Tutorial on adhesives and how to use them for mounting

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Introduction:

This tutorial reviews the various adhesives used today in photonics and they specific uses. First, a general overview of the different type available is provide and then a details look at the theory behind how they behave mechanically are reviewed. From there this information is used to take a closer look at some specific uses and applications for which bonding is used for mounting the advantages and pitfalls of using bonding in each.

Typical Types of Adhesives Used in Photonics

Adhesives can be very useful in photonics for things like mounting, bonding glass components together, and bonding components to metal. Given the wide range of applications and uses of adhesives that are used in photonics, there are a range of types which are used. Each has their own specific advantages and disadvantages which make them ideal for use in certain applications.

The most obvious type used commonly in photonics are optical adhesives. These are typically used to cement optical components together to make doublet, triplets, cube beamsplitters, etc. They are special in that there are transparent for specific wavelength ranges, and their optical properties are known and controlled. One of the most commonly used optical adhesives is Norland Optical Adhesives #61 which is commonly used for cemented doublets. This is ideal for visible to near-infrared applications at is has high transmission from 400nm to 2um.

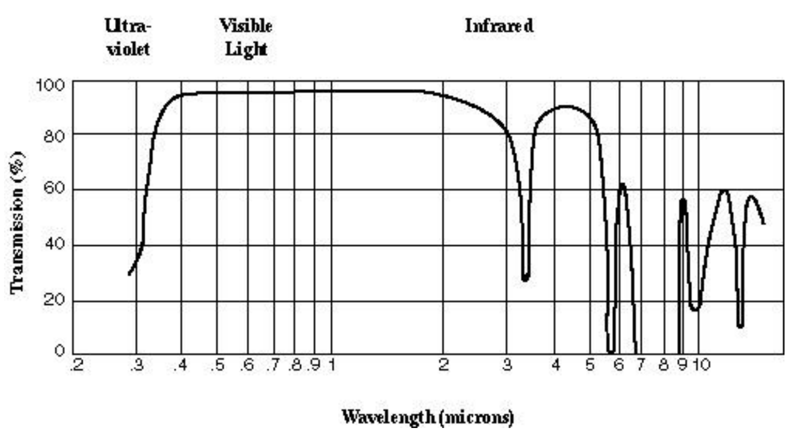


Figure 1: NOA 61 Spectral Transmission (From Norland Products)

There are also alternatives for UV and IR applications which can be found as well. One example of this is Araldite 610 which offers transmission from 2-14um. To properly bond optical surfaces using these types of cements the surfaces must be thoroughly cleaned prior to bonding. It is typically recommended to apply the adhesive to the center of the bottom surface, the slowly bring down the top surface and then use small lateral movements to spread it. This will help minimize the introduction of bubbles, and work out any which are created. This is crucial as these bubbles can degrade performance. One the two components are aligned and compressed together (generally bond thickness of 8-12um is ideal) the adhesives is typically cured via UV light or thermally.

One of the next most common types are structural adhesives. These are used for mechanical parts of the system, generally as a replacement for a mechanical fastener like a screw, rivet, or clamp. They tend to be lighter than the traditional mechanical fastener while having high strength & stiffness, as well as more uniformly distributing stress. Additionally they are easy to implement and generally lower cost. Some of the commercially available type of Loctite would call in to this category.

Elastomers are an alternative option to our structural adhesives as these tend to be more compliant, and used in situations where the compliance and CTE can be a benefit. In assemblies where the temperature range can vary these types of adhesives can help to absorb the stresses created by the CTE differences in metal and glass components. Also, they can act as a passive athermalization component when chosen correctly.

The last type are the Cyanoacrylates. These are high strength, fast curing adhesives like superglue. They are used to do things like thread lock retainers, which are applying a preload, that need to be held tightly in place. The advantage to using these adhesives is that they tend to have good adhesion to both metal and glass, and they typically cure in under 30s. The disadvantages tend to be that there is a high potential for outgassing which can be detrimental to optical coatings, and there is a high potential for failure in temperatures over 71C.

Table 1: Typical Adhesives

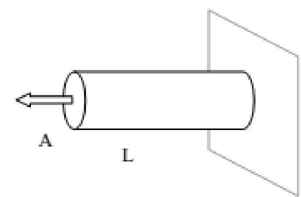
Adhesive	Temperature Range	Viscosity	Tensile Strength	Shear Strength	Total Mass Loss %
RTV112	-55 to 200 C	-	325 psi	-	1.00
3M 2216	-55 to 90 C	High	-	2,500 psi	1.01
Milbond	-60 to 100 C	High	2,100 psi	-	0.98
Hysol 1C	-55 to 100 C	High	2,000 psi	-	0.81
RTV 142	-55 to 200 C	Medium	550 psi	300 psi	0.24
E-30CL	-55 to 100 C	Low	8,000 psi	4,200 psi	-
NOA 61	-150 to 125 C	Medium	3,000 psi	-	-

Mechanical Modeling:

In order to correctly implement the use of adhesives into an optical system an understanding of how to model them mechanically and quick hand calculations is needed. A clear understanding of how the bond thickness and area affect the axial and shear stiffness of the adhesive are crucial to appropriately specifying how the adhesive it to be used during the assembly process to ensure best performance.

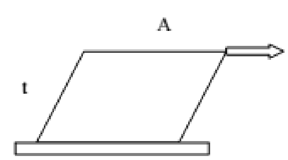
The axial stiffness (K_a) of the adhesive can be calculated just like modeling a spring. This is calculated using the equation below when the length (or thickness) of the adhesive bond is considerably less than the width of the bond. Here E_0 is equal to the Young's modulus of the adhesive, and a constant once the adhesive is chosen. Given this once the adhesive is chosen the bond area and thickness (in this case L) are what the designer can use to adjust the axial stiffness.

$$K_a = \frac{\delta F_{axial}}{\delta L} = \frac{E_0 A}{L}$$



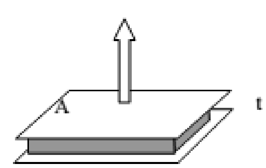
Similarly the shear stiffness of the adhesive can modeled by replacing the Young's Modulus with the shear modulus of the adhesive. For cases where the thickness is less than the width the equation below can be used to calculate this where G is the shear modulus. Again the thickness and area of the bond are what can be used to adjust the stiffness of the bond.

$$K_s = \frac{\delta F_{shear}}{\delta y} = \frac{GA}{t}$$



In both of these cases the bond if very compliant, and in the case of an axial load buckling and non-linear behavior can occur. Many times to get the highest strength from the bond axially we try to reduce the thickness as much as we can. In this case we transition from using the Young's modulus in our calculations to the bulk modulus of the adhesive.

$$K_b = \frac{\delta F_{axial}}{\delta t} = \frac{E_B A}{t}$$

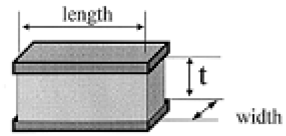


In cases where the adhesive is under compression we use the compression modulus (E_C) which will depends on the shape factor (*S*) and the material compressibility coefficient (ϕ). Depending upon how much compression there is the compression modulus will scale from a minimum of the Young's modulus and a maximum of the bulk modulus as show in Figure 1.

$$K_c = \frac{\delta F_{axial}}{\delta t} = \frac{E_C A}{t} \qquad E_c = E_0(1 + \emptyset S^2)$$

This will depend upon how large the shape factor is, where the shape factor is equal to:

$$S = \frac{Load\ Area}{Bulge\ Area} = \frac{A}{Perimeter \times Thickness} = \frac{l \times w}{t \times (2w + 2l)}$$



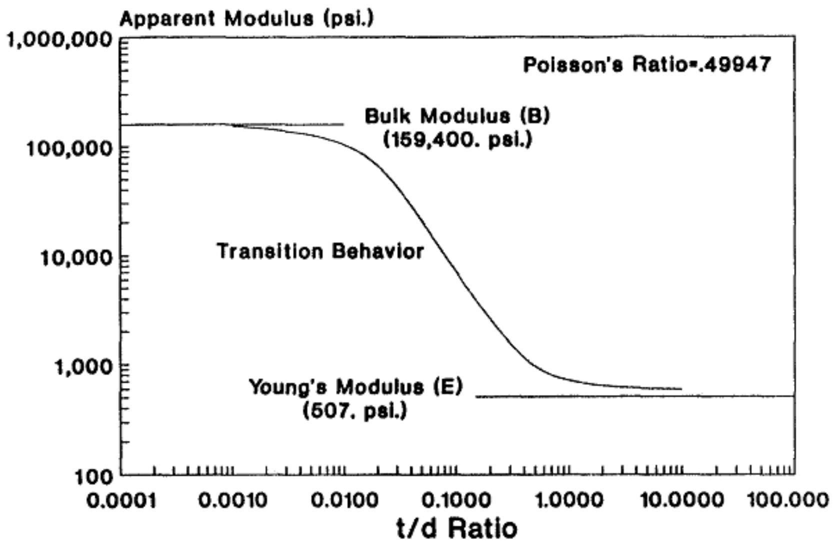


Figure 2: Apparent stiffening in thin bonds (From Hatheway, A.E., *Proc. SPIE*, 1993)

Mounting Prisms and Mirrors by Adhesive Bonding:

For many applications where an optical assembly has stringent size and weight requirements the use of adhesives can be the favored mounting solution. Generally they reduce the complexity of the mechanical design and the mechanical envelope, while providing the required strength to meet the shock and vibration requirements of the most demanding applications. For mounting prisms this can be ideal as they tend to have more weight compared to other glass components, causing some metal mechanical mounting schemes to grow in size and weight. For handheld direct view optical systems this can be detrimental to the functionality, making the use of bonding for prism assemblies that go into things such as binoculars crucial.

The key to successful implementation is choosing the correct adhesive, and ensuring adequate control of the area and thickness of the bond. As detailed in the previous section control of the thickness is key to maximizing the bond strength. This can be done with high precision through the use of shim or spacers to control the gap between the two mating parts. An alternative technique which will offer a uniform bond to an exact thickness is to mix small glass or plastic beads into the adhesive. The diameters of these beads should match the desired bond thickness, so that when two components are tightly clamped together a single layer of beads are in contact with the two parts.

Once the appropriate thickness has been determined for optical strength of the adhesive the next step is to determine the optimal bond area. To determine this one must know the weight of the optic (W), shear or tensile strength of the adhesive (J), the maximum relative acceleration (a_{max}), and desired safety factor (SF) to ensure a buffer between the design specification and expected failure. Combine in the following equation these will give you the ideal bond area (A_{Bond}):

$$A_{Bond} = \frac{W \cdot a_{max} \cdot SF}{J}$$

One additional consideration when using adhesives bonds for mounting is that many adhesives upon curing will undergo some shrinkage. This can cause stress in the optical components and will partially deform their surfaces of the optic. In case of most completely transmissive optics like thin lenses, windows, and filters this deformation of does not have a large impact on the transmit wavefront performance. Additionally for prism which do tend to have at least one internal reflection, given that these tend to be thicker components they are stiffer and therefore less susceptible to deformation.

On the other hand, the wavefront error due to surface errors is much higher for reflective optics and they tend to utilize much thinner substrates which are still susceptible to deformations during adhesive shrinkage. In the case of mounting these types of components via adhesive bonding the designer should also be careful not to over specify the bond area. While the bond area directly related to the bonds strength, it is also proportional to the stress induced on the surface when shrinkage occurs. For designs which require a high bond area one way to compensate for this is to divide up the bond area into multiple smaller bond areas. The ideal bond configurations are triangular or a ring shape at about 70% zone.

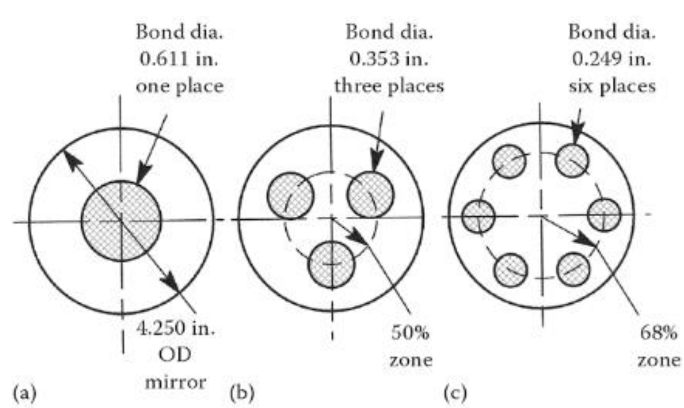
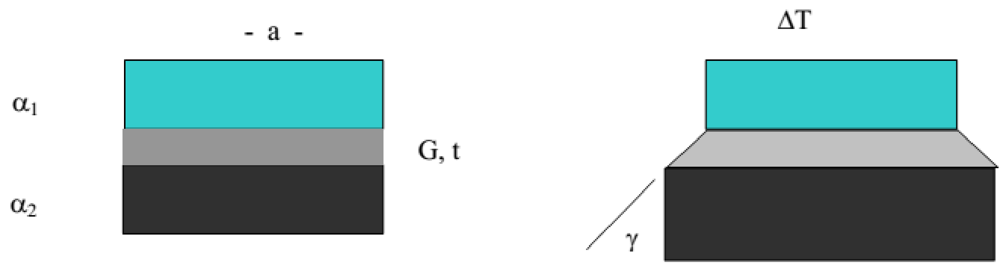


Figure 3: Design example of equal area bonds (From Yoder & Vukobratovich 2015)

Thermal Considerations

In the case of thermal mismatches where an adhesive bond is used for mounting, the differences in the CTE of the two components is generally accommodated by the adhesive. This is due to the fact that the adhesive tends to be the most compliant of the three. Also, given that most of our ideal both thickness lead to the adhesive layer being considerably small than our substrates the thermal expansion of the adhesive tends to be negligible by comparison. To find the maximum shear stress that is created in this situation we must know the CTE of our two substrates, temperature change, bond area, bond thickness, and the shear modulus of the adhesive. Combine these are used to calculate the maximum shear as follows:

$$\gamma = \frac{a}{2t}(\alpha_1 - \alpha_2) \cdot \Delta T \qquad \tau = G\gamma = \frac{Ga}{2t}(\alpha_1 - \alpha_2) \cdot \Delta T$$



Additionally, in multi-element assemblies adhesives can be used to help passive athermalize a system. For the system to stay in focus the change in focal length due to the index changes with temperature must match the change in air spacing which is created by the CTE difference in the materials. Here adding adhesives provides additional variables for helping to cancel out these two factors. Given the relatively thin layers of the adhesives they can provide small scale adjustments to these spacing for precision matching.

Additional Information

For additional detail and information on the topics discussed above please refer to the list below of reference materials that were used in this tutorial.

References

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