Assignment 2: Optical Handling and Positioning

1. Describe the nature (properties) of optical materials and their transmission and reflection characteristics as a function of wavelength.

A transparent optical medium such as a window, prism, or a lens requires these properties:
1. Low absorption of light while passing through it
2. Low reflection loss of light incident on its interfaces (surfaces)
3. Low refraction of the transmitted light (smaller refractive index)
4. Minimum distortion of light while passing through—due to imperfections in the material or the surface finish
5. A high damage threshold to laser radiation
6. Minimal optical degradation due to temperature, water vapor or other "hostile" environmental conditions

A beam of light incident on a flat, optically transparent medium is partly reflected, partly absorbed, partly scattered, with the rest transmitted

Reflection takes place at an interface between two media due to the difference in refractive indices. An equation for the percentage of reflection *R* when light is *incident perpendicular (normal) to the interface* is given by Equation 2-4. A simple calculation with $n_1 = 1$ (air) and $n_2 = 1.5$ (glass) shows that for *perpendicular incidence* at the interface from air-to-glass, about 4% of the light will be reflected back into the air. When considering Fresnel and Brewster reflections, coatings and angles influence the amount of reflectivity. Coatings effecting reflection when used per a certain wavelength can create close to 100% reflectivity. Varying the wavelength can also change the angle of reflection.

The transmittance *T* is often used in describing the percentage of light passing through an absorber. It is given by Equation 2-3. The transmittance ($T=E/E_o$ x100%) decreases with an increase of either or both, α and *x*, since $E = E_0e^{-\alpha x}$ decreases as α and *x* increase. The absorption coefficient α depends on the nature of the material and the wavelength of the light. Most of the optical glass materials transmit nearly 100% of visible light—from the near ultraviolet to the near infrared. However, transmittance generally decreases beyond these regions.

2. Define the term refractive index. Why does it vary with wavelength?

Refractive index is an important property of an optical material. It is defined as the ratio of the speed of light in a vacuum to the speed of light in a particular medium. The larger the refractive index of the medium, the larger will be its variation with changes in wavelength. In general, the refractive index of an optical medium decreases with increase of wavelength.

3. What are the factors that determine the transmission of light through a medium?

The amount of scatter, absorption and reflection. The absorption factor depends on the thickness and nature of the medium and the wavelength of the light. Changes in the refractive index of the coatings. The thermal, mechanical, and chemical properties.

4. Record the thermal, mechanical, and chemical properties of optical materials used in making optical components.

Thermal: Extreme heat or cold and rapid changes in temperature can cause temporary or permanent changes in the physical characteristics of an optical element. Since the element is mounted on a metallic mount, variations in temperature can cause unwanted changes in the dimensions of the mount. Minimal changes in the physical properties of both the optics and the mounts are important for maintaining the integrity of the system. Some of the important parameters are *melting point* and *coefficient of thermal expansion*.

Mechanical: A non-uniform stress on an optical component can result in distortion in the bulk medium and therefore its surface. This distortion is unacceptable in many applications. A relationship between the maximum stress P (Pascals) and the geometry of a window is given by Equation 2-7.

Chemical: Chemical damage to optical elements is caused mainly by the chemical's ability to etch or dissolve the window material. Examples of such damage can be seen in the effect of acetone on plastics as well as on the effects of water vapor on ionic crystal windows such as NaCl and NaBr.

5. Briefly explain how materials are chosen for specific use in the visible, ultraviolet, and infrared region.

Fused silica and fused quartz can be used in the ultraviolet region from 200 to 400 nm. Practically all glasses have reduced transmission beyond 3400 nm in the infrared region. A study of this Figure 2-3 helps one choose a suitable optical material for a given transmission region. For far infrared transmission, semiconductor materials such as germanium (1800 - 2500 nm), cadmium telluride (900 - 3300 nm) and sodium chloride (500 - 2600 nm) can be used. However, sodium chloride is hygroscopic (absorbs water) and will be fogged when exposed to the atmosphere. Transmission characteristics and properties of some of the infrared materials are given in Table 2-1.

6. Describe how single and multiple anti-reflection coatings and filters are made and used. Be sure to include: How optical coatings are deposited on a substrate. How can the thickness of the coating be controlled and measured?

There are many ways (evaporation, sputtering) in which the coatings can be applied. In most of the optical coatings, the material is deposited in a vacuum chamber with pressures of the order of 10–8 Torr (2×10^{-8} psi). The optical element on which the material is deposited is called a "substrate." A typical vacuum deposition chamber is shown in Figure 2-7.

For optical coatings, control of coating thickness is very important. There are two ways to monitor the thickness of a thin film while it is still in the chamber. The first method is to use a *crystal oscillator*. For optical coatings, control of coating thickness is very important. There are two ways to monitor the thickness of a thin film while it is still in the chamber. The first method is to use a *crystal oscillator*.

7. Explain the use of 4 different mountings for lenses, mirrors, and other optical components.

The *sliding-grip* lens holder has a V-groove in which the lens can rest and the movable horizontal bar can be fixed with a side screw. Thus, a lens can be held between the V-groove and the horizontal bar. This support is mounted on a cylindrical rod that can be moved vertically to fix the lens at any height.

In the *spring grip* lens holder, the lens is held in the jaws of a double "V" spring. The lens is positioned between the two jaws. This mount is inexpensive and simple, but not very stable. A slight variation of the double "V" spring is a single swing spring that can move vertically up and down. A lens is firmly held in a metal "V" groove at the bottom and the lens is held in position by the spring above. This holder also is simple but unstable.

A semi-permanent mounting is the *threaded lens* holder. This holder has to be made specifically for a lens of particular diameter. The cylindrical holder has threads inside and a retaining collar at the end. Once the lens is inserted in the cylinder, a threaded retaining screw can be used to hold the lens. This holder is sturdy and can be used when lenses need not be changed often.

The *self-centering* holder helps in moving the position of the lens in a vertical axis. In this holder, three arms that can hold the lens in position are held by springs. These arms have grooves to hold a small portion of the lens at three points along the edge of the lens. This holds the lens securely in position but allows the lens to move along vertical and horizontal axes. This type of mount allows alignment of the lens with other components of the system. It is not usually recommended for permanent type set-up

8. Tell how single and multi-dimensional translational and rotational stages work.

Translation tables provide adjustable motion in one or two dimensions. These can be combined with other devices to produce either a three-dimensional motion or a combination of linear and rotational motions. Motion in two axes can also be accomplished by stacking two linear translators above and perpendicular to each other.
Rotational motion about an axis is achieved with rotary stages. The rotary stage is controlled by a worm gear on the knob shaft that drives a circular ring gear through a full 360°.

9. Describe how to inspect surfaces of optical elements for scratches, chips, or digs.

The simplest method of observing and measuring a surface defect is to observe the surface under a microscope. The surface is first cleaned by an approved method and then placed on a stage of a microscope. A lamp using a condensing lens illuminates the test piece.

10. Tell how to handle, clean, and store optical elements. Be sure to include: What are the precautions to be taken in cleaning an optical element such as a lens or a mirror? What are the materials that are required to clean a lens?

While the optical surface is being inspected, it should never be touched by a bare hand; a latex glove must be used. Fingerprints can permanently damage an optic surface. Lenses, mirrors, and flats should only be held by the edges and never on the front and back sides. First, the dust and grime must be removed from the surface. For this, air has to be blown along the surface using the air duster. Observing the surface in a bright light will show whether dust particles are still there. The surface is not to be blown on by mouth since saliva can deposit itself on the surface. Rubber gloves must be worn on the hands and cleaned in water to remove any powder on the glove. A dryer must then be used to dry the gloved hand. With a Q-tip wetted by a small amount of cleansing liquid, the surface must be gently cleaned using a circular motion from outside towards the center. Only light pressure should be applied. A clean lens tissue or a clean Q-tip must be used to wipe out the excess cleaning liquid and let the surface dry. The process must be repeated until the surface is clean

Mirrors usually require only a dust-off and not a cleaning. If they do not have some greasy impurities sticking to the surface, they can be given a “bath.” The mirror must be removed from its casing and then put under gently running water. A small amount of detergent liquid is applied to the surface and once again put under running water. Finally, the surface must be cleaned with distilled water and allowed to dry. A hot air dryer should never be used to dry the surface. After the surface is dry, an air blower can be used to blow away any other particles sticking to the surface.
Precautions to be taken in cleaning an optical component
(a) Water and soap solutions make hands slippery. Care must be taken to see that the object does not slip from the hands. A good idea is to keep the hands ‘on’ the table so that the height of a fall will be small!
(b) Lens tissue, cotton swabs, or fingers should never be inserted in methanol.
(c) Dry lens tissues can scratch the surface. Hence, a drop of cleaning liquid should always be used.
(d) Optical components must always be held by their edges.
Storage of optical components
The proper storage of optical components is important. A well-stored component will last longer and will be very effective in an optical system.
(a) Clean optical components must always be kept covered so airborne particles do not again settle on them.
(b) Optical components must be stored in a clean, covered area.
(c) They must be in a cool area with minimum temperature fluctuation.
(d) When the component is not in use, it should be stored in a covered place and not left on the table.
(e) From time to time, optical components must be inspected for defects and scratches. Defective optics should not be used in a system since they will negatively affect overall system performance.
Materials required
Some of the materials required for cleaning are:
(a) Reagent-grade methanol or 2-propanol in a drop dispensable bottle (commercial lens cleaners also can be used).
(b) Long fiber, low ash content lens tissues with no additives or chemicals.
(c) Clean air duster—such as a camera cleaning brush/ air blower or any of the “dust-off” spray cans.
(d) Q-tips.
(e) Clean, dust-free rubber gloves.

11. Name some of the materials that can be used as a window in the ultraviolet, visible, and infrared regions respectively.

Material	Wavelength range (nm)
Visible:	
Most all optical glass	350 - 800
UV:	
Fused Silica	200 - 400
Fused Quartz	200 – 400
IR:	
Germanium (Ge)	400 to 35000
Gallium arsenide (GaAs)	1000 to 11000
Zinc selenide (ZnSe)	500 to 22000
Cadmium telluride (CdTe)	2000 to 25000

12. What are the important criteria in choosing a window material?

Elasticity, solubility, see #1

13. Why is germanium more suitable as a window material for a CO2 laser than NaCl?

Germanium: Low absorption coefficient at 10600 nm; suitable for low power CO2 laser mirrors
Sodium Chloride: Hygroscopic; dissolves in high humidity (salt), high absorption coefficient

14. Explain what Brewster's angle is and where is it useful?

Fresnel showed that the reflected light will have more of the *E*-field vibration *E*TE than *E*TM. And the transmitted light will have more of the *E*-field vibration *E*TM than *E*TE. At a specific angle of incidence called the **Brewster angle**, the reflected light will have **only** the *E*-field vibration *E*TE (dots). See Figure 2-5. The refracted beam will have all of the *E*TM vibration (arrows), but less of the *E*TE vibration since some has gone off in the reflected beam. Thus, the light in the reflected beam (around 15% of the incident light on an air-glass interface) is completely polarized with the *E*TE vibration (dots). Thus at Brewster's angle, there is no reflected light, only refracted light. And the refracted light is totally of the polarization *E*TM.

15. How does a change in temperature affect the optical properties of a material?

Extreme heat or cold and rapid changes in temperature can cause temporary or permanent changes in the physical characteristics of an optical element. Since the element is mounted on a metallic mount, variations in temperature can cause unwanted changes in the dimensions of the mount. Minimal changes in the physical properties of both the optics and the mounts are important for maintaining the integrity of the system.

16. What are the important thermal properties that have to be considered when selecting a material for an optical component?

Some of the important parameters are *melting point* and *coefficient of thermal expansion*.

17. How does mechanical stress affect the optical properties of a window material?

A non-uniform stress on an optical component can result in distortion in the bulk medium and therefore its surface. This distortion is unacceptable in many applications

18. How is the thickness of an AR coating determined?

A useful quantity when dealing with coatings is defined as the **optical thickness**. The optical thickness of a medium is defined as the product of its refractive index and thickness, *nt*. The *minimum* thickness *t* of a coating that causes a low reflectivity (high transmittance) is obtained from equation: $\mathbf{t = \lambda/4n}$. The thickness of the optical coating is also dependent on the angle of incidence of the light, and as the angle changes, the wavelength peak of the reflectance changes.

19. Describe the following type of filters and state what they are used for:

a. Neutral density
Not wavelength sensitive. They are intensity sensitive (do not like a lot of power). Knowing the OD or optical density is important. Attenuates incident light for various applications.

b. Short wavelength pass filter
A cut-off filter that allows radiation up to a specific wavelength and cutting off the rest. A short wavelength pass therefore only passes wavelengths that are short. Its graph would be the inverse of Figure 2-13.

c. Band pass
A type of broadband filter. These transmit a certain band of wavelengths and block the rest. See Fig 2-12 for some very useful information as in Tmax, full width/half max (FWHM), pass band, 50% of Tmax, Peak λ, Central λ

d. Multiple layer
More than one layer of a dielectric coating. Layers alternate refractive indices; higher/lower. Used to increase/decrease reflectivity.

20. Name five different types of lens and filter holders. Explain their advantages and disadvantages.

The *sliding-grip* lens holder has a V-groove in which the lens can rest and the movable horizontal bar can be fixed with a side screw. Thus, a lens can be held between the V-groove and the horizontal bar. This support is mounted on a cylindrical rod that can be moved vertically to fix the lens at any height.

In the *spring grip* lens holder, the lens is held in the jaws of a double "V" spring. The lens is positioned between the two jaws. This mount is inexpensive and simple, but not very stable. A slight variation of the double "V" spring is a single swing spring that can move vertically up and down. A lens is firmly held in a metal "V" groove at the bottom and the lens is held in position by the spring above. This holder also is simple but unstable.

A semi-permanent mounting is the *threaded lens* holder. This holder has to be made specifically for a lens of particular diameter. The cylindrical holder has threads inside and a retaining collar at the end. Once the lens is inserted in the cylinder, a threaded retaining screw can be used to hold the lens. This holder is sturdy and can be used when lenses need not be changed often.

The *self-centering lens* holder helps in moving the position of the lens in a vertical axis. In this holder, three arms that can hold the lens in position are held by springs. These arms have grooves to hold a small portion of the lens at three points along the edge of the lens. This holds the lens securely in position but allows the lens to move along vertical and horizontal axes. This type of mount allows alignment of the lens with other components of the system. It is not usually recommended for permanent type set-up

Slide holders can hold a filter or multiple filters as shown in Figures 2-24b and c. In the first case, a rectangular frame holds the filter by means of two spring clips. In the second case, a number of grooves along vertical sides can hold several slides aligned in a row.

21. What are the types of surface defects that can occur on an optical surface? How can they be observed?

Surface defects include *scratches*, *digs*, *chips*, and *fractures*.
The simplest method of observing and measuring a surface defect is to observe the surface under a microscope. The surface is first cleaned by an approved method and then placed on a stage of a microscope. A lamp using a condensing lens illuminates the test piece. This arrangement is shown in Figure 2-31.

22. Name three types of optical benches. State one advantage and one disadvantage of each.

Triangular Rail: Aluminum, cast iron, or steel. Guide the carriages. Secure with locking screws. 2 – way tilting. Minimum stability.

Double Rectangular Rail: Aluminum. Has a linear scale for easier positioning. Allows different types of mounts.

Flat-bed Optical Bench: Maximum stability. High grade stainless steel or granite. Heavy.

Optical Tables: More than one axis positioning. Vibration isolation. Drilled/Threaded holes. Costly and hard to move around.

23. Explain the experimental procedure for determining the flatness of an optical element.

The flatness of a plane surface such as an optical window can be measured with the help of an *optical flat*. When the test plate is placed on the optical flat and viewed in monochromatic light, a number of fringes (dark and bright bands) appear due to the interference of light reflected from the top surface of the test piece and the interface between the test piece and the optical flat. The flatness of the test plate is defined in terms of a fraction of the wavelength. The smaller the value, the greater is the flatness of the test piece. See Figure 2-33.

24. What are the precautions to be taken for storing optical components?

The proper storage of optical components is important. A well-stored component will last longer and will be very effective in an optical system.
(a) Clean optical components must always be kept covered so airborne particles do not again settle on them.
(b) Optical components must be stored in a clean, covered area.
(c) They must be in a cool area with minimum temperature fluctuation.
(d) When the component is not in use, it should be stored in a covered place and not left on the table.
(e) From time to time, optical components must be inspected for defects and scratches.

Defective optics should not be used in a system since they will negatively affect overall
system performance.

25. If the wavelength of light incident perpendicular to an interface in air is 650 nm and its wavelength changes to 644 nm in the medium, what is the refractive index of the medium?

Equation 2-1: $n = \lambda_o/\lambda_m$
Therefore $n = 650/644 = 1.0093$. Which is very close to the n of Carbon Dioxide.

26. The absorption coefficient of a material is 4.5 cm–1. If the thickness of the material is 12 mm, find the percentage of light transmission.

$\alpha = 4.5$ cm-1
x = 1.2 cm
%T = ?
$E = E_o e^{-\alpha x}$
-(4.5 x 1.2) = -5.4

$e^{-5.4} = 0.0045165809\ E_o$

T – E/E$_o$ x 100%   T = .0045E$_o$ / E$_o$ x 100%   T = .45%