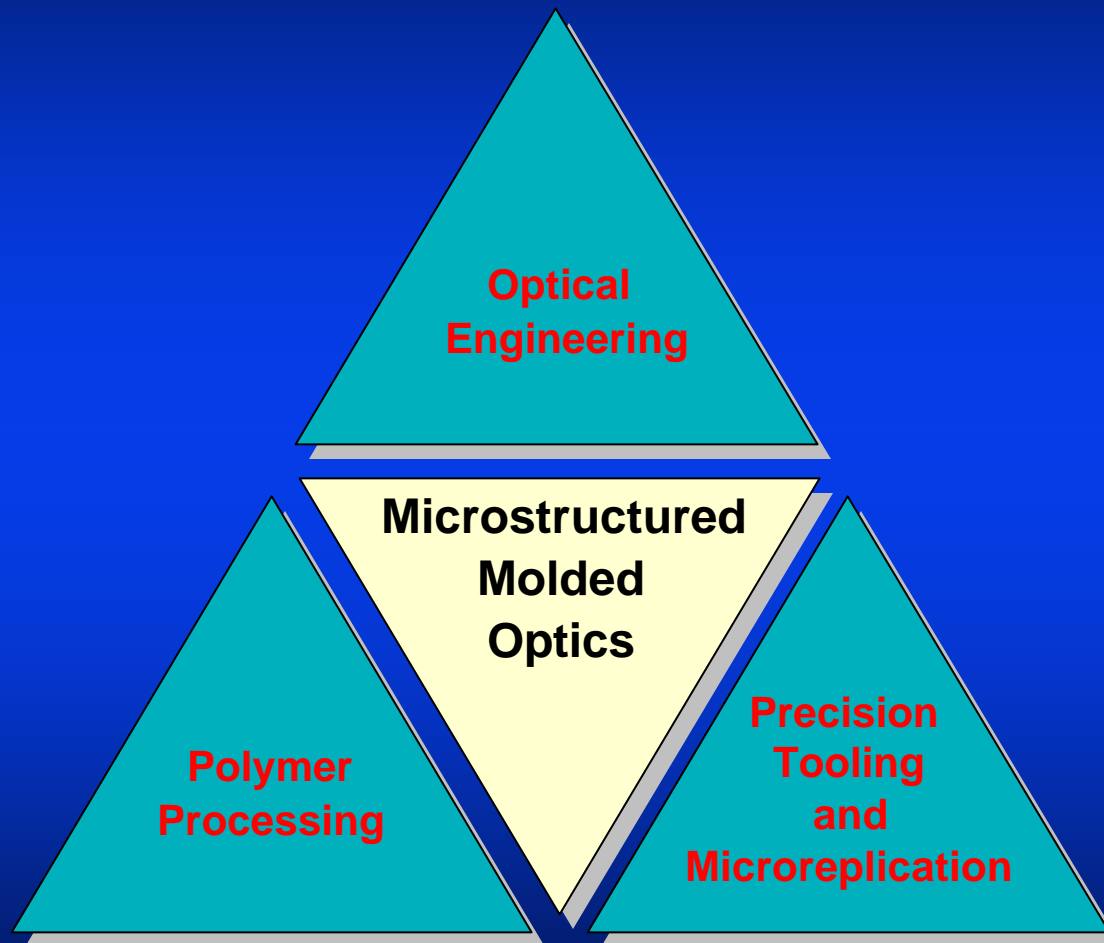


Opto-Northeast and Imaging 2001
NE04-21: Microstructured Plastic Optics
for Display, Lighting, and
Telecommunications Applications
By Michael F. Foley, PhD

Abstract

This poster will present recent technological advances in the field of replicated, microstructured plastic optics, and their applications in display optics, lighting, and telecommunications. Microstructured plastic optics are a family of components which incorporate features such as facets, lenticles, prisms, surface relief structures, or microlenses, to achieve some design intent. Multiple features can be incorporated into a single component or system, and hybridization is possible. The poster will discuss products, materials, processes, and applications for microstructured plastic optics. Products described include microlens arrays, gratings, fresnel lenses, Moth-eye Antireflective Microstructure™, and engineered surface relief diffusive structures. Processes which will be discussed include casting, injection molding, compression molding, embossing, and High Precision Molding (HPM). Tradeoffs between process fidelity, relative cost (recurring and non-recurring), and suitability to task will be assessed. Material considerations such as temperature stability, optical properties, and manufacturability issues will be detailed. Finally, a number of applications for microstructured plastic optics will be described including several display applications (including backlit displays, imaging screens, LCD projectors, camera displays), lighting applications (including LED systems and waveguide based luminaires) and telecommunications applications (including gratings, microlenses, and multi-function subsystems for DWDM) will be described.

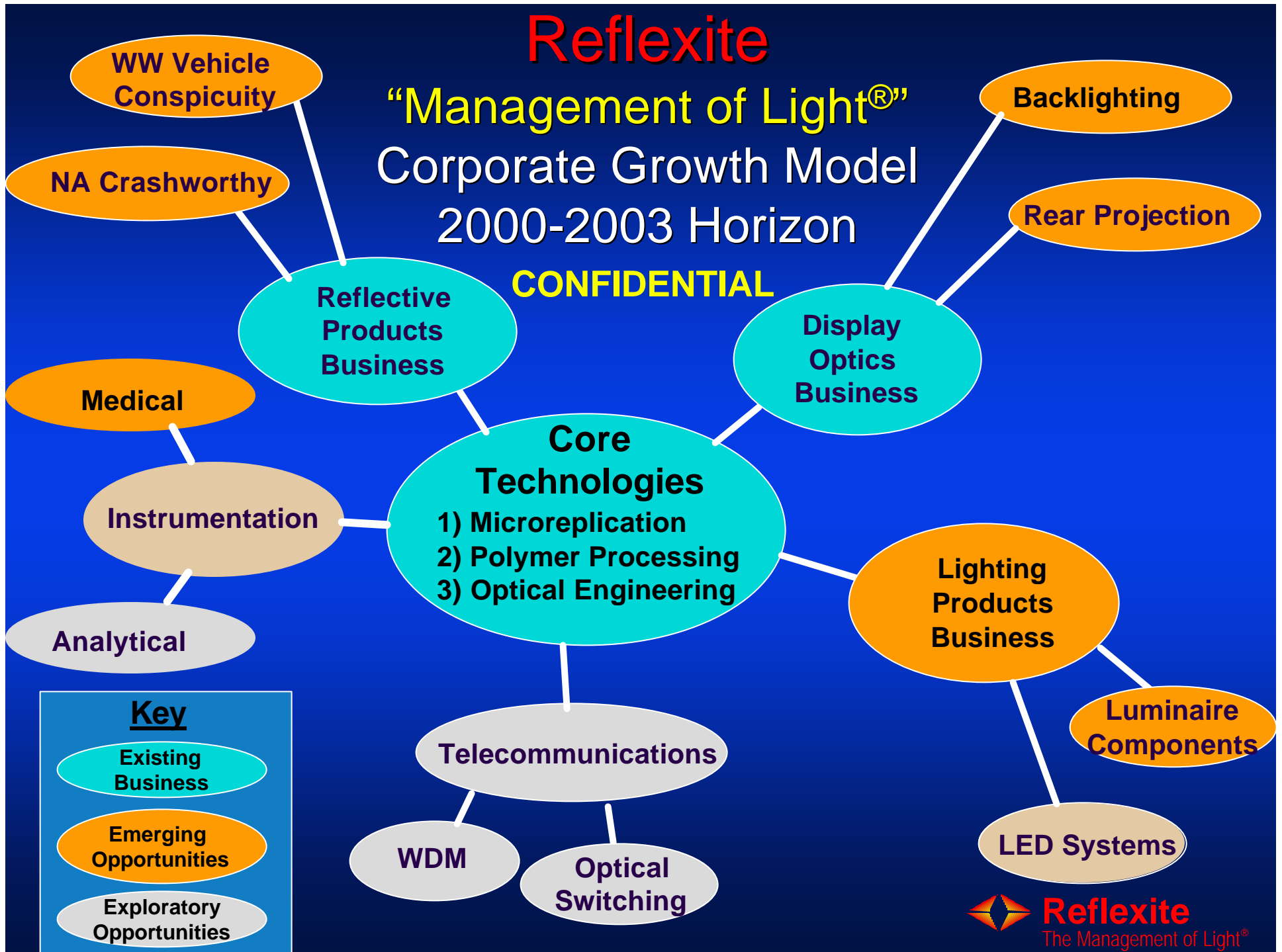
Reflexite's Technology Focus



Reflexite

“Management of Light[®]” Corporate Growth Model 2000-2003 Horizon

CONFIDENTIAL



Reflexite

Reflective Products Business



**Personal
Safety**



**Reflexite Technology Center
Avon, CT**



**Marine
Safety**



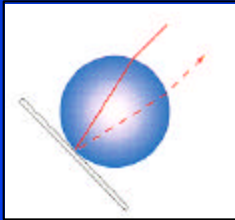
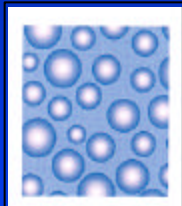
**Vehicle
Conspicuity**



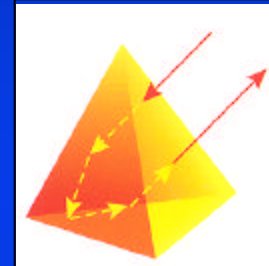
**Traffic
Control**

Reflexite Reflective Products Business Cornercube Microprism Technology vs. traditional Glass Bead

Glass Bead



Cornercube
Microprism



Advantages of Cornercubes

- Reflect up to 250% more light
 - more reflective surface area
 - higher optical efficiency
- Precise control of angular return
- Do not lose reflectivity when wet

Reflexite Worldwide Subsidiaries



Reflexite Beijing
Beijing, China



Reflexite France
Dardilly, France



Reflexite Malaysia
Ampang Sel, Malaysia



Reflexite Products
Australasia
Queensland, AUS



Reflexite Ireland
European Conversion Center
Waterford, Ireland



Reflexite Scandia
Hoersholm, Denmark



Reflexite Canada, Inc.
Mississauga, Ontario



Fresnel Optics
Rochester, NY



Reflexite Sweden
Stockholm, Sweden



Reflexite Italy
Milan, Italy



Precision Technology Center
Rochester, NY



Reflexite North America
New Britain, CT



Reflexite Japan K. K.
Tokyo, Japan



Fresnel Optics GmbH
Apolda, Germany



Reflexite Taiwan
Pan Chiao City, Taipei



Reflexite Technology Group
Avon, CT



Reflexite UK, Ltd.
Southall, Middlesex



Rui Fei Optics
Xiamen, China



Reflexite West Coast Office
Sacramento, CA

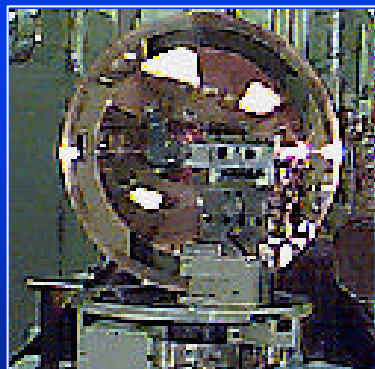
Yellow denotes Integrated Manufacturing Site

Grey denotes Sales office

Blue denotes Corporate Manufacturing/Core Competency Center

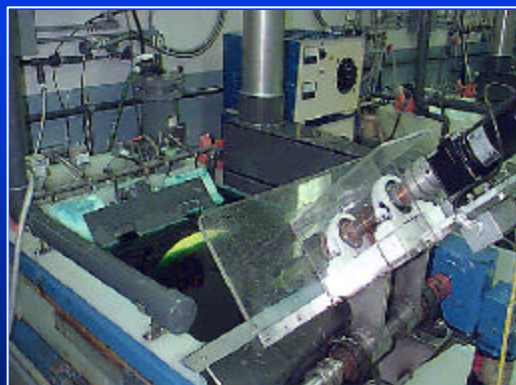
Microreplication

Reflexite Precision Technology Center

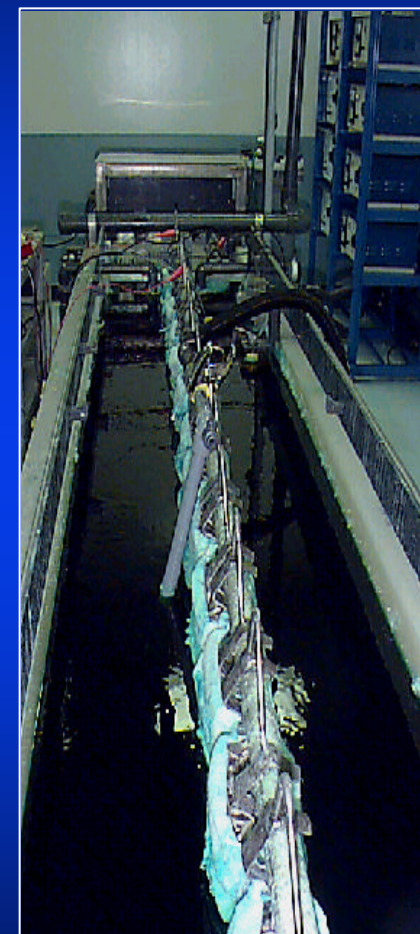


Mastering

- Flycutting
- Holography
- Diamond Turning
- Linear Ruling



Electroforming

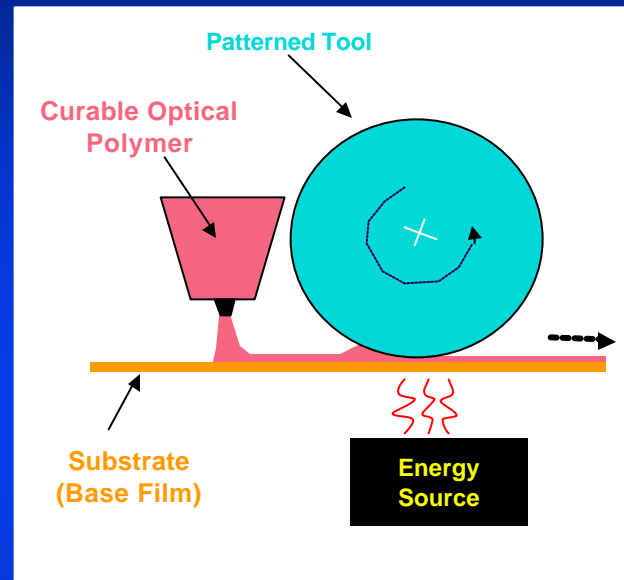


Plating

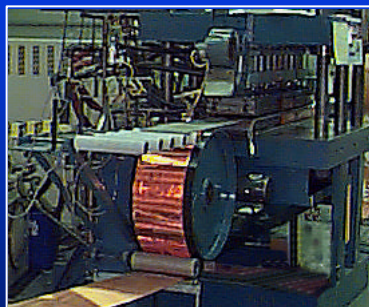
Reflexite/Fresnel Plastics Processing



Compression Molding



Continuous Casting



Continuous Embossing

**High
Precision
Molding
(HPM)**

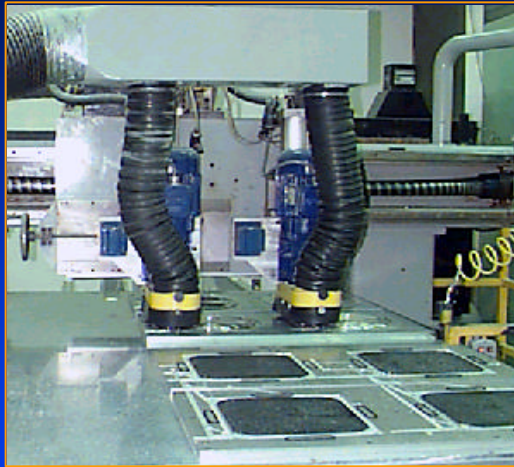
In-line enhancements

- laminating
- slitting
- rotary screen printing
- coating
- Gravure Printing

Advantages of HPM

- fast cycle time
- no internal stress
- high precision
- 2 sided registration

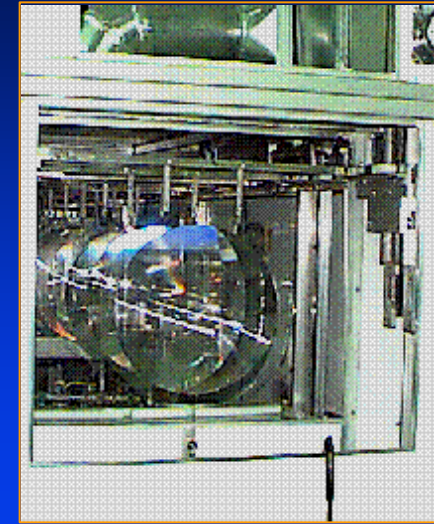
Fresnel Optics Manufacturing Capabilities



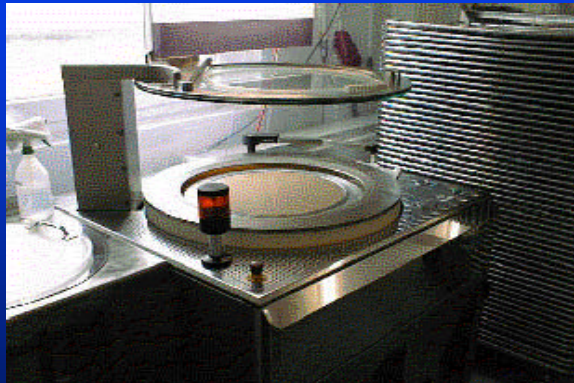
NC Trimming



Laser Trimming



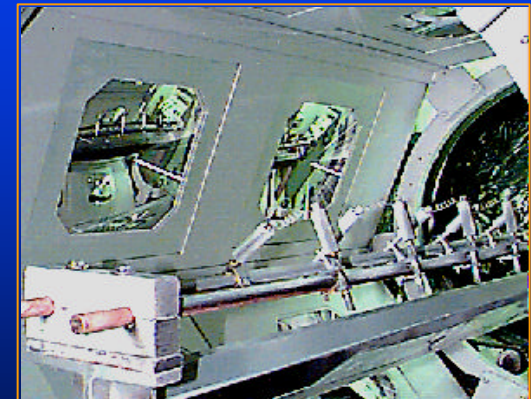
Hardcoating



Spin Coating



Lamination



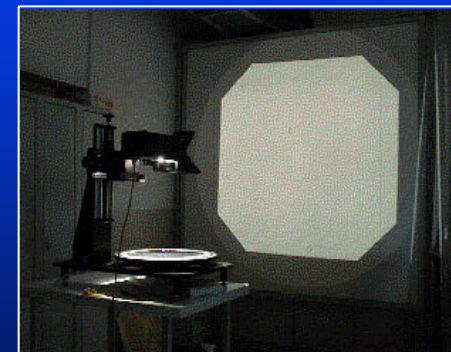
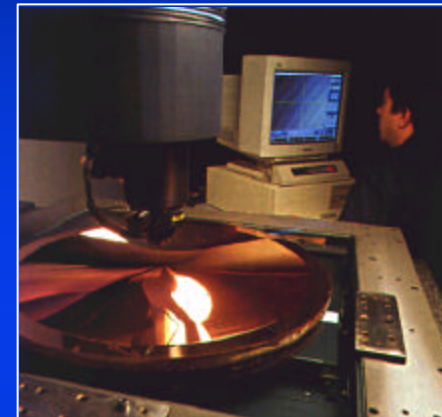
Metallization

Fresnel Optics

Integrated Capabilities

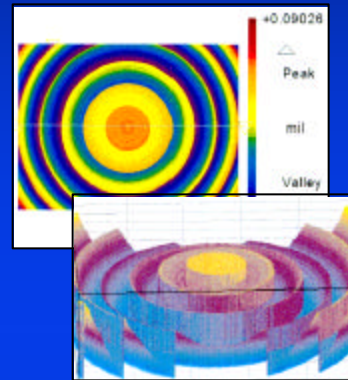


- Optical Design and System Engineering
- Tool Generation
 - Mastering
 - Electroforming
- Plastic Molding
 - Process Engineering
 - Product Development
- Finishing Operations
- Metrology and Optimization



Optical Engineering

- **Modeling Capabilities**
 - TracePro for 3D geometries
 - OptiCAD for 2D geometries
 - Zemax for imaging applications
 - Custom in-house software
- **Testing Capabilities**
 - Oriel high-aperture white light sources
 - LS-100 Luminance Meter
 - IL1700 Research Radiometer
 - PR-650 Spectro-colorimeter
 - Cary 500 Spectrophotometer
 - DIAS 1600 Birefringence Analyzer
 - Many semi-custom test beds
- **Design Expertise**
 - Refractive Optics
 - Diffractive Optics



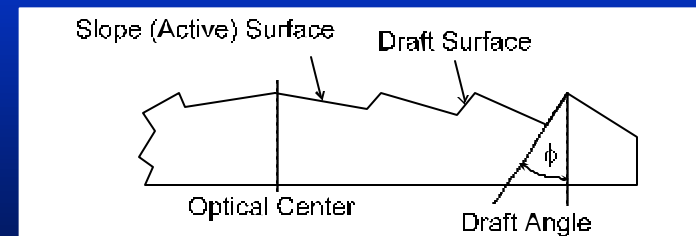
Plastics Processing Technologies for Microstructured Optics

Comparison of Processes

	Compression Molding	Injection Molding	HPM	Coining Standard/DVD	Casting Discrete/Continuous	Embossing Discrete/Continuous
Precision	Very High	Low	High	Medium/High	High	High
High Aspect Ratios	Easiest	Difficult	Easy	Difficult	Moderate (2)	Moderate
Replication Fidelity	Very High	Low	High	Low/High	Very High	High
Tooling Cost	Low	High (1)	Medium	High	High	Medium
Unit Cost	High	Low	Medium	Medium/Low	High/Low	High/Medium
Internal Stress	Very Low	High	Low	Medium/Low	Medium	Low
Notes						
(1) Tooling Cost can be minimized using MUD mold base, but is in general high						
(2) High aspect ratios are possible but in UV cured casting systems there are practical limitations on feature size due to shrinkage						

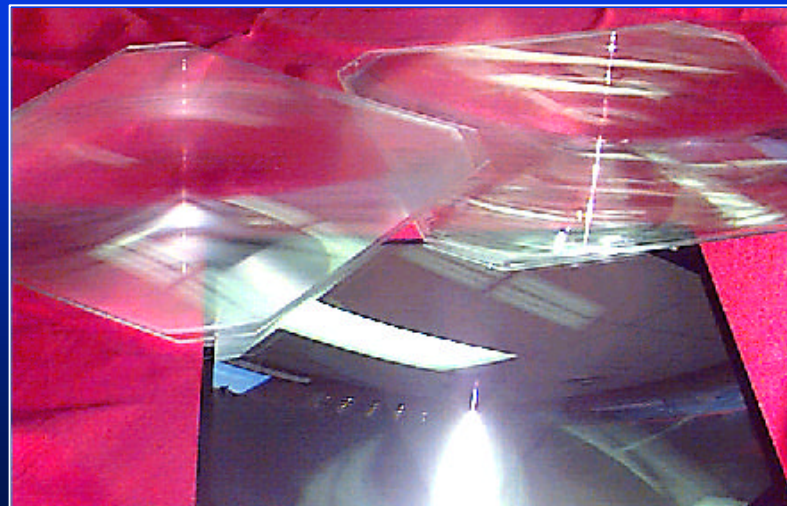
Performance Metrics

- High Fidelity
 - Feature Sharpness
- Process Cycle Time
- Control of Internal Stress
 - Feature Aspect Ratio



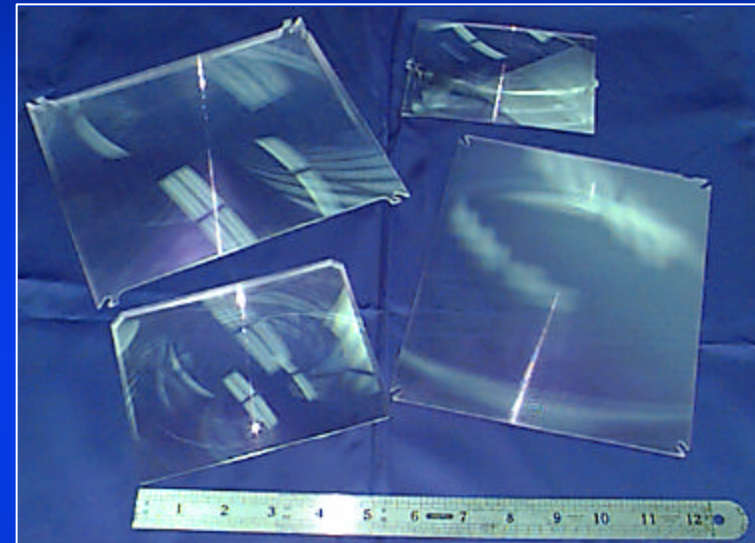
Overhead Projector Lenses

Transmissive and Reflective



LCD Projector Lenses

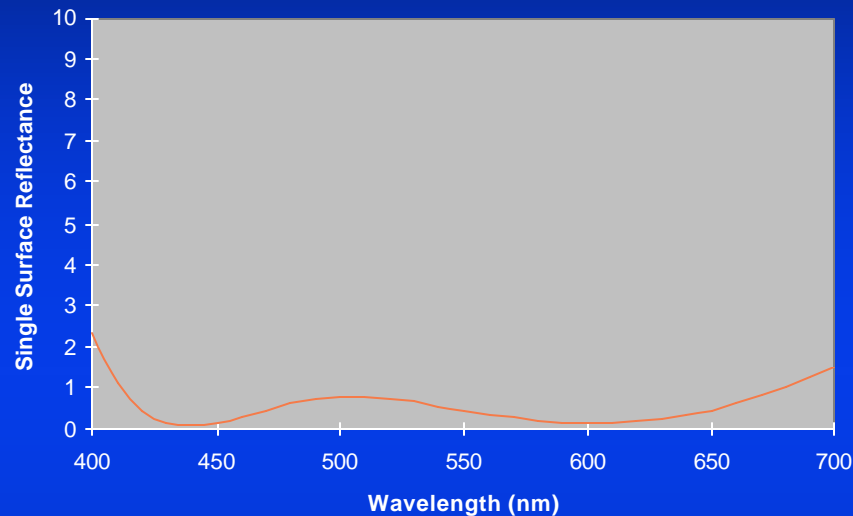
Field and Condensors for Single Panel Designs



Field and Condensor Lenses

WB1

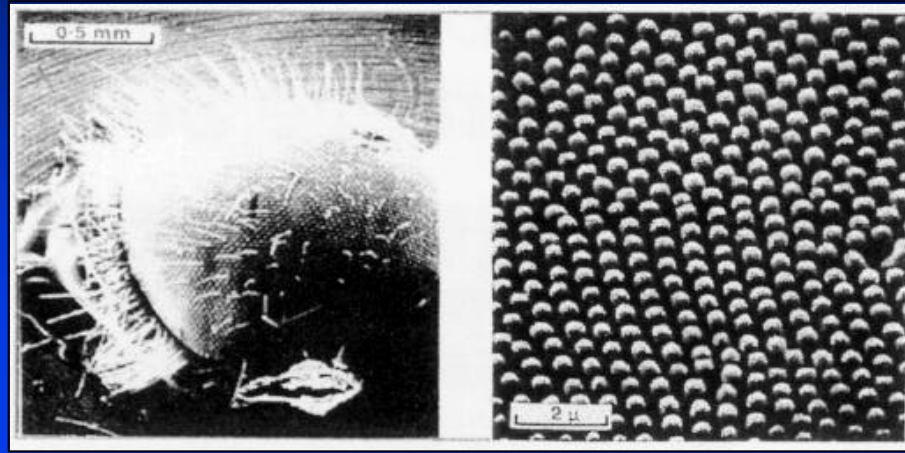
Wide-Band Anti-Reflection Coating



- Low deposition temperature process ideal for plastic substrates.
- Provides substantial improvement in the efficiency of projection, display and imaging systems.
- Absolute reflectance of less than 1% from 450-650nm.
- Average reflectance of less than 0.75% from 450-650nm.
- Withstands humidity, adhesion and moderate abrasion testing per Mil-M-13508.
- Withstands 10 cycles between +60°C at 90% relative humidity and -20°C at 10% relative humidity within a 12 hour period without evidence of flaking, peeling, cracking or blistering.

Moth Eye

Antireflective Microstructure™



- It has been noted that the eyes of nocturnal insects such as the moth reflect little or no light
- No glare or glint regardless of angle of incidence or wavelength
- Moth cornea comprised of conical array, height of 200nm and grid spacing of 200 nm

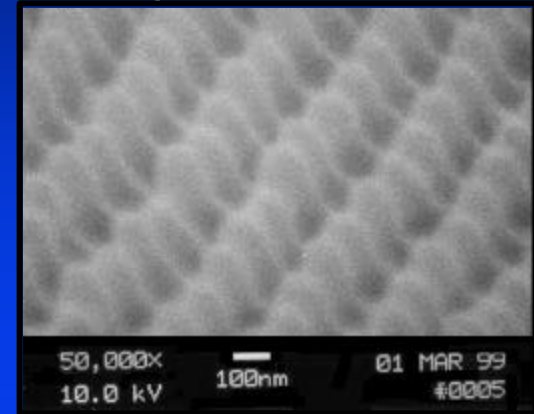
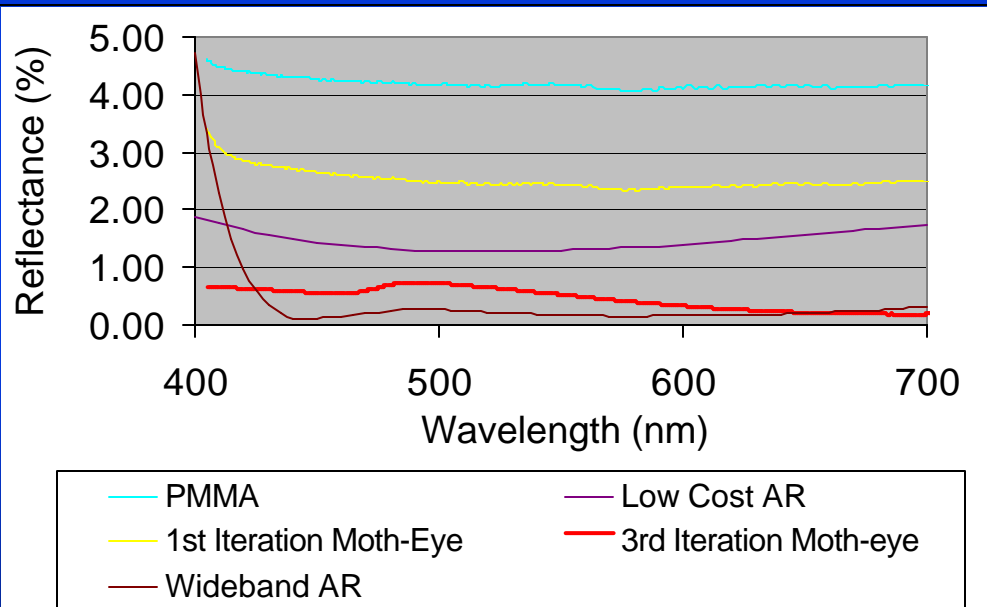
Sample Results:

Moth-eye Antireflective Microstructure™

Visible Spectrum Application

TG 30/25 Moth Eye in Polymer
(4th generation replicate of Moth-eye master)

Single Surface % Reflectance vs. Wavelength



300nm period
250nm depth

- Alternative to anti-reflective coating
- Achieve AR w/microstructure
- Engineered performance optimized for wavelength and incidence angle
- Advantages in comparison to thin film coatings
 - Durability
 - Cleanability
 - Value

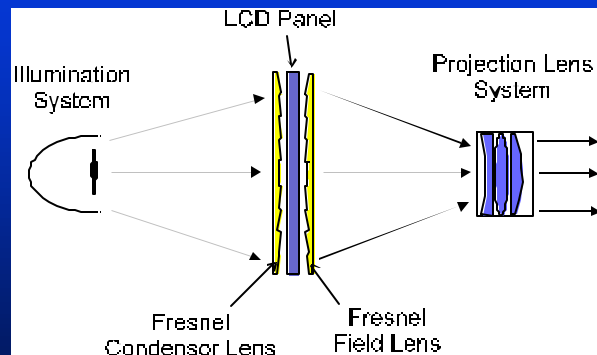
Sample Results:

Moth Eye Antireflective Microstructure™

Performance Improvements in LCD Projector

Test #1, Sample 4					
No Treatments			Field Sum	754	
202		185	Axis	261	
	261		Field/Axis		
190		177	Ratio	72.2%	

On Screen Light Measurements as per
ANSI IT7.228-1997 and
ANSI IT7.204-1991



Test #	Lens Treatments		Avg		Field
	Plano Side	Facet Side	Field Sum	Avg Axis	Axis Ratio
1	None	None	753.8	261.3	72.1%
2	ME	None	790.7	275.2	71.8%
3	ME	AR	812.8	284.6	71.4%
4	AR	AR	806.6	283.0	71.3%

LCD Projector Application

Projection Lenses System

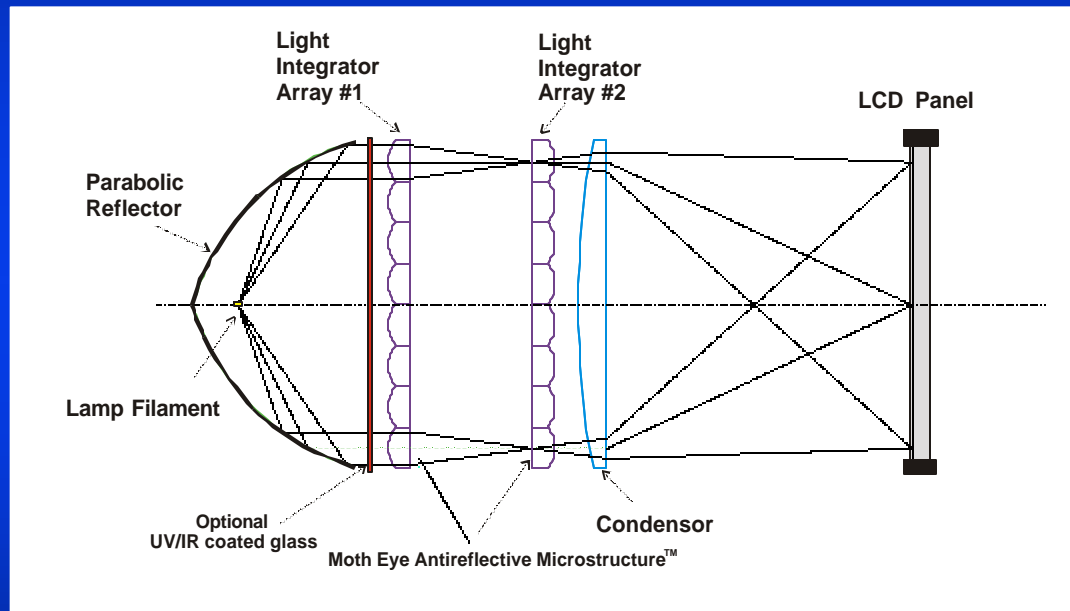


Single panel ACS ultra-portable projector
"Scout" courtesy of Lightware



AR Coated Fresnel Lens
in Projection Lens System

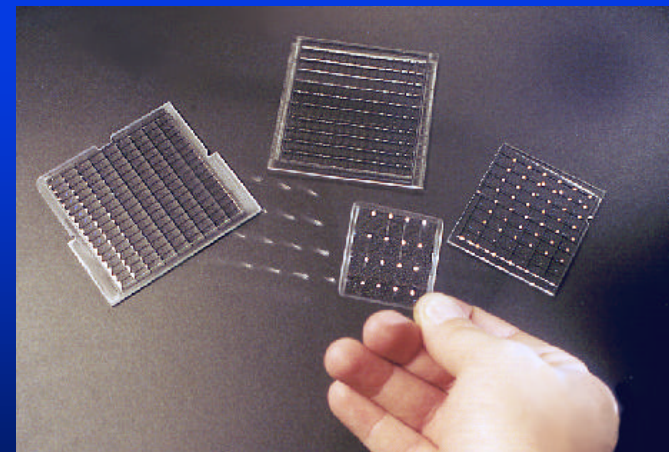
LCD Lens Arrays and Light Integrators



Schematic of Light Source for LED Projection System



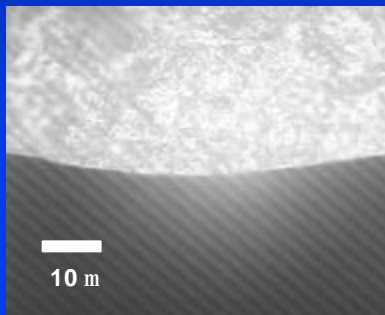
Microlens Arrays



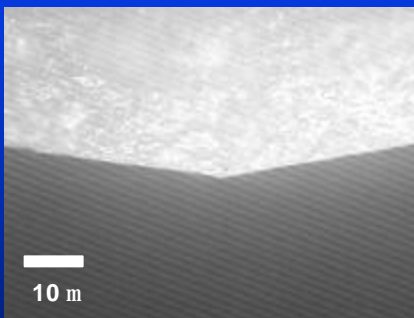
Light Integrators

High Fidelity Replication

Cross sectional photomicrograph of lenslet intersect

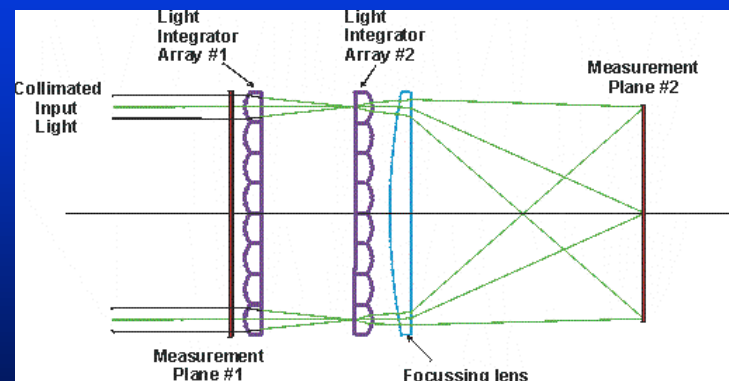


Glass array



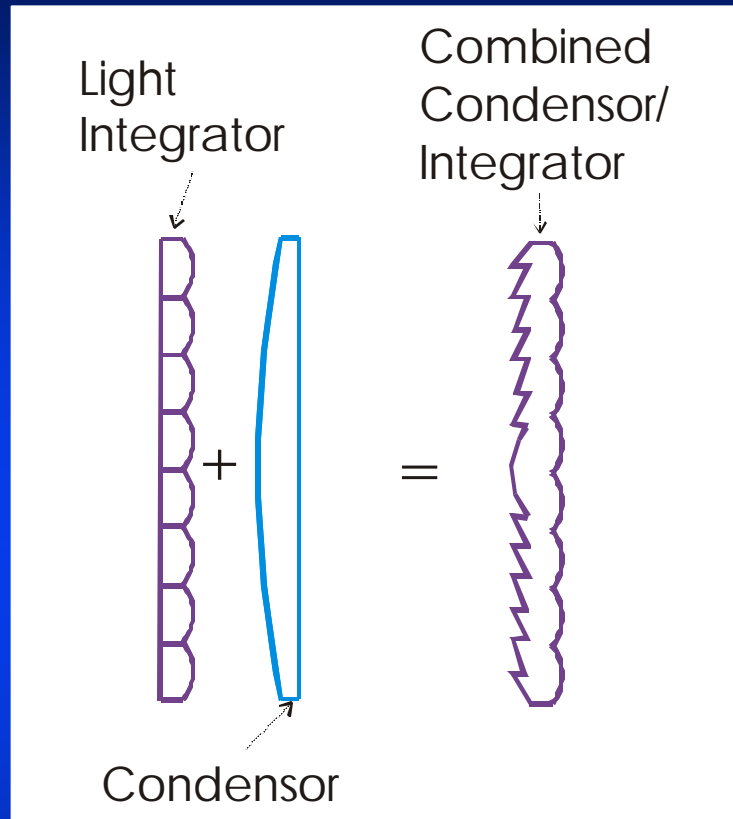
Plastic array

- Better replication at lenslet junctures
- Better Uniformity
 - Glass: $2\sigma = \pm 14.9\%$
 - Acrylic: $2\sigma = \pm 10.0\%$ of mean
 - PC: $2\sigma = \pm 8.9\%$.
- Better Transmission than Glass
 - 4% better in PC
 - 5% better in Acrylic



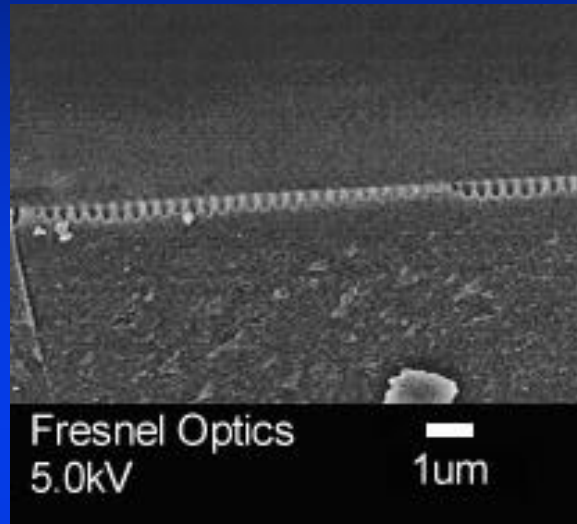
Transmission Test

Hybridization of Components



- Combine functionality of multiple elements in single component
- Piece Part Reduction Possible

3D MothEye

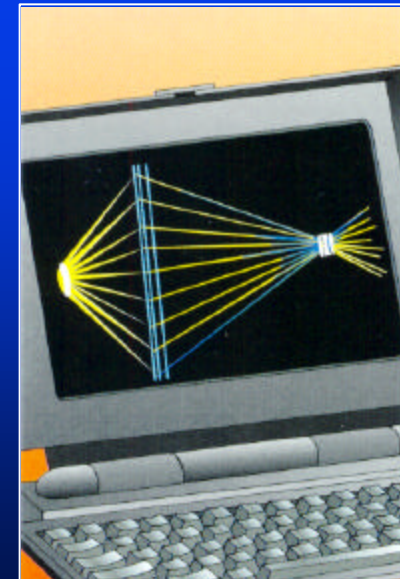
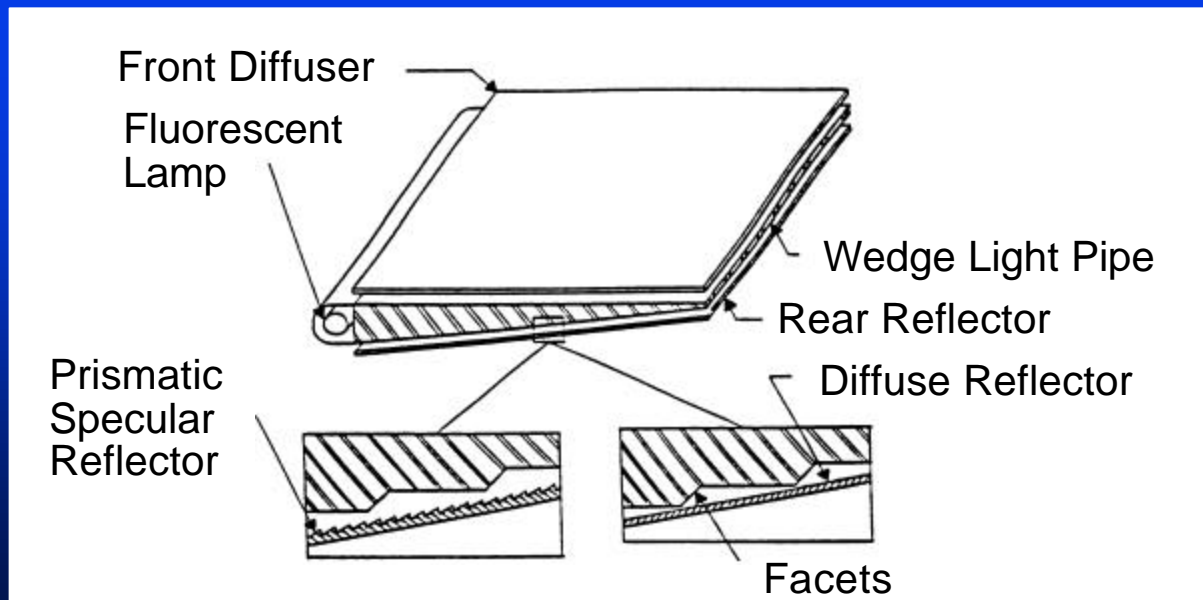
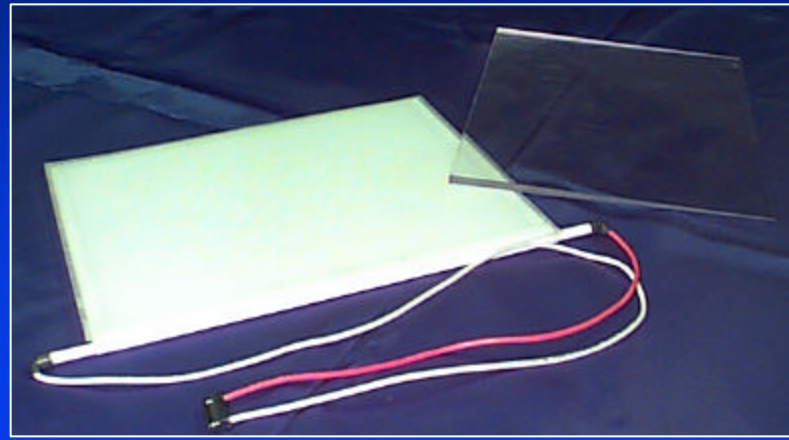


- Patterning moth-eye on 3D surfaces possible
- Reduced to practice on light integrator

High Temperature Materials

- **Optical Polymers (Cyclo-olefins incl. Arton, Zeonex, and Topas)**
- **Proprietary Cast Polymer on Glass Substrate**
- **Advantages**
 - Higher operating temperatures (up to 150° C)
 - Lower Moisture Absorption
- **Disadvantages of the Cyclo-olefins**
 - Cost
 - Slightly yellow
 - Brittle
- **Manufacturing Scale-up of Polymer on Glass required**

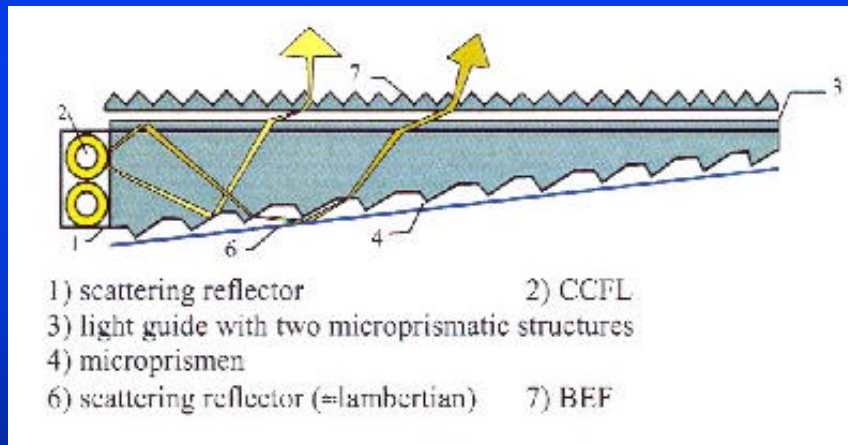
Backlit Displays



Bosch Automotive Display Project

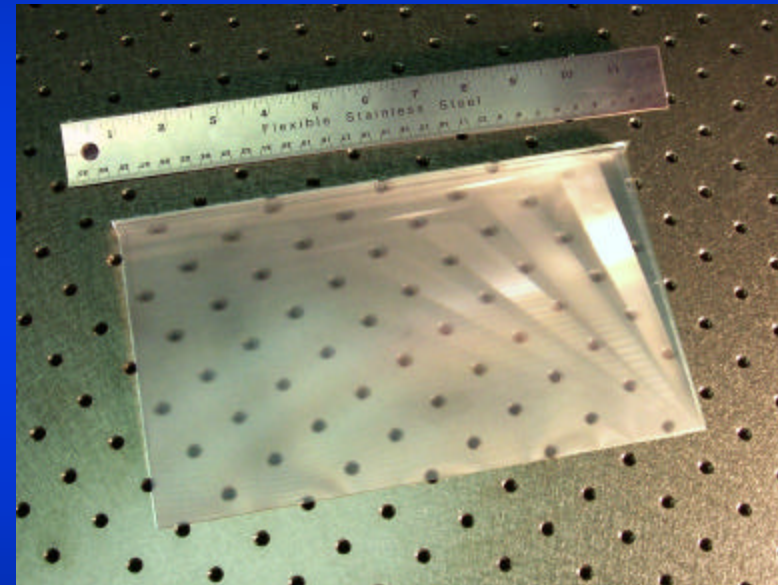
Project Goals

- Daylight Readable System
- Eliminate one sheet of BEF



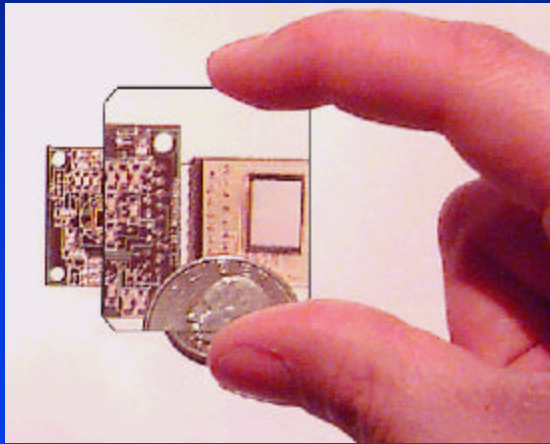
Schematic

Note: Output face of light guide has 90 degree Prism perpendicular to Bulb



Photograph of Wedge Light Guide

Microstructured Optics for Microdisplay Applications



**Fine
Pitched
Fresnel
Objective
Lens**

**Cellular
Videophone
Application**



(photograph courtesy of inViso Inc.)

- **Applications Include**

- lightweight thin objective lenses
 - **Very high ambient light rejection**
- novel front-light or back-light architectures
- one-piece, collimating diffusers
- very small optics (microlens arrays, gratings, etc.)
- **Optical coatings (antireflective, reflective, etc.) possible**
- **Low stress/low birefringence possible for polarization sensitive application**

Rear Projection Screen Systems



Mission Control



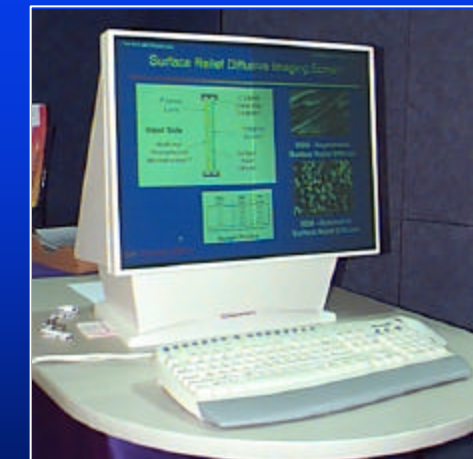
Large Fresnel Lenses



Cubes and Video Walls

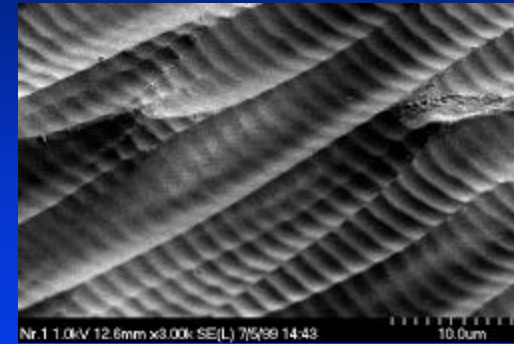
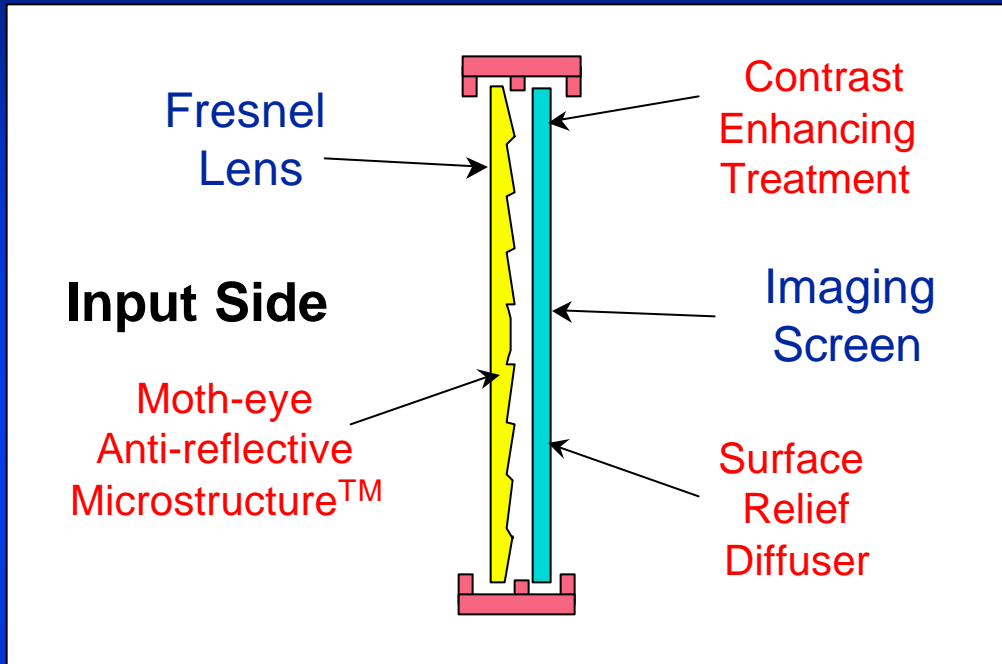


Next Generation Digital RPTV

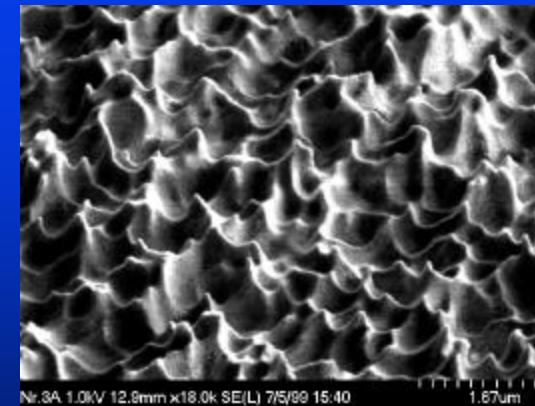


Rear Projection Monitors

Surface Relief Diffusive Imaging Screen



SEM - Asymmetric Surface Relief Diffuser

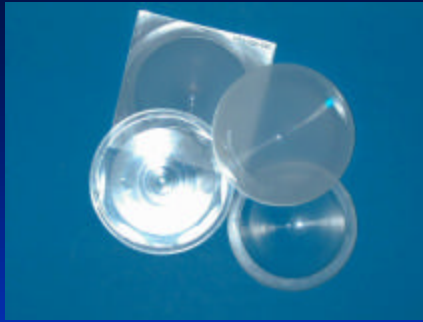


SEM - Symmetric Surface Relief Diffuser

Peak Gain*	Half Gain	Half Gain
2.1	±48°	±26°
3.2	±38°	±20°
5.9	±35°	±10°
23.0	±8.5°	±8.5°

*Gain before addition of any contrast enhancing tints or filters

Sample Profiles



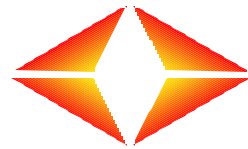
Fresnel Lenses



Imaging Lens for Machine Vision



Mirrors for passive infrared sensors



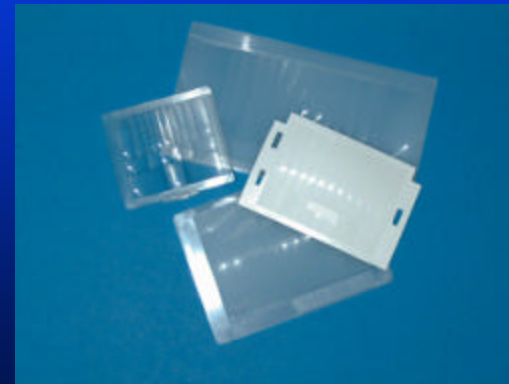
Reflexite
Instrumentation Optics

Products and Markets

www.instrumentation-optics.com



Cylindrical and aspheric lenses for bar code scanners and imaging systems



Fresnel lens arrays, used in passive infrared sensors

Reflexite Lighting Products

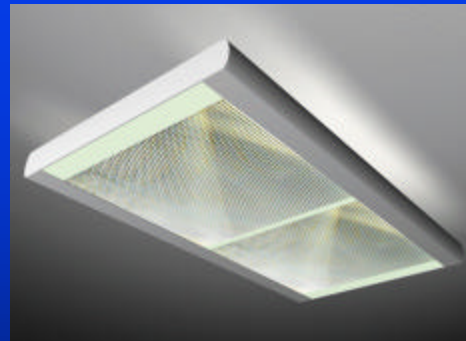
www.lighting-optics.com



Specialty Applications



**Waveguide based
luminaires**



**Direct Fluorescent
Luminaires**



(photograph courtesy of inViso Inc.)

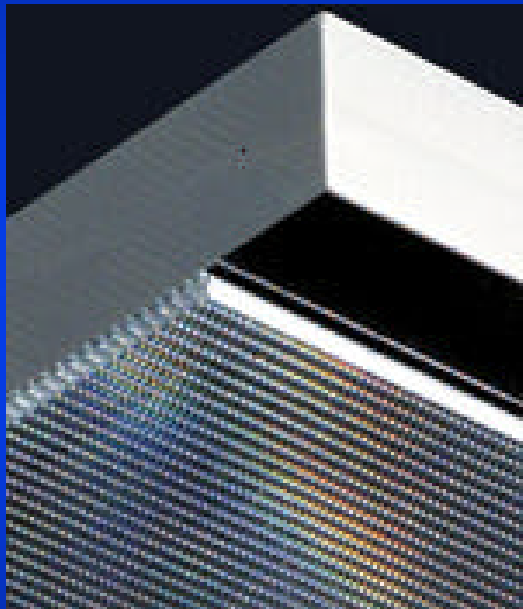
**Video Cell Phone with
RGB LED Lightguide**

LED Systems

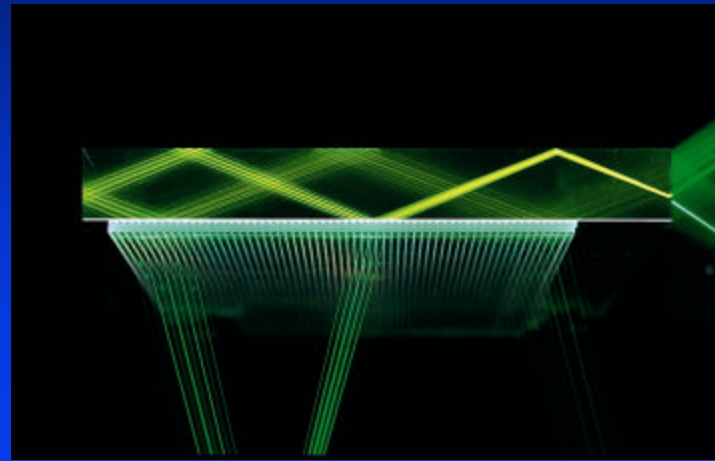
Custom LED Systems



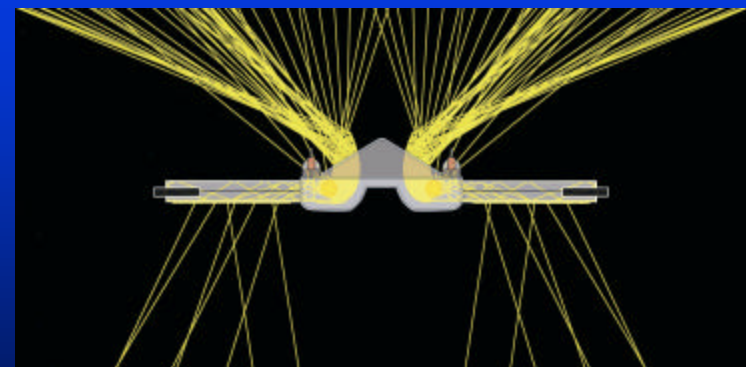
Waveguide Based Luminaires with Precision Microprisms



**Light Distributing Array (LDA)
with microprism technology**



**Path of single coherent light
ray illustrates principle of operation**



Direct and Indirect Lighting

Siteco Wave Product Family

Tasklight



Wall Washer

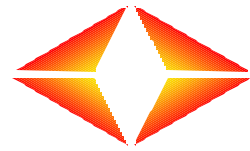


Wave design by Michael English

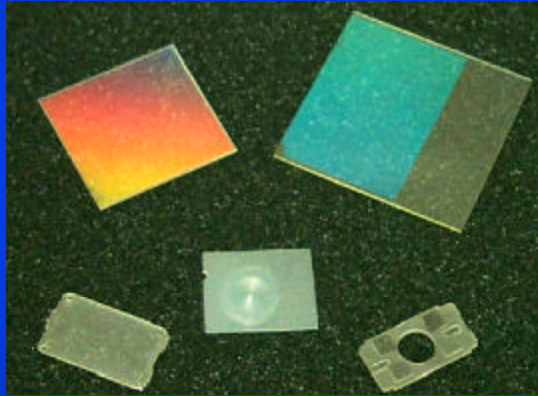


Uplight



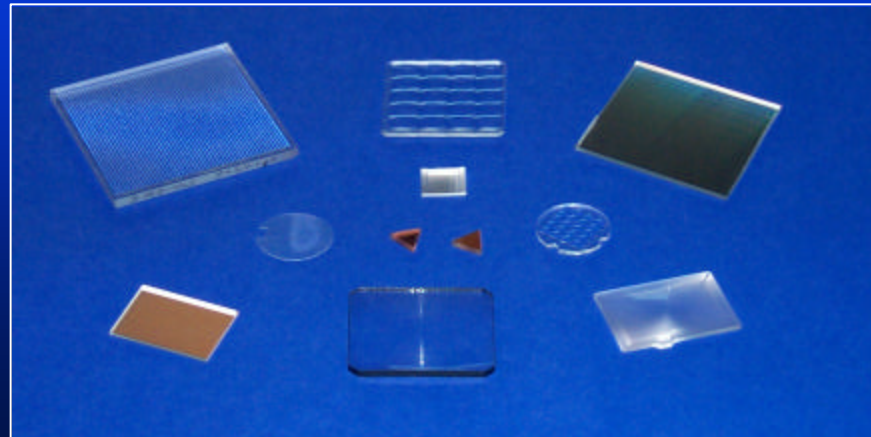


Reflexite
Telecom Optics



- **Gratings**
- **Diffractive Optical Elements (DOE's)**
- **Microlens Arrays**
- **Collimating Lenses**
- **Fresnel Lenses**

www.telecom-optics.com



Reflexite Telecom Optics

- Mastering and Microreplication Processes:
 - Linear Ruling (In-house Ruling Engine)
 - Holographic Lithography
 - Flycutting
 - Diamond Point Turning
 - Plating
 - Electroforming
- Polymer replication:
 - Volumes from one-of-a-kind to millions of units or square feet per year
 - High fidelity replication
- Precision assembly and electro-optical systems integration
- Materials
 - PMMA (Acrylic)
 - PC (Polycarbonate)
 - Cyclo-olefins (Topaz, Zeonex, Arton)
 - Proprietary polymers
 - **Polymers on glass substrates available for temperature stability**