrative Staff:**

Gerald Grover, Administrative Assistant
Wavelength in micrometers

Applications

Chemistry
Microchip etching

Solid State Physics
Biophysics
Medical

Fusion Energy
WAVE PROPAGATION GROUP

Ronald L. Phillips
Professor of Electrical Engineering
and
Professor of Mathematics

Students

Robert Heileman, M.S. Electrical Engineering
Robert Murphy, Ph.D. Electrical Engineering
Dara Molen, M.S. Mathematics

Center for Research in Electro-Optics and Lasers
Figure 2. Angular distribution of the far field intensity of the backscatter for a normally incident wave. The computer simulation was performed for a strong turbulent random phase screen with averaging of returns from 100 pulses.
Figure 3. Angular distribution of the far field intensity for a wave incident at an angle of 0.012 degree with the same parameters as in Figure 2 except for averaging of 80 pulses.
Figure 5. (a) TV image of a laser beam after passing twice through the same screen; (b) an averaging of the TV images. The bright spot is the conjugate return.
Figure 6. Image of the detected return beam from a retro-reflector located at 1,000 m from the transmitter. The image has been processed by averaging the data from a CCD array.
Figure 7. Schematic diagram of optical system and definition of resolution angles.
LASER RADAR RESEARCH

Objective:

- The evaluation, analysis and development of advanced coherent array laser radar receivers with emphasis on atmospheric effects and target signatures.

CREOL Activities:

- Coherent array receiver development
- Laser radar simulation
- Array image processing
- Prototype Nd:YAG ladar testbed
UCF PARTICIPANTS

- Dr. C. Martin Stickley - Professor, EE/CREOL
- Dr. Philip Gatt - Research Scientist, CREOL
- Dr. Arthur R. Weeks - Assistant Professor, CpE
- Dr. Harley R. Myler - Associate Professor, CpE
- Mr. Robert Murphey - Graduate Student, EE/CREOL
- Mr. Robert Beeson - Graduate Student, EE/CREOL
- Mr Wilson Perez - Graduate Student, CpE/CREOL
- Mrs. Michelle V. Lewis - Graduate Student, CpE/CREOL
- Mr. Tony Centore - Undergraduate Student, EE/CREOL
- Mrs. Kathy VanScoter - Administrative Assistant, CREOL
COHERENT ARRAY RECEIVER DEVELOPMENT

To evaluate, develop and characterize coherent array laser radar technologies with emphasis in the following areas:

- Heterodyne efficiency optimization
- Fiber optic receivers
- Detector Arrays
- Distributed aperture arrays
LASER RADAR SIMULATION

To develop a laser radar simulation capability to evaluate the performance of laser radar systems.

- In house end-to-end laser radar performance simulation
- Computer simulation of array laser radar systems for diffuse targets
- Atmospheric scintillation effects on laser radar systems
- Computer modeling of track mount jitter
- LOWTRAN7 (Low frequency resolution transmittance and background radiance)
- FASCOD3p (High frequency resolution transmittance)
- DELTAS (Laser Radar Simulator)
ARRAY IMAGE PROCESSING

To develop new techniques of using optical computing devices to implement image processing algorithms normally calculated using digital computers.

- Spatial light modulators for optical image processing
  - Hybrid homomorphic (non-linear) filters to remove image shading
  - Coherent processing for phase reconstruction using deformable mirror devices
- Adaptive filters:
  - Image processing filter using feature extraction techniques to preserve edge detail
- UCFImage®:
  - An MS-DOS based image processing software package that includes 2-D FFT, histogram equalization, edge detectors, morphological and adaptive filters, and color capability
PROTOTYPE Nd:YAG LADAR TESTBED

Development, packaging and delivery of a solid state 1.06 μm incoherent laser radar testbed to a facility at Kennedy Space Center

- **Source:**
  - Continuum NY82-20, Nd:YAG, injection seeded, 1.5 J, 8 ns

- **Transceiver optics:**
  - Bistatic 10 cm transmitter, 50 cm receiver

- **Experiments:**
  - Hard target and plume backscatter at 532 nm and 1064 nm
  - Autodyne laser tracker
  - Target discrimination
FACILITIES

Laser Ladar Lab:

- Lightwave 122-50, 50 mW ring laser with fast PZT frequency tuning
- Lightwave 120-01, 5 mW ring laser with fast PZT frequency tuning
- Newport super cavity optical spectrum analyzer
- Newport acousto-optic modulator
- Hewlett Packard RF spectrum analyzer (2.9Ghz)
- Optical tables (Qty 2)
- MS-DOS 386 PC's (Qty 3)
- Beam diagnostic system (CREOL developed)

Image Processing Lab:

- Ncube supercomputer
- Sun 4 fileserver
- SunSparc 1 color workstations (Qty. 5)
- Sun 3 color workstation
- NCR Towerviews display terminals (Qty. 4)
- DATA TRANSLATION video frame grabber for the Sun 4 fileserver
- Video frame grabber boards for MS-Dos Compatible Computers
APPLICATIONS OF THERMAL IMAGING

CREOL AFFILIATES DAY

JANUARY 13, 1992

DR. GLENN BOREMAN
ASSOCIATE PROFESSOR, EE
INFRARED SYSTEMS LABORATORY
UCF/CREOL
(407) 658-6815
THE INFRARED GROUP

DR. BOREMAN - 8 YRS IN UCF'S ELECTRICAL ENGINEERING DEPT.
CURRENTLY 3 MS AND 3 PHD CANDIDATES

RESEARCH SPECIALTIES

INFRARED/OPTICAL SYSTEMS: ANALYSIS & DESIGN
PROTOTYPE INSTRUMENTATION DEVELOPMENT
DETECTOR AND FOCAL PLANE CHARACTERIZATION
MODULATION TRANSFER FUNCTION
INFRARED SCENE PROJECTION
CUSTOM MEASUREMENTS
SPECIALIZED TRAINING

APPLIED RESEARCH IN COLLABORATION WITH INDUSTRY
CURRENT RESEARCH

IR SCENE PROJECTION - REFLECTIVE LIGHT MODULATOR

Supported by:

Photonic Systems, MELBOURNE, FL (SBIR COLLABORATION)

AND Florida High-Tech Council

ANALYSIS OF FUNDAMENTAL PERFORMANCE ENVELOPE, AND
DEVELOPMENT OF PROOF-OF-PRINCIPLE INSTRUMENT

CHARACTERIZATION OF DETECTOR-ARRAY IMAGE QUALITY

Supported by:

Air Force Armament Lab, EGLIN AFB, FL

DEVELOPMENT OF INSTRUMENTATION FOR RESOLUTION TESTING
USING STATISTICAL PROPERTIES OF LASER SPECKLE

ANGULAR DEPENDENCE OF IR EMISSIVITY & REFLECTANCE

Supported by:

ALCOA Corporation, PITTSBURGH, PA

MEASUREMENT OF IR SIGNATURES FROM HIGH-TEMPERATURE
ALUMINUM SURFACES
THERMAL IMAGING OF CORNEA TISSUE

In collaboration with:

University of Miami Medical School

MEASUREMENT OF TIME DEPENDENCE & TEMPERATURE PROFILES DURING LASER SURGERY

MODELS FOR MINIMUM RESOLVABLE TEMPERATURE

Supported by:

Cl Systems, Hawthorne, NY

DEVELOPMENT OF NEW FIGURES OF MERIT FOR IR IMAGING SYSTEMS
REPRESENTATIVE PAST PROJECTS

SPRITE DETECTOR ANALYSIS

Supported by:

McDonnell Douglas Missile Systems, TITUSVILLE, FL

THEORETICAL ANALYSIS AND MEASUREMENT OF DETECTORS USED IN THE SENSOR OF THE DRAGON MISSILE; DEVELOPMENT OF NEW FIGURES OF MERIT RESULTING IN DESIGN MODIFICATIONS

SINCE 1986, THIS PROJECT HAS GENERATED 6 JOURNAL ARTICLES, 2 MS GRADUATES, AND ACCEPTANCE OF OUR ANALYTICAL MODELS FOR SPRITE PERFORMANCE IN THE US ARMY STANDARD COMPUTER CODE (MICOM IMAGING IR SYSTEM PERFORMANCE MODEL)

LASER BEAM STABILITY MEASUREMENT

Supported by:

Laser Ionics, ORLANDO, FL

INSTRUMENTATION DESIGN AND MEASUREMENT OF ARGON LASER ANGULAR BEAM STABILITY
IR SYSTEMS LAB FACILITIES

Using seed support from CREOL, Florida High-Tech Council, and loans & donations from industry, we have built a complete infrared research facility.

IMAGERS
- IR 512 × 512 PtSi CCD CAMERA: 3-5 MICRON
- IR SPRITE SCANNER CAMERA: 8-12 MICRON
- IR PYROELECTRIC VIDICON CAMERA: 1-12 MICRON
- VISIBLE CCD ARRAYS
- VARIOUS IR DETECTORS AND VACUUM DEWARS

SOURCES
- BLACKBODY SOURCE TO 1300 C
- 3.39 MICRON HE-NE LASER (50 mW)
- 10.6 MICRON CO₂ LASER
INSTRUMENTATION

SCANNING SPECTRORADIOMETER: 2-14 MICRON INTERFEROMETER - SURFACE FIGURE TESTING IR SCENE PROJECTOR VIDEO-BAND SPECTRUM ANALYZER VIDEO-TRIGGERED OSCILLOSCOPE

COMPUTER SYSTEM

SUN WORKSTATIONS: SPARC 330 AND SLC1 VIDEO DIGITIZER IDL NUMERICAL ANALYSIS SOFTWARE SEMPER IMAGE PROCESSING SOFTWARE CODE-V OPTICAL DESIGN SOFTWARE FLIR-90 INFRARED SYSTEMS DESIGN SOFTWARE
OPTICS

IR ZOOM TELESCOPE (8-12 MICRON)
12" DIAMETER OFF-AXIS PARABOLIC COLLIMATOR
IR LASER COLLIMATOR
POLYGON SCANNERS
VISIBLE AND INFRARED INTEGRATING SPHERES
IR ACOUSTO-OPTIC MODULATOR
HUGHES LCLV
21-ELEMENT DEFORMABLE MIRROR

FUTURE FACILITY

RF ISOLATION CHAMBER (NEW BLDG)
   FOR LOW-NOISE
DETECTOR & SYSTEM SENSITIVITY MEASUREMENTS
Graduates of the IR Systems Lab are working at:

MARTIN MARIETTA - ORLANDO, FL (3)
LITTON LASER SYSTEMS - ORLANDO, FL
MCDONNELL DOUGLAS - TITUSVILLE, FL
AIR FORCE ARMAMENT LAB - EGLIN AFB, FL
NASA - HUNTSVILLE, AL
INTERGRAPH - HUNTSVILLE, AL
ARNOLD AFB ENGINEERING CENTER - TULLAHOMA, TN
MEMPHIS STATE UNIVERSITY - MEMPHIS, TN
IT&T ELECTRO-OPTICS CENTER - ROANOKE, VA
NAVAL COMBAT SYSTEMS CENTER - NORFOLK, VA
Principal Investigator:
Dr. James E. Harvey, Associate Professor
CREOL/UCF
12424 Research Parkway
Orlando, FL 32826
(407) 658-6818

Graduate Research Assistants:
Kenneth J. Jerkatis, Ph.D. (EE)
Kristin L. Lewotsky, M.S. (EE)
J. Brooks Sweet, M.S. (EE)
Anita Kotha, M.S. (Physics)
William Gresslor, M.S. (EE)
A. The optical design and image analysis of advanced optical systems for state-of-the-art applications in the laboratory, in the industrial marketplace, and in space.

B. The simulation and modeling of systems performance for unconventional optical systems such as diffractive optical elements (binary optics), synthetic aperture optical systems (phased telescope arrays), and X-ray/EUV imaging systems for both astronomical and lithographic applications.

C. The experimental characterization of various optical materials and optical fabrication processes for precision optical surfaces and components. Of particular interest is the diffraction efficiency and scattering behavior of current state-of-the-art binary optical elements, the anomalous scattering behavior of beryllium optics for space applications, and the image degradation due to small angle scattering in X-ray multilayer coatings for enhanced reflectance at normal incidence.
• EUV Performance of Wolter II Telescopes for Space Astronomy Applications

• Performance Limitations of Imaging Microscopes for Soft X-ray Applications

• Nested Conical Foil Imaging Mirrors for High-energy X-ray Telescopes
  • NASA/GSFC: BBXRT with 101 Concentric Mirror Pairs
  • Soviet Spectrum-X-Gamma Mission: XPECT with 154 Concentric Shells
  • Japanese SXO with 89 Concentric Foil Shells
  • Italian X-ray Astronomy Satellite (SAX) with 30 Nested Coaxial Shells

• Interface Correlation Effects in Enhanced Reflectance X-ray Multilayers

* Residual design errors are seldom the limiting factor in the performance of very short wavelength high-resolution imaging systems. Even our best optical surfaces are not smooth relative to these wavelengths; hence, optical fabrication errors (over the entire range of relevant spatial frequencies) must be included in the modeling and simulation of such systems. Commercially available optical design codes do not adequately model these effects.
The concept of binary optics is to fabricate diffractive multi-level Fresnel zone phase profiles with the lithographic technology used in the production of integrated circuits. These "binary" optical elements can be used by themselves or in conjunction with conventional refractive or reflective optical elements.

**Fabrication Process**

- U.V. Light
- Computer Generated Amplitude Mask
- Photoresist
- Substrate (index = n)
- Photoresist Development
- Reactive Ion Etch to Depth = 0.5λ/(n-1)
- Remove Residual Photoresist

**Concept of Binary Optics**

- "Hybrid" Lens
- "5 MM Thick"
- Conventional Optic
- Fresnel
- Binary Profile
- Multilevel Binary Profile
- 2-Micron Thick
- 1-2 Microns

**Potential Advantages of Binary Optics**

- Improved Performance
- Reduced Weight
- Reduced Cost
- Meets Emerging Needs for Micro-optics
- Enabling Technology for the Integration of Micro-optics and Micro-electronics

**Proposed Experimental Program**

- Theoretical Predictions of Diffraction Efficiency
- Measurements of Diffraction Efficiency
- Measurements of Scattering Behavior
- Comparison of Theory with Experiment
- Parametric Results and Sensitivity Analyses
PHASED TELESCOPE ARRAYS

MOTIVATION

- Fabrication and Testing
- Reduction of Weight and Moment of Inertia
- Potential Cost Savings
- Emerging Technology to be Evaluated

PHASED TELESCOPE ARRAY CONCEPT

POTENTIAL ERROR SOURCES

- Phasing Errors
- Relative Pointing Errors
- Relative Focus Errors
- Optical Fabrication Errors
- Assembly and Alignment Errors
- Lateral Pupil Mapping Errors
- Longitudinal Pupil Mapping Errors
- Relative Magnification Errors
- Off-axis Aberrations

FIELD-OF-VIEW LIMITATIONS

Large apertures (small field angles) Dominated by Field Curvature
Small Apertures (large field angles) Dominated by Distortion.
Quantum Well Optoelectronics & Femtosecond Spectroscopy

Alan Miller

- Physics of advanced semiconductors
- New ultra short pulse laser sources
  - Semiconductor optical switching devices
  - Integrated optical circuits

Post-Doctoral Research Scientists:

- Patrick C. Kam-Wai: MOQWs, all optical switching, mode-locked lasers
- Michael Smalley: Solid state spectroscopy, spin relaxation in MOQWs
- David Hutchings: Theory of optical nonlinearities, MOQWs and switching devices

Collaborations:

- UT&D, Port Monmouth
- AT&T, Holmdel
- Amoco, Naperville
- CSDL, Pavia, Italy

Funding: DARPA, ARL, STIC, NATO
New Tunable Femtosecond Solid State Laser Sources

Patrick Erkam Wa, Bruce Chai, Alan Miller

- cw argon pumped K: Sapphire
  - 80 fs

- Nd:YAG synchronously-pumped K: Sapphire
  - 100 fs

- cw krypton pumped Cr: LiSAF
  - 150 fs

- cw krypton pumped Cr: LiSCAF
  - 150 fs

- cw krypton pumped Cr: LiCAF
  - in progress

Collaborations:
- Laser Ionics
- NEOS
- Schwartz PO
- Lightning Optical Corp.
Schematic layout of X-fold, dispersion compensated LiSAF or LiSCAF laser.

Characteristics of the dispersion compensated LiSCAF laser
Time resolved optical pump-probe set-up

(1) Undoped MQW zero-gap directional coupler
(2) P-i-n doped MQW zero-gap directional coupler
(3) P-i-n doped SQW single mode waveguide
**MQW Directional Coupler**

- Zero-gap directional coupler to minimize length
- Band-filling and exciton saturation nonlinearities
- Undoped structure gave 1.5ns recovery
- P-i-n doped structure gave ~100psec recovery by employing carrier sweep-out in an applied field
- Potential for < 10psec recovery

**SQW Waveguides**

- Both QCSE effects and exciton saturation monitored
- 113psec saturation recovery due to carrier sweep-out with no applied field
  (in collaboration with A Moretti, Amoco)
- Asymmetric barriers studied to distinguish between the role of electrons and holes
  (in collaboration with D A B Miller, AT&T)

MQW waveguide directional coupler response as a function of reverse bias.

SQW waveguide response showing fast recovery in the absence of an applied field.

Center for Research in Electro-Optics and Lasers
GaAs/AlGaAs SEED Structure
**Fundamental Limits of Optical Switching**

**Approach**

- Time resolved measurements of the dynamical quantum confined Stark effect (QCSE) in p-i-n doped structures.
- Modeling of the cross-well carrier dynamics to determine carrier emission rates, tunneling rates and retrapping times.

---

**Diagram representing the various time constants involved in cross-well transport of carriers**

**Comparison of experimental transient transmission changes with the theoretical model for different bias voltages.**

**Comparison of experimental and theoretical rise times showing resonant tunneling at 5V bias.**

**Representation of the electron densities in the quantum wells at various delay times and bias voltages.**

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Center for Research in Electro-Optics and Lasers
1µm $p^+\text{Al}_0\text{Ga}_{0.5}\text{As}$

0.1µm undoped GaAs

50Å undoped In$_{0.2}$Ga$_{0.8}$As

0.1µm undoped GaAs

1µm $n^+\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$

$n^+\text{-GaAs buffer}$

$n^+\text{-GaAs substrate}$
Optical Switching with Gain

Results

- First demonstration of dispersive optical bistability with gain in a quantum well laser.
- \( \text{InGaAs/GaAs} \) single quantum well strained layer laser biased below threshold.
- Measurements of gain saturation
  (in collaboration with Robert Park, U. Florida)

Goals

- Time resolved measurements of gain recovery
- Optical bistability in a single mode laser
- Demonstrate a directional coupler switch with gain
  (in collaboration with Paul Cook, ETDL)

Optical bistability at 960nm at an electrical bias of 0.8th.

Gain saturation at 965nm for three different bias conditions
Approach:

- A large blue shift of the absorption edge is induced by disordering the MQWs by zinc diffusion and annealing (in collaboration with Mitra Dutta, ETDL)
- Non-dopant, gallium vacancy induced disordering is being investigated (in collaboration with Gareth Parry, UCL)

Goals:

- Characterization and optimization of selective area partial intermixing of MQW waveguides
- Cascading of MQW directional coupler switches
- Demonstration of an all-optical waveguide switching circuit

Center for Research in Electro-Optics and Lasers
NONLINEAR WAVEGUIDES

Presented by Dr. George Stegeman,
Professor of Physics and Electrical Engineering

and

Cobb-Hooker Eminent Chair
NONLINEAR WAVEGUIDES

George Stegeman

Long Range Goals:
To investigate the physics and applications of nonlinear optics in waveguides.

Personnel:
5 post-doctoral fellows, 1-3 visitors, 9 graduate students, 1 technician

Program:

1. Nonlinear Materials
   - characterization from 450 → 2000 nm
   - physics of the nonlinearities
   - device figures of merit

2. Waveguide Fabrication
   - fabrication of thin film and channel waveguides
   - grating couplers
   - waveguiding characteristics, loss etc.
   - nonlinear characterization

3. Nonlinear Waveguide Phenomena
   - physics of nonlinear waveguides
   - soliton phenomena
   - out-of-plane second harmonic generation
   - all-optical switching in fibers and channels
WAVEGUIDE MACH-ZEHNDER INTERFEROMETER

Channel Waveguides

Nonlinear Interferometer

$$\Delta \phi_{NL} = n_2 I k_0 L_{eff}$$
NONLINEAR DISTRIBUTED FEEDBACK GRATINGS

\[ n = n_0 + n_2 l \]

Schott BGG21 glass has \( \sim 10\% \) Na

- 3 \( \mu \)m wide, 1 cm long channels, \( > 20\% \) throughput

- planar waveguide losses \( \sim 0.6 \) db/cm (channel \( \sim \) same)
NONLINEAR DIRECTIONAL COUPLER

$\lambda = 1555$ nm (communications band) 500 fs pulses

$n=3.305$ AlGaAs $x=0.24$ Strip Loading

$n=3.337$ AlGaAs $x=.18$
Guide $t=1.5$ $\mu$m

$n=3.305$ AlGaAs $x=0.24$
Cladding $t=4$ $\mu$m

$n=3.4$ GaAs Substrate

$P_1(z) \rightarrow P_2(z)$

$P_1(0) \rightarrow P_2(L)$

$P(L)/P_1(0)$

Input Intensity (GW/cm$^2$)
Novel Applications of Diffractive Optics

Graduate Students

Tim Ayers - MS student
Dan Gray - Ph.D Student
Drew Pommet - Ph.D. Student

Government and Industrial Sponsors and Collaborators:

Florida High Technology Industrial Council
Harris Corporation Electronics System Division - Melbourne, Fl
CECOM Center for Night Vision & Electro-Optics - Fort Belvoir, VA
LTV Missiles and Electronics Group - Dallas, TX
Northrup Electronics Systems Division - Hawthorne, CA
Teledyne Brown Engineering - Huntsville, AL
Geltech - Alachua, FL
Binary Diffractive Elements Applications

Multi-Level Binary Broadband Anti-reflection Surfaces
Surface-Relief Gratings for Spot Array Generation
Multiplexed Gratings for Optical Interconnects
Two-Dimensional Binary Grating Filters
Binary Grating Polarizers

Real Time Holography Applications

Acousto-Optics-Photorefractive Signal Processing
   Correlation and Adaptive Nulling
Novel Technique for the Characterization of Photorefractive Materials
Three-Level Binary Grating AR Coating

Unpolarized Light

- \( \Lambda = \lambda / 2 \)
- \( \Lambda = \lambda / 4 \)
- \( \Lambda = \lambda / 8 \)

Reflectance %

Wavelength (microns)
Four-Level Binary Gating AR Coating

Unpolarized Light

% Reflectance

3.00  2.25  1.50  0.75  0.00

3.00  4.00  4.50  5.00

Wavelength (microns)
Binary Grating AR Coating

Unpolarized Light $(\theta=7.5^\circ)$

- 1 Level
- 2 Levels
- 3 Levels
- 4 Levels

$\%$ Reflectance

Wavelength (microns)

<table>
<thead>
<tr>
<th>5.00</th>
<th>3.75</th>
<th>2.50</th>
<th>1.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.00</td>
<td>4.50</td>
<td>5.25</td>
<td>6.00</td>
</tr>
</tbody>
</table>
TM POLARIZATION

\[ \Lambda = \lambda \]
\[ R = 50\% \]
\[ \theta = 45^\circ \]
\[ \phi = 45^\circ \]

DE (%) vs GROOVE DEPTH/WAVELENGTH

0.0
0.1
1.0
1.1

0 1 2 3 4 5
Response of BaTiO$_3$ as a Function of Spatial Frequency
\[ \int S_1(t) S_2(t - D) \, dt \]

Photorefractive Correlator Concept
Photorefractive Adaptive Filter Concept
A NEW CLASS OF OPTICAL THIN FILMS

Principal Investigator:
Prof. Karl H. Guenther
Electrical Engineering and Physics
Collaborators:
Dr. K. Balasubramanian
Drs. M. Himel (now at AT&T) and S. Zarrabian
Prof. K. Beck (Chemistry) and Prof. A. Grogan (ME)

MAJOR TOPICS
- React. Low Voltage Ion Plating
- Plasma Process Diagnostics
- Thin Film Characterization and Analysis
- Feasibility Studies for Florida and National Industry, Federal Agencies and Labs

ACCOMPLISHMENTS
- Glassy, Dense, Smooth Films
- Better Oxidation Mechanism
- Optical Micrometrology and Surface Microanalysis Labs
- Laser Coatings, Eye Protection, Polarizers, AR-Coatings, Waveguide Beam Deflector

1/12/92 Center for Research in Electro-Optics and Lasers
CERAMIC OPTICAL COATINGS?

K. H. Guenther

Comparison of Thin Film Deposition Processes

Reactive Evaporation

Ion Assisted Deposition

Ion Beam Sputtering

Low Voltage Ion Plating
High Vacuum Deposition System  
(Balzers BAP 800)  
for Reactive Electron Beam (EB) and Thermal Evaporation  
and Reactive Low Voltage Ion Plating (RLVIP)
ZrO₂/SiO₂, ion plated multilayer coating: electron micrograph of a direct cross-section obtained by microtome slicing normal to its interfaces (origin mag 100,000x D. Windham)
Laser-Quality Coatings Deposited by

Reactive Low Voltage Ion Plating (RLVIP)

K. H. Guenther, K. Balasubramanian, and X.-Q. Hu
Center for Research in Electro-Optics and Lasers (CREOL)
University of Central Florida
Orlando, FL 32826

R. Chow and C. J. Stolz
Optical Initiative Project and KMI
Lawrence Livermore National Laboratory
University of California
Livermore, CA 94551

CLEO/QELS
May 12-17, 1991
Baltimore, Maryland
LIDT @ 532 nm of 1 QWOT Single Layers, EB–Deposited and Ion–Plated (IP) on FS

Absorption [ppm]

LLNL–LIS Damage Testing

Center for Research in Electro-Optics and Lasers
LIDT @ 1064nm of Single Layers, QWOT@532
EB—Deposited and Ion—Plated (IP) on FS

LLNL—ICF Damage Testing
Center for Research in Electro-Optics and Lasers
Discussion

- RLVIP coatings have desirable properties:
  - Refractive index invariant to environment (stable spectral characteristic)
  - Expected high durability / longevity (hardness, imperviousness, abrasion resistance)

- Microstructure and surface roughness investigation indicate dense, glassy (vitreous) or nano-crystalline phases with little (or no) increase of surface roughness

- RLVIP is suitable for mass production and scale-up to large substrate sizes alike (potentially 2 m diameter)

- Absorption of our RLVIP single layer samples is higher than that of comparative e-beam evaporated thin films

- Absorption seems to be a dominant factor for laser damage, independent of the deposition process

Center for Research in Electro-Optics and Lasers
Conclusions

- RLVIP thin films still have good promise for becoming ideal optical and laser coatings.

- Further investigations into the influence of absorption on laser induced damage and, conversely, of process parameters on absorption are necessary.

- Collaboration between industry, national labs, and universities works and assures broad base for leading edge technology.