LU02: Optical Materials & Handling

LU02 introduces the student to some properties of the materials optics are made of, and how it affects laser beams.

As we learned earlier, index of refraction is a ratio. A ratio of the speed of light in a vacuum to the speed of light in a different medium, and the ratio of the wavelengths in and out of the medium.

Index of refraction is wavelength dependent. As the wavelength of light increases, the index of refraction of a give material decreases. If you ask why, look at it this way and it may make more sense. Like in physics when more energy is exerted on a situation, the more work (in our case ray bending or light speed changing…) is done. The lower wavelengths have higher photon energy and thus, do more work! That makes their index of refraction higher in all materials.

The speed of light in a vacuum is $3x10^8$ m/s. Light always slows down when inside of a medium.

Remember the "STARR" theory of light interaction (Scatter Transmit Absorb Reflect Refract). This is the case no matter what the angle the incoming or "incident" light makes with the optical surface. All of these parameters are important when considering the quality of optics. With transmissive optics like lenses, prisms, and windows, transmission must be near 100%. So that means all of the other factors must be eliminated or close to it for the optic to be of high quality.

Transmission is the ratio of output over input. This could be any measurable quantity like power, irradiance, or energy. It is a ratio so transmission is unit-less.

As photons pass through a material, some will be absorbed by the atoms or molecules in the material. This energy is lost to the transmitted beam, but converted to another form of energy, like heat. A term called Absorption Coefficient is a constant for each material and wavelength, and it indicates how much light could be absorbed over a certain distance or thickness of a material.

Absorption of light by a material happens exponentially over the thickness or distance the light travels.

Think of it as removing a percentage of light over a given distance. You lose the same percentage each increment, you just have much less each time to take from. An exponential change ideally never reaches zero.

Here transmission is found by knowing the absorption coefficient and the thickness of material the light has to travel through. We can also solve the equation for absorption coefficient if we know the transmission and thickness.

Don't forget most all of our parameters we use in optics are wavelength dependent. If you find the absorption coefficient of a material at a certain wavelength, it is NOT the same at other wavelengths. For instance, ordinary fused silica glass transmits visible light very well and absorbs nearly nothing, but it absorbs all infrared light above 5 microns.

Optical density or OD is a term we use to indicate how well a material absorbs light. Many optical filters and laser eyewear are labeled with their OD at certain wavelengths.

Optical density is unit-less, we can use the transmission of an optic to figure the OD by taking the logarithm of the inverse of the transmission.

Or we can use the optical density, take its negative to the power of ten to figure out how much light an optic will transmit. Try a few.

You see the optical density since it is logarithmic its transmission is easy to find. Just count the decimal places. An OD of 1 transmits 0.1 or 10%. An OD of 6 transmits six decimal places less.

Most of the time, we will align optics “Normal” or perpendicular to the optical path or “axis”.

This will minimize the amount of light reflected and relay a much cleaner image, than if you come into an optic off axis.

The reflectivity equation works only if you are aligned “normal” to the optical axis.

If you are using a 100 watt carbon dioxide laser to cut material, and you have an uncoated window in the beam path, it will reflect 4 watts of light back toward the laser head. Four watts of laser light is enough to start a fire if it hits the right material.

When light is incident on any reflective surface at a very specific angle called Brewster’s Angle, the light that is reflected is missing light that is polarized at a certain angle. The all of the light that is polarized parallel to the plane of incidence is transmitted into the glass, none is reflected.

You can see this with linear polarized sun glasses. Look out into the distance at a shiny floor or road and rotate the glasses 90 degrees and back. You should see the reflections nearly disappear. Now take the same glasses and rotate them while you look into a parking lot. You will see car windows and windshields go totally clear. The closer you are to Brewster’s Angle the more reflection you will block. People don’t know it, but with polarized glasses you can easily see right into their car.

So reflected light coming off the lake at a 53 degree angle will be blocked by your polarized sunglasses! You can see down into the water!

Heat or temperature changes can actually move a beam around enough to be an issue in some applications. Thermal expansion in mounts and in the actual optics they are holding can distort beams. If a laser beam starts absorbing into a glass it could easily reach its melting point and “blow-out”.

If the optic is put under a large amount of stress by clamping or uneven pressure, it could distort the optic causing beam movement.

Also, optical materials react to some chemicals. Acetone eats plastics and optical cements. Don’t use acetone on a Pellical Beamsplitter, which is a very thin, plastic splitter.

UV lasers sometimes require Salt windows. This type of optic can absorb moisture out of the air over a short period. You have to be careful how they are handled and even packaged or stored.

Care and Handling of Optics

Coating optics is an industry all of its own. From depositing one coating to hundreds at a time, the technology or “art” of coating optics has grown exponentially, and the need for optical coating technicians is great.

The part or optic being coated is called the substrate. The substrate is a term used to define a raw piece of glass ready for coating. The substrate will be loaded into a “chamber” or vacuum housing because most of the coating is not performed at atmospheric pressure. The little container that holds the raw coating material is called the “boat.”

Evaporating one material and having it collect on the substrate is a very accurate way to deposit small layers of a substance on an optical surface. Thermal vaporization is heating the boat until just the coating material vaporizes and jumps up to the optic to be coated. Electron beam deposition and MOCVD are two more methods of depositing coatings.

A cooled substrate to be coated is placed very close to a target material made of the coating to be applied. A high voltage is applied and a plasma generates ions that bombard the target and knock loose particles of the target that are attracted to or condense on the cool substrate. This process works well for even coatings on large optical surfaces.

It is a trick to measure the thickness of a coating to ¼ the wavelength of light. But coating technicians use several techniques to do so. First is aligning a quartz oscillator to the plane of the optic being coated. The resonant frequency of the crystal is directly correlated to the mass of the crystal. So as material is deposited on the optic, it is also deposited on the crystal, changing its mass and resonant frequency. A laser is used to measure the amount of light transmitted or reflected off of the optic. As the thickness changes, so does the transmission or reflection. Each ¼ wavelength the light will go through a maximum or minimum. This is very effective for multilayer coatings.

Antireflection coatings are a must in the optical world. Losses in optical systems must be kept to a minimum in order for quality images to be formed in most applications. AR coatings nearing 0% reflection are possible. Anti-Reflection coatings use wave interference to reduce reflections.

The optical coating has an index of refraction that is between the index of air and the material substrate. When light travels from a low to a high, index of refraction the reflection is 180 degrees out of phase with the reflection from the second surface, the reflection is essentially cancelled, and the light remains in the initial beam.

Optical thickness is used to show ¼ wave thicknesses of a coating material. If the optical thickness is an odd number of ¼ waves, multiple reflections reach zero. If optical thickness is an even multiple of ¼ waves, the reflection is high because the reflections are in phase and add together or constructively interfere.

Highly Reflective, or HR, coatings are used in all laser systems. They work the same way as AR coatings they are just different thicknesses. Good coatings can reach greater than 99.5 percent reflection at a specific wavelength. Dielectric coatings are nonconductor coatings at a narrow wavelength range. Metallic coatings are good in the sense that they are highly reflective at most higher wavelengths. However, they are sometimes soft, they oxidize and tarnish.

Filters are used to remove or clean up light for particular applications. There are many types designed to transmit or reflect the usable portion of a light beam. Broadband filters are designed to allow a wide range of light to pass and block all of the surrounding light. Laser eyewear designed to pass much of the visible wavelengths is nice. You can protect your eyes from stray laser beams and still see where you are going.

Hot mirrors and cold mirrors are types of Cut-off filters. They allow only wavelengths above or below a certain level to pass. For instance, if you want to allow visible light to pass through your optic and want to block the heat from the IR wavelengths, use a hot mirror or a short pass filter. Neutral Density filters allow a certain level of light to pass at all wavelengths. ND filters are used to cut down the intensity of light to a certain level. They are categorized by their optical density. So you would purchase an OD 1 filter to block out 90% of your light. An OD 2 would only allow 1% of the light to pass. Narrow band pass filters allow only a tiny spike of a wavelength to pass. These are used in outdoor laser systems like L.I.D.A.R. (Light Detection and Ranging) or laser radar to block all bright sunlight and allow only the laser light to be seen.

When a detector alone sees a change of wavelength, its response may be way different than what it is really incident on its surface. This throws off the accuracy of your measurements. A radiometric filter in front a specific detector allows for a ‘flat’ response over a wide range of wavelengths giving you a more accurate look at what you are really reading.

The human eye as a detector is most sensitive to green light near the middle of the visible spectrum and the sensitivity tails off on both sides toward red and violate. The curve resembles a bell curve, beginning at 400nm, peaking at 550nm, and ending at 700nm. A filter can be attached to a detector to closely simulate the human eye response.

The surface of an optic must be free of any defects that could add optical “noise” to the beam and cause poor image relay. Scratches and digs are common defects caused by mishandling of optics. Scratch and dig standards can be purchased at optics stores and can aid in quick inspection and identification of scratches and digs.

Inspecting optics can be a challenging feat. Some optical defects like scratches, digs, contamination, and other defects are hard to see without using tricky techniques to illuminate the optic. Changing the angle of illumination of the test piece tends to enhance the reflection of some defects. Also, changing the wavelength of the incoming light will make some defects stand out.

A quick method of testing the quality of an optic is to scan it through a laser beam and watch the transmitted light for changes in direction or small changes in intensity. Any interference patterns that show up in the expanded beam will cause image problems if the optic is used in certain applications. To test the flatness of optics an optical flat is used, that has a flatness of 1/10 wavelength or better. A monochromatic light source illuminates the flat and test piece and visible interference fringes are observed and recorded.

If an optic is dropped, chips may fly. If so, don’t worry. If it is not into the usable portion (clear aperture) of the lens, you are fine. Keep an eye on edge chips because under the right conditions they can propagate on their own. Optics that are glued together are susceptible to separating due to a number of conditions, such as mishandling or using the wrong solvent on a glued optic. Soft coatings can be damaged just by the slightest touch. Unprotected gold is a great IR reflector, however, if you have to clean it, you cannot even touch it. It is soft enough that the weight of a tissue alone will scratch the surface. Extreme heat or cold could cause other cracking, or clouding of the lens depending on the type of material. Improper use of chemicals can cause other severe problems with optics including fungus attacks on coatings. Your optic looks like a golf ball after a good fungus attack.

Internal defects of optics usually occur during the manufacturing process, and sometimes make it through quality control, and to your optical system. Inclusions are pieces of contamination inside of the glass. They will block the beam creating unwanted diffraction and poor image quality. Bubbles are just that, air trapped in the element. Cracks can occur in an optic and can travel if conditions are extreme. Striae are lines in an optic that are variations in the index of refraction across an optic. There are many techniques to inspect optics prior and during use. Again, it is all what your employer requires or suggests that you must do.

This procedure details steps for cleaning coated optics, whether discrete or bonded, to cleanliness levels required by most laser systems. Coated optics should not be cleaned unnecessarily. All known cleaning methods degrade coatings. Unfortunately, cleaning coated optics is not an exact science. Each engineer or technician has their own method of cleaning – learned from a colleague, during formal education, or personal experience. Many employers will train you how they clean optics. Whatever the method, be careful. It can be so easy to damage an optic by trying to clean it. You’ll need to have a few items to prepare prior to the cleaning.

There are basically four types of cleaning that are accepted methods for cleaning optics:

1. Blowing off the optic with clean air.
   Doesn’t always work and if it does go away, where did it go? Did you just move it to another optic?
2. Detergent method
3. Drag-wipe method
4. Twist-n-wipe method