Optics – Friends and Foes

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Edmund Optics® - a leading, global provider of optical technology solutions serving a variety of markets since 1942

3

Generations Devoted to Optics

Norman Edmund (1916 – 2012)
Robert Edmund
Mari Edmund

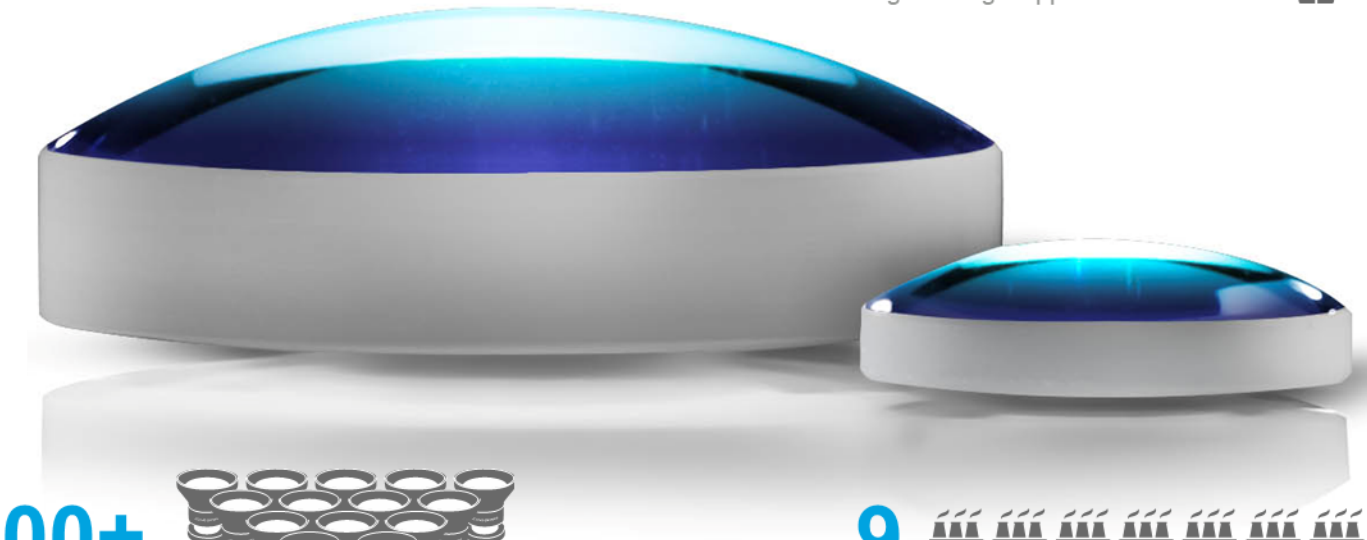
1,300+

Employees

Across **19** Global Locations
Engineering Support Available 24/7

24/7

Technical Support



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Distribution Centers

34,000+

Optical Components

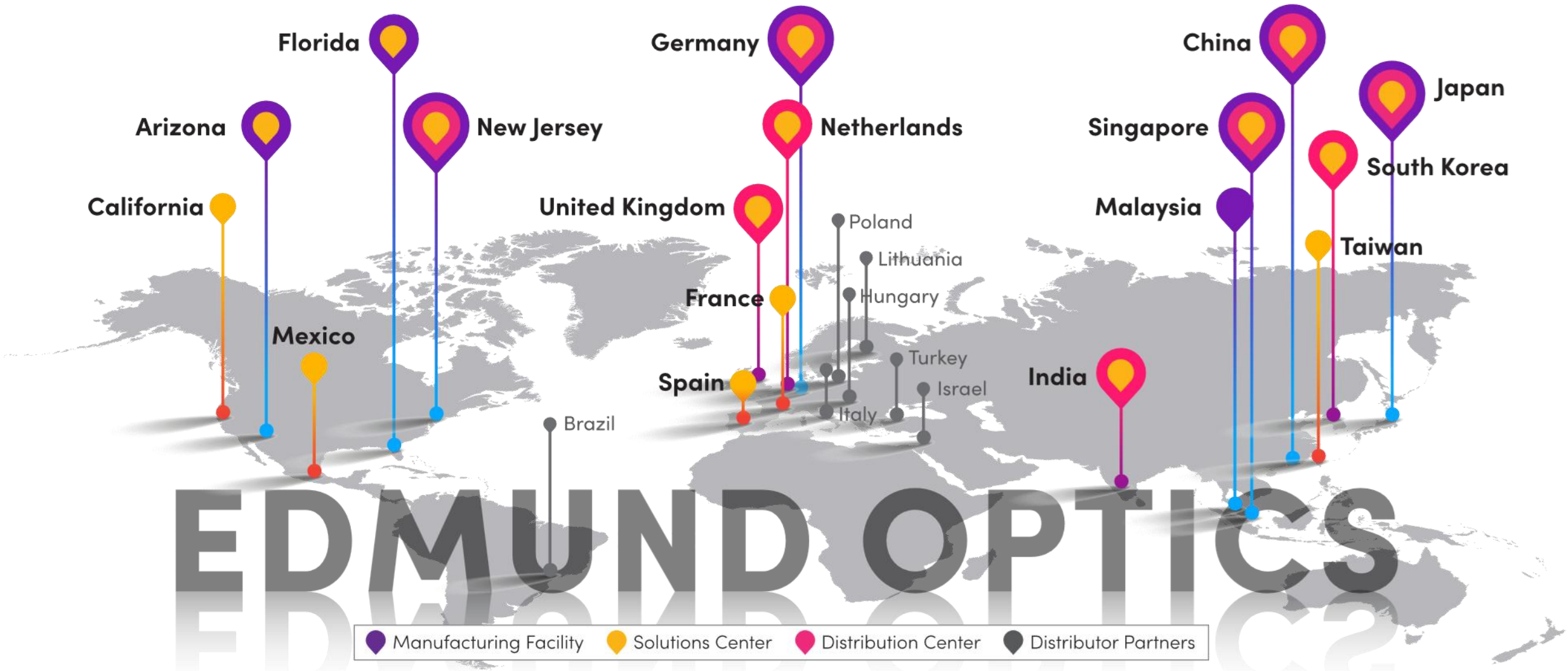
Nearly **3 Million** Items In Stock, Ready to Ship
from the Industry's Most Trusted Brands

9

Manufacturing Facilities

Over **2.5 Million** Optical Components Made Each Year
Over **175 Thousand** Optical Assemblies Made Each Year

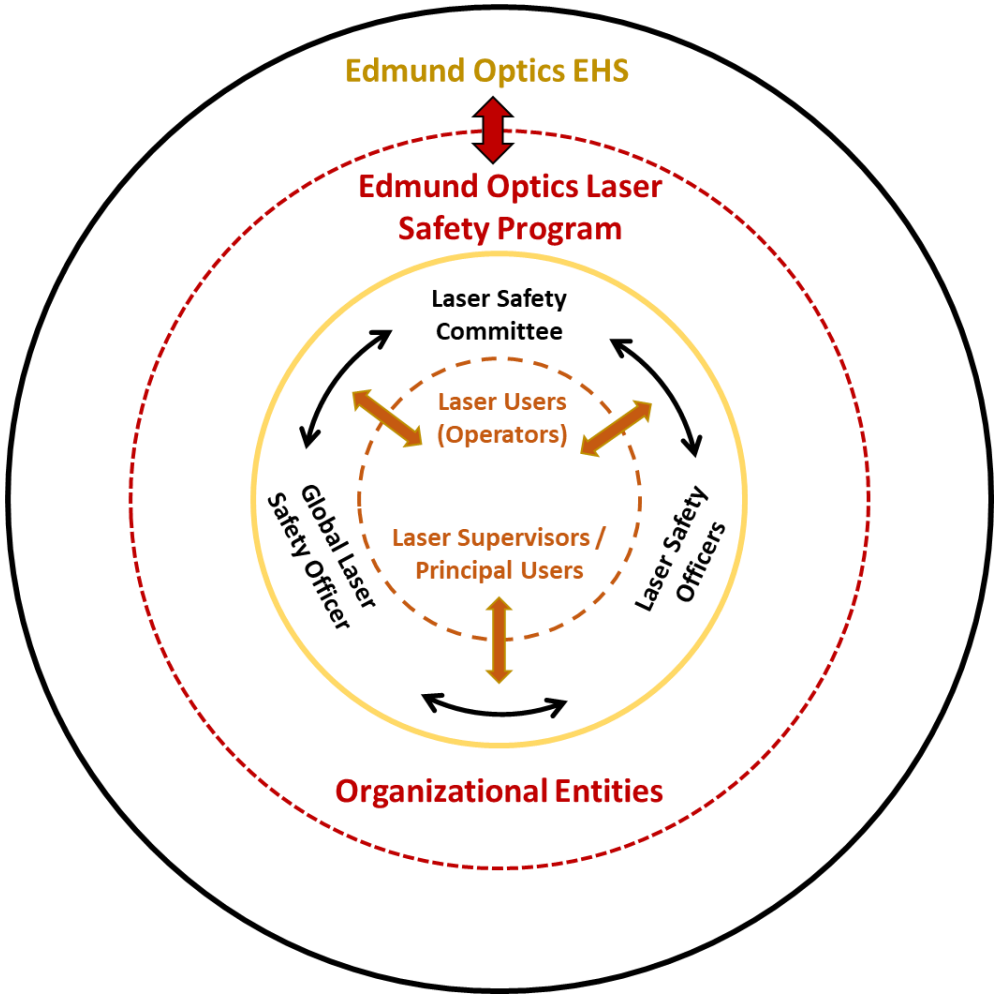
Edmund Optics – Global Footprint



About Presenter

- MSc in Physics, York University, Toronto, Canada (https://www.collectionscanada.gc.ca/obj/s4/f2/dsk2/tape15/PQDD_0007/MQ33515.pdf)
- Scientific Roles:
  - Project Scientist, Centre for Research in Earth and Space Technology
  - Test Scientist, Optech, Inc. (Teledyne Geospatial)
- Management Roles:
  - Manager and Test and Integration Specialist, Optech, Inc. (Teledyne Geospatial)
  - Laser Test Manager, VLOC – Subsidiary of II-VI, Inc. (Coherent)
- Engineering Roles:
  - Laser Test Engineer, VLOC – Subsidiary of II-VI, Inc. (Coherent)
  - Sr. Manufacturing Engineer, CVI Laser Optics
  - Sr. Project, Sr. Laser, and Principal Applications Engineer, all Edmund Optics, 2016 – Present
- Passive and Active Characterization of Optics (Glass and Crystalline Substrates*), Component-, Assembly-, Subsystem-, and System-Evaluation

Edmund Optics Laser Safety Program



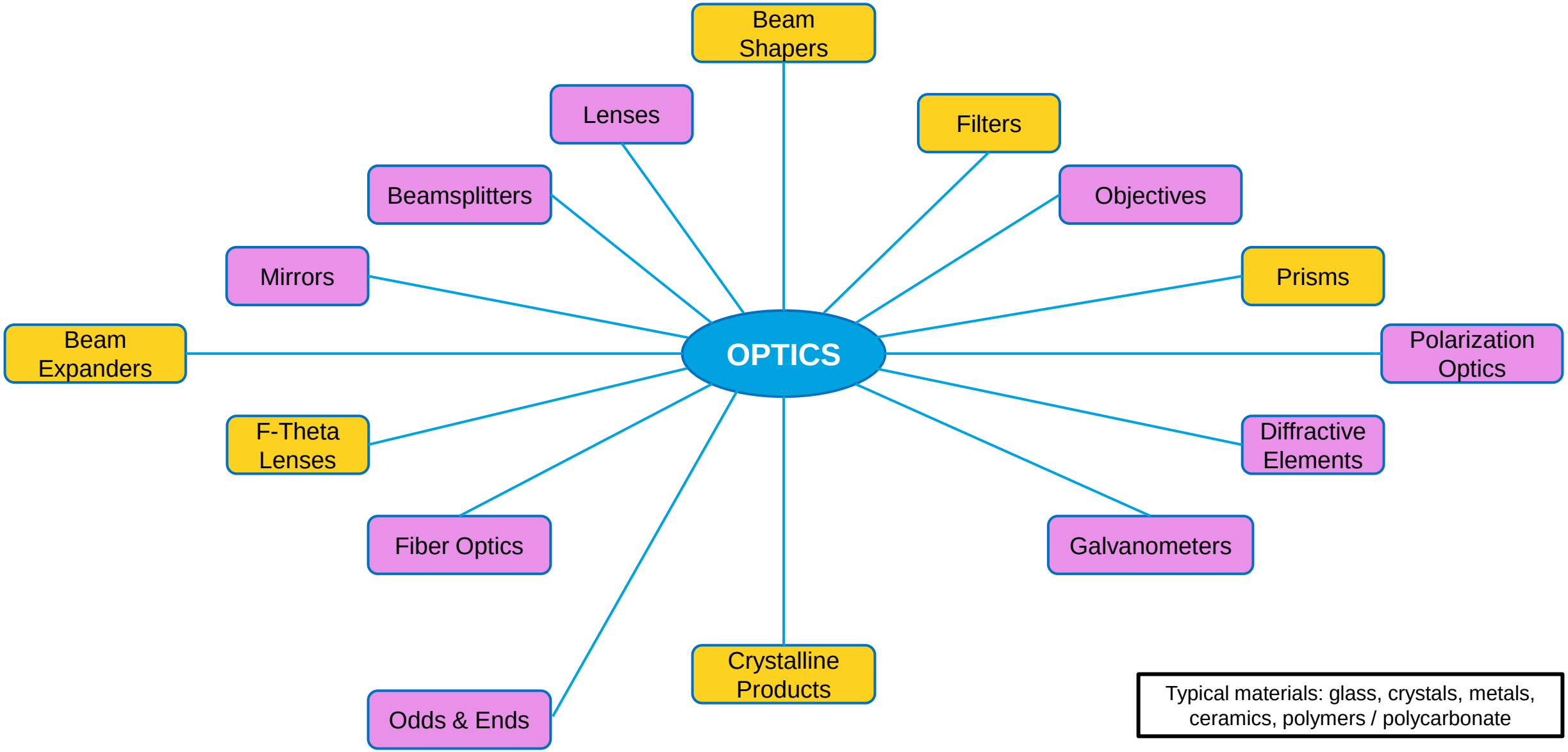
- Established at the Corporate level in 2019
- Worldwide-coverage includes 8 laser safety jurisdictions in North America (3), Europe (2) and Asia (3)
- The Program is governed by the Laser Safety Committee consisting of the LSOs and Management representatives / sponsors

Optics vs. Optics

optics* - plural in form but usually singular in construction: a science that deals with the genesis and propagation of light, the changes that it undergoes and produces, and other phenomena closely associated with it

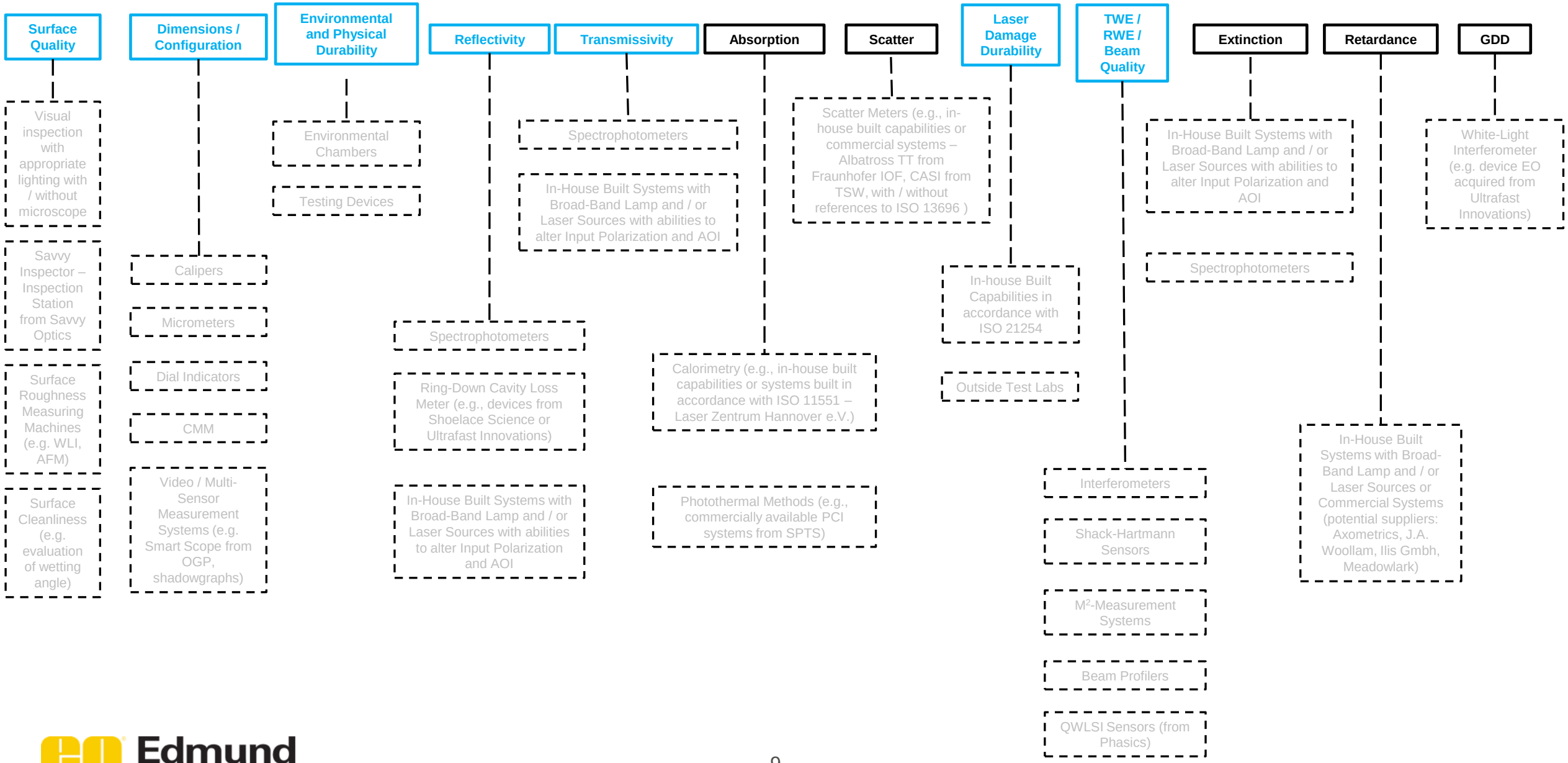
optic* - noun - any of the elements (such as lenses, mirrors, or light guides) of an optical instrument or system → usually used in plural

Commonly-Found in Laser Laboratories and/or Laser Processing Facilities

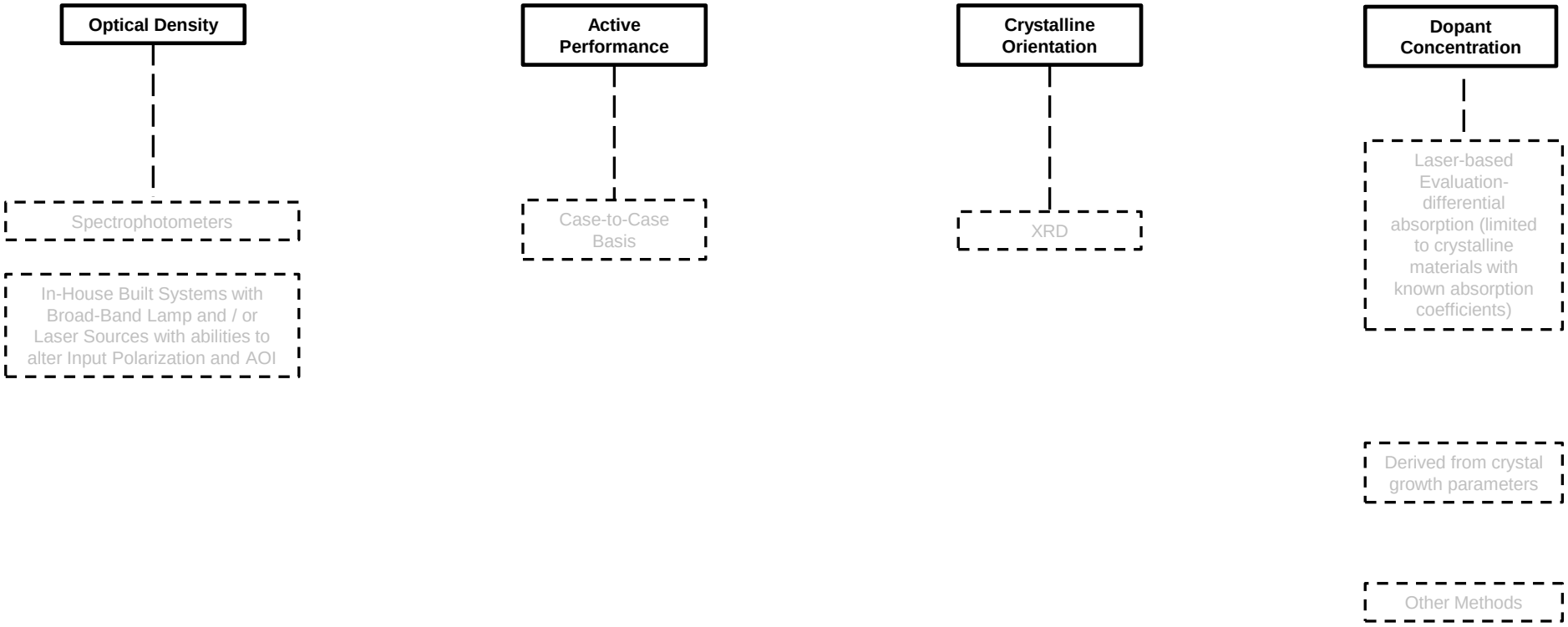


Typical materials: glass, crystals, metals, ceramics, polymers / polycarbonate

Typical Characteristics and More



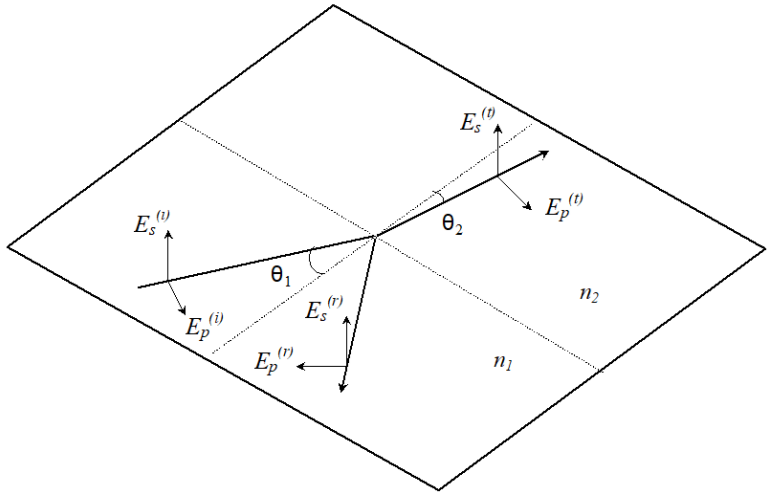
Typical Characteristics and More



Uncoated vs. Coated

Optical coatings are used for altering characteristics of uncoated optics, e.g., improving transmittance and reflectance, tailoring response to different polarization inputs, suppressing broadening of impinging ultrashort pulses (picosecond, femtosecond and attosecond pulse regimes) and handling their high repetition rates and high peak powers.

Fresnel equations are used to calculate amplitudes of transmitted and reflected light at the boundary between two different media



From air to FS with 1064.1 nm input at 0° AOI

Input Data						
Index of Refraction n_1	1.00000	Index of Refraction n_2	1.44963	Incident Angle θ_1	Deg	Min	Sec
					0.00	1.00	0.00

Output Data					
Output Angle θ_2	Deg	Min	Sec	p-pol Power Reflectivity [%] $R_p = [\tan^2(\theta_1 - \theta_2)]/[\tan^2(\theta_1 + \theta_2)]$	s-pol Power Reflectivity [%] $R_s = [\sin^2(\theta_1 - \theta_2)]/[\sin^2(\theta_1 + \theta_2)]$
	0.00	0.00	41.39	3.369	3.369

From air to FS with 1064.1 nm input at 30° AOI

Input Data						
Index of Refraction n_1	1.00000	Index of Refraction n_2	1.44963	Incident Angle θ_1	Deg	Min	Sec
					30.00	0.00	0.00

Output Data					
Output Angle θ_2	Deg	Min	Sec	p-pol Power Reflectivity [%] $R_p = [\tan^2(\theta_1 - \theta_2)]/[\tan^2(\theta_1 + \theta_2)]$	s-pol Power Reflectivity [%] $R_s = [\sin^2(\theta_1 - \theta_2)]/[\sin^2(\theta_1 + \theta_2)]$
	20.00	10.00	35.92	2.085	4.935

Uncoated vs. Coated

Fresnel Losses [%] at Wavelength λ [nm]

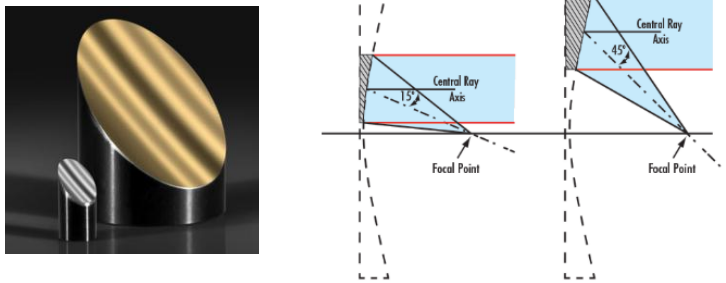
Substrate	Density [g/cm³]	532						632.8						1064.1					
		n	n_o	n_e	n_x	n_y	n_z	n	n_o	n_e	n_x	n_y	n_z	n	n_o	n_e	n_x	n_y	n_z
Nd:YAG	4.55	8.770						8.643						8.422					
$Nd:YVO_4$	4.22		11.373	14.805					11.005	14.287					10.476	13.548			
Quartz	2.65		4.611	4.739					4.555	4.683					4.443	4.581			
N-BK7	2.51	4.251						4.194						4.085					
FS	2.20	3.505						3.460						3.369					
SF11	4.74	8.087						7.852						7.501					
N-SF11	3.22	8.088						7.852						7.494					
SF6	5.18	8.392						8.146						7.781					
N-SF6	3.37	8.392						8.146						7.775					
Nd:YLF	3.97		3.440	3.724					3.407	3.688					3.349	3.623			
Sapphire & Ruby	3.98		7.752	7.634					7.668	7.552					7.503	7.389			
KTP	3.03				7.850	8.006	9.474				7.621	7.755	9.123				7.266	7.377	8.604
CaF_2	3.18	3.196						3.166						3.113					
N-SF10	3.05	7.247						7.052						6.751					
SF10	4.28	7.247						7.051						6.752					
$LiNbO_3$	4.65		15.853	14.562					15.321	14.102					14.532	13.416			

Mirrors

- Typical substrates: glass and metal with/without appropriate HR thin films
- Can use mirror functionality to introduce different application (e.g., reflective beam expander)
- Mirror surface can have different geometries (flat and curved figures)
- Mirror side can act as highly reflective surface for one wavelength/wavelength band and transmissive at others
- Used to reflect light with desired outcome (curved mirrors focus or enlarge input beams)

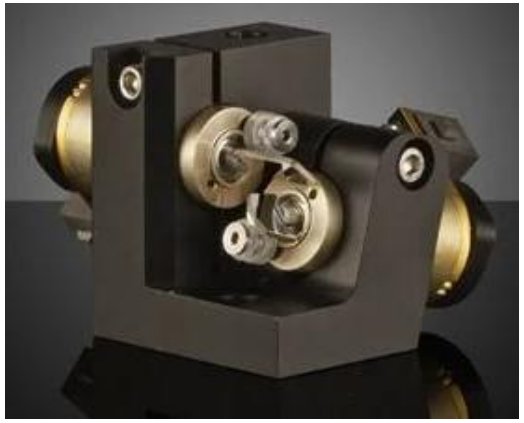
<u>Be aware of:</u>

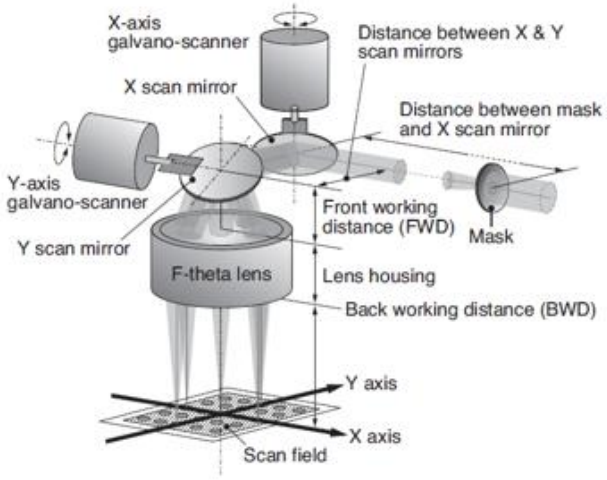
- Unwanted beam leakage through mirrors
- Mirrors that focus beams (increased intensities in focal planes) and OAPs (**O**ff-**A**xis **P**arabolic) Mirror**s**



- Size of the mirror and its clear aperture vs. size of the input beam
- Mounting (with its degrees of freedom) and aiming of the beam in the desired direction / zone
- Environmental and laser damage durability of the employed mirror (watch for decaying performance)

Galvanometers





General Concept of Hole-Drilling / Marking System with Two-Axis Scanning Head and F-θ Lens

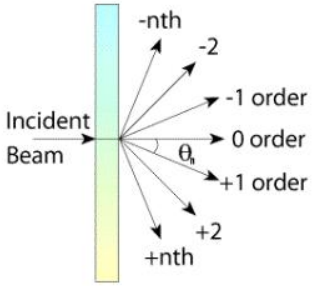
- Used in laser material processing applications, frequently in combination with beam expanders and F-theta lenses, and sometimes with beam conditioning optics like beam shapers

<u>Be aware of:</u>

- Directions of the beam projected from the second mirror in the galvanometer
- Back reflections of first and higher orders landing on surfaces of the employed optics / optical assemblies and intensities that can result in catastrophic component failure
- Choices of the mirrors employed in the galvanometer / scanning head vs. the characteristics of the input beam

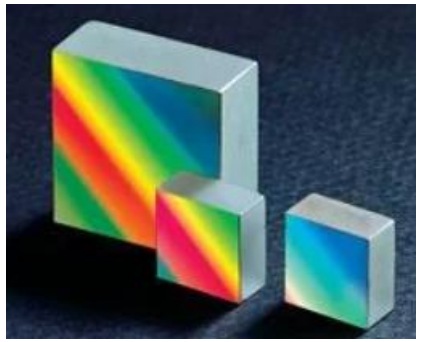
Diffractive Elements

Transmissive Gratings



- Used to disperse incident beam at specific angles
- Require special handling, cleaning (if possible at all) and storage

Reflective Gratings



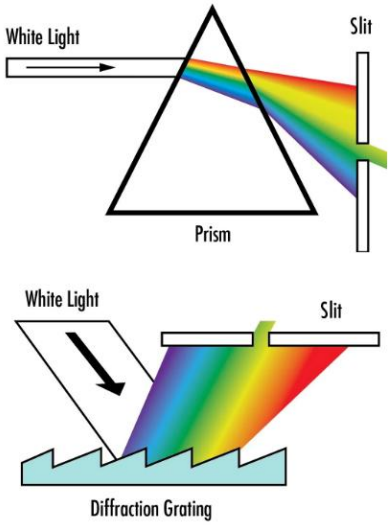


Figure 1: While dispersion prisms separate wavelengths through refraction (top), diffraction gratings instead separate wavelengths through diffraction because of their surface structure (bottom).

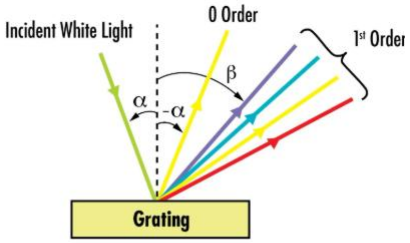
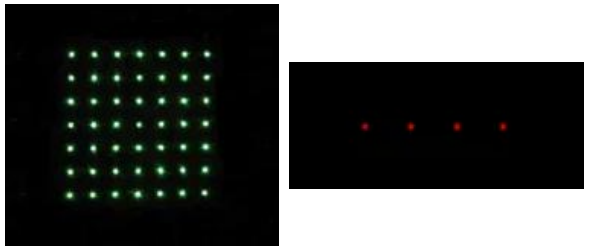
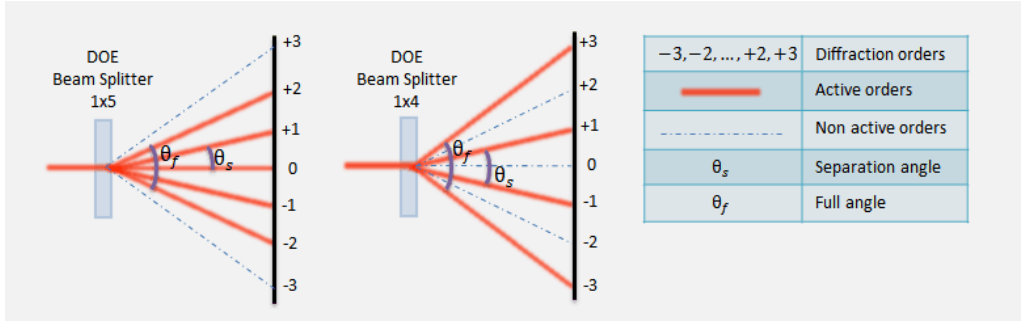


Figure 2: While some light reflects directly off of this grating as "0 order" diffraction, other parts of the incident light are diffracted into 1st order angles based on wavelength. Smaller amounts of the incident light will also be separated into larger 2nd and 3rd orders at higher angles.

Diffractive Beam Splitters



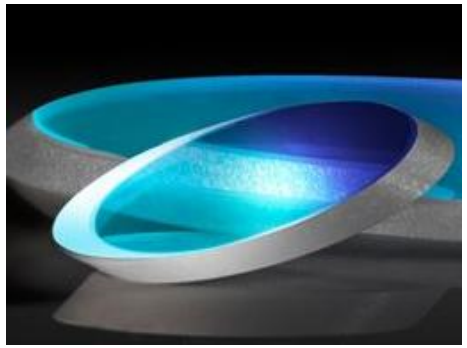


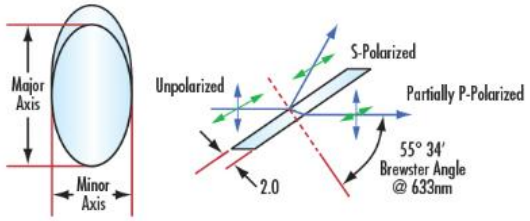
Be aware of:

- Multiple beams of varying intensities transmitting / reflecting
- Unwanted / unexpected beam directions
- Uneven spacing of beam of different orders

Beamsplitters and Polarization Optics

Brewster Window





- Reduce loss of p-polarized input
- Uncoated and used at the Brewster angle at the application wavelength
- Its performance (allowing higher transmittance for p-polarization and higher reflectance for s-polarization) can be improved with appropriate coatings on sides 1 and 2; in this case the optic is better known as thin film plate polarizer
- Can be used in combination with half-wave waveplates to create continually adjustable attenuator
- Falls into the category of beamsplitters

Cube Beamsplitters

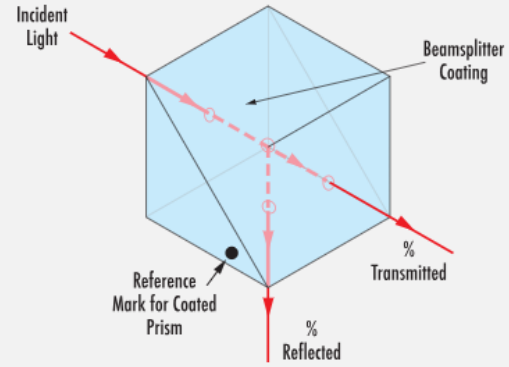


Figure 1: *Cube Beamsplitter*

Cube beamsplitters are constructed using two typically right angle prisms (Figure 1). The hypotenuse surface of one prism is coated, and the two prisms are cemented together so that they form a cubic shape. To avoid damaging the cement, it is recommended that the light be transmitted into the coated prism, which often features a reference mark on the ground surface.

Plate Beamsplitters

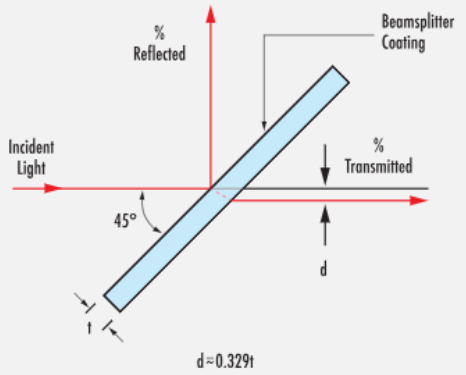


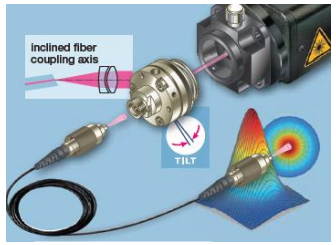
Figure 2: *Plate Beamsplitter*

Plate beamsplitters consist of a thin, flat glass plate that has been coated on the first surface of the substrate (Figure 2). Most plate beamsplitters feature an anti-reflection coating on the second surface to remove unwanted Fresnel reflections. Plate beamsplitters are often designed for a 45° AOI. For substrates with a 1.5 index of refraction and a 45° AOI, beam shift distance (d) can be approximated using the equation in Figure 2.

<u>Be aware of:</u>

- Reflected and transmitted beams and their intensities
- Changes in beam directions and beam line offsets in case of plate beamsplitters

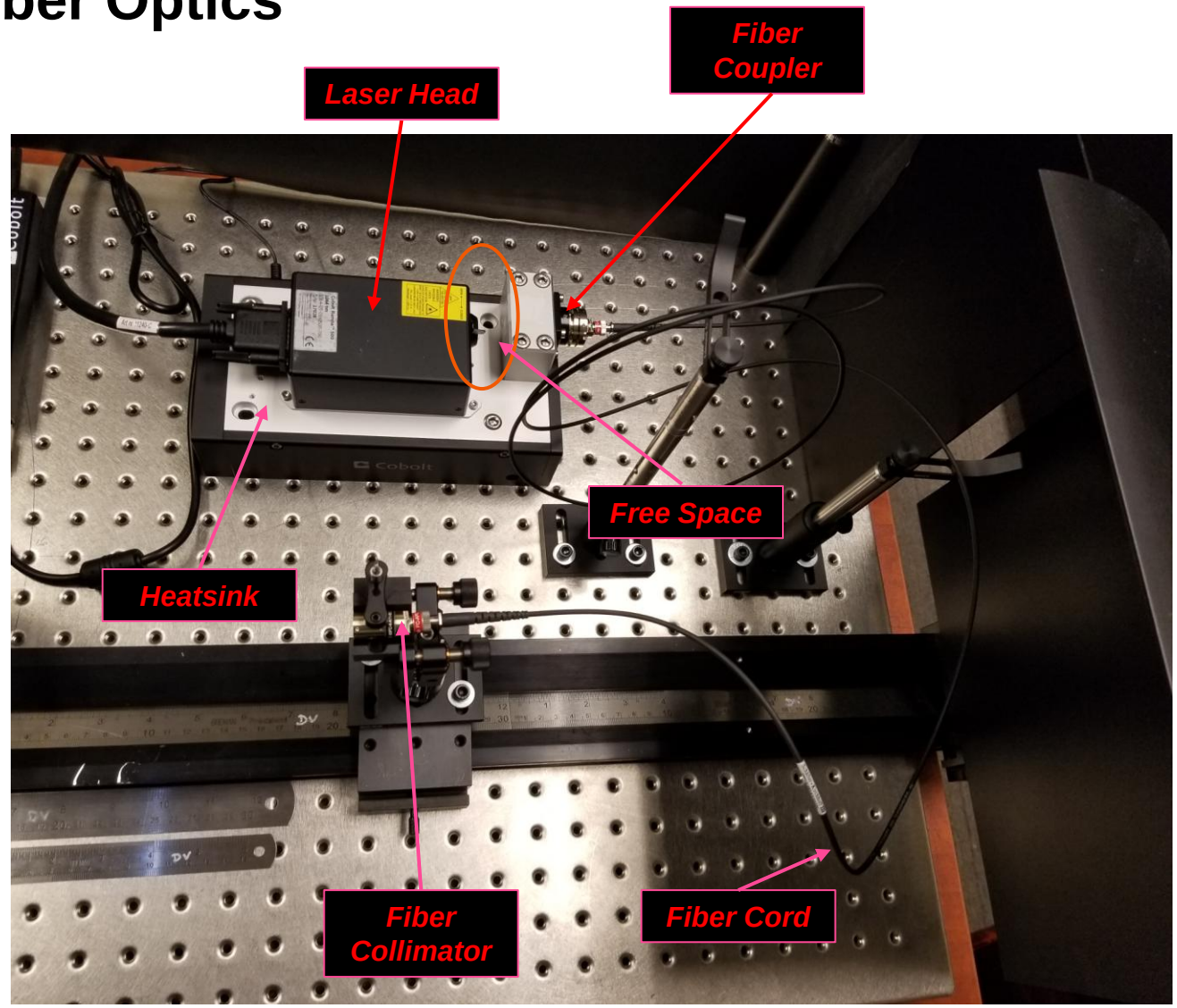
Fiber Optics



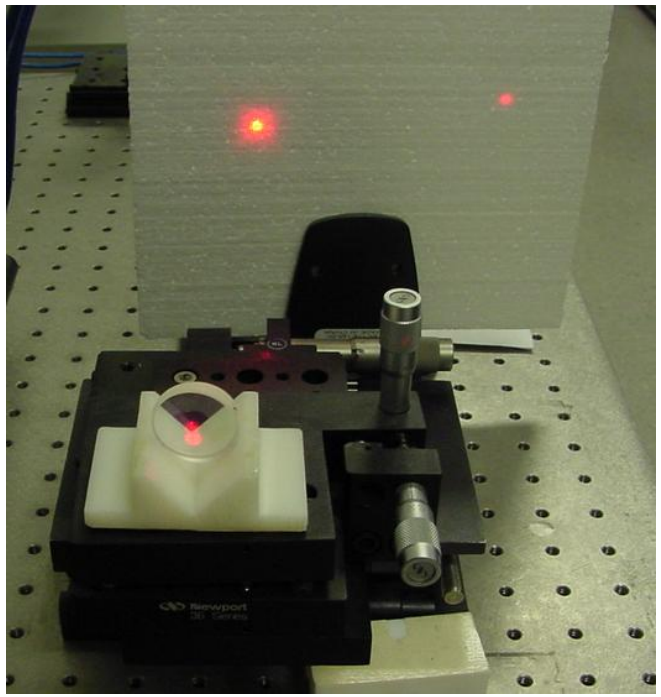
- Convenience of delivering the beam away from the laser source while maintaining the beam quality
- Delivering the beam with larger diameter and smaller divergence than the intrinsic laser beam
- Variety of accessories for tailoring the output beam
- Possibility of having the fiber coupler being aligned and directly attached to the laser head

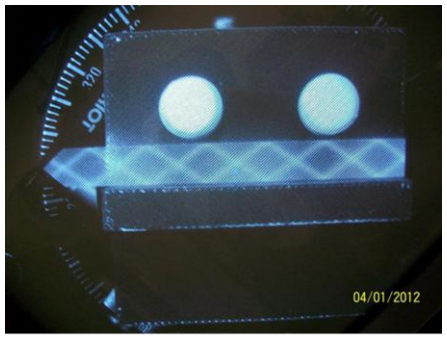
<u>Be aware of:</u>

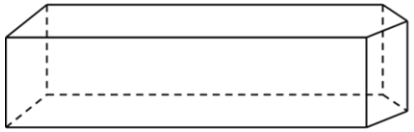
- Coupling of the free space beam into the fiber coupler / cord
- Power handling capabilities of the chosen fiber cords
- Back reflections being coupled into the collimator and then all the way to the laser source

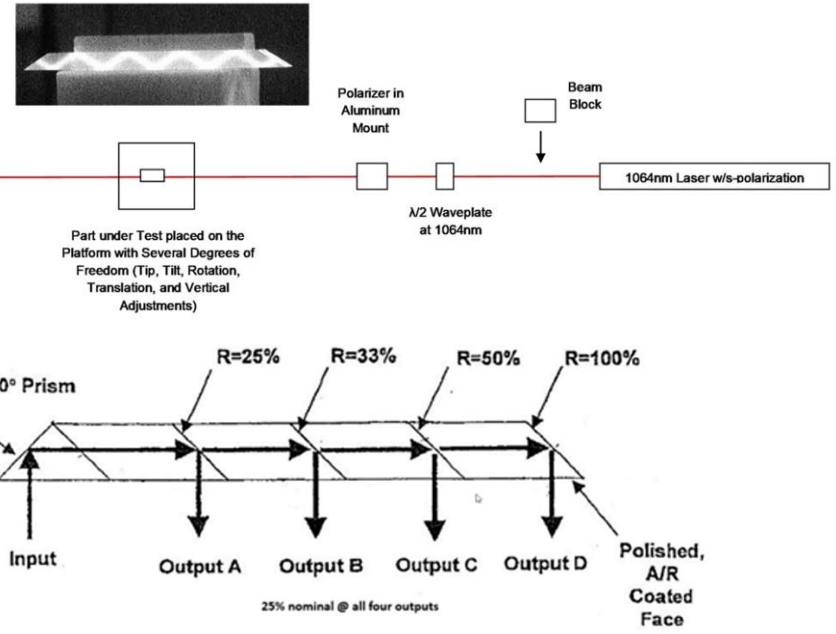


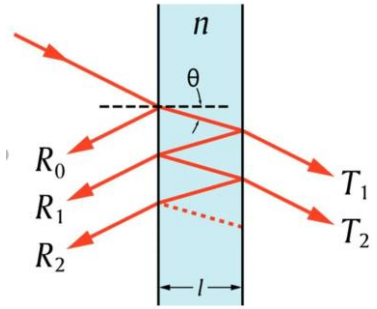
Be Aware, Be Very Aware –
Follow the Beam Paths and Resultant Back Reflections and Multiple Reflections









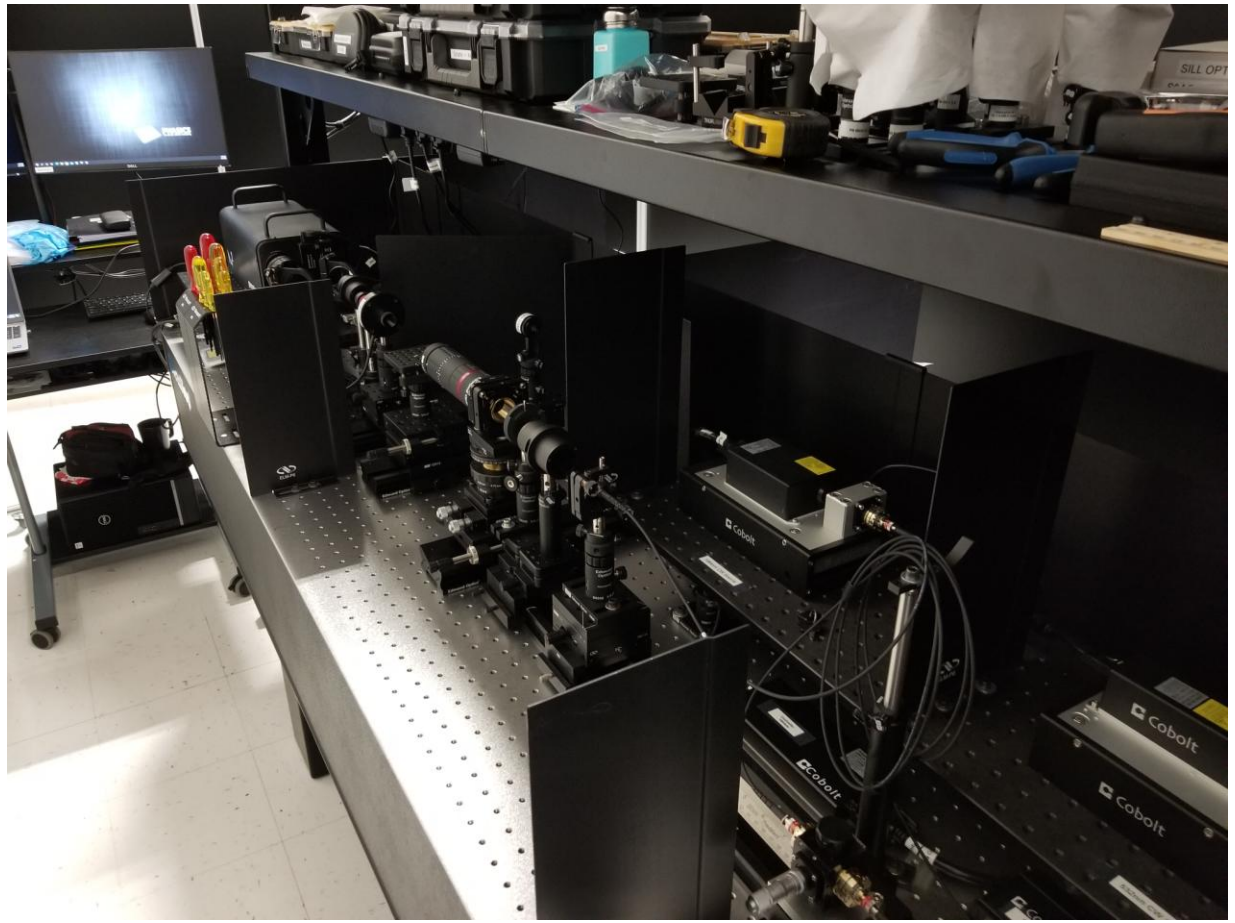


Reflections are not always hazardous but you better know where they land, what their intensities are (at least estimate) and whether they are intentional / serve the application.

Communicate and Collaborate

- Recognize responsibilities within the Laser Laboratory / Laser Operations
- Work with the respective Management / Laser Supervisors first and present the plan
- Ask as many questions as you need to develop better understanding of the personnel hierarchy and the operations
- Ask users / operators to guide you through the beam paths, employed equipment, existing measures (if they are implemented) and concerns they have
- Learn, seek suggestions from those who are directly involved in operations, capture current state and work together on the future state what they and you would like to see
- Be the one who wants to protect and protects the personnel and the property of the organization through laser safety solutions that would not hamper work / operations and who will be open to suggestions for the improvement of the measures and the laser safety program
- Communicate, communicate, communicate and do not stop improving

Final Remarks



Laser laboratories and production facilities that operate lasers can have a multitude of lasers with different power / energy levels, various equipment and optics employed. There is never enough caution about the use of any item in these environments. Optics are particularly vulnerable as they are directly exposed to laser radiation. They are meant to be friends but could be foes if we do not understand their characteristics and their purpose even within a seemingly simple laser test setup. Developing such understanding will help establish the most appropriate laser safety measures (engineering, administrative and PPE, as applicable) and assure that the personnel, equipment and facility are protected and laser processes well-controlled.

Thank YOU!

- **Questions?**

- Please provide feedback, via e-mail to dvelkov@edmundoptics.com or by calling 1-800-363-1992 x 6325