Introduction to Bond in Place Optics

Michael Hemmat
University of Arizona
College of Optical Sciences

December 2011

Abstract

This tutorial presents an introduction to the various options for selection of UV curing epoxy and mechanical glasses for the application of 'bond in place' optics. Ambient environment and application of the optical structure direct the selection of materials. Common considerations such as thermal excursion and tensile strength will be treated by example.

Introduction

Laser system specifications are requiring smaller and smaller footprints for the laser assembly. Reducing the size of the optics is not an option for many applications. The beam diameter must be large enough to reduce the fluence below a safe level to protect the optics (bulk and coatings) so other avenues of miniaturization must be explored. One path is common practice of beam folding. Another path is to reduce the physical dimensions of the optical mounting structures. Standard optical mounts are bulky and have one or several degrees of freedom. In the case of flight or space based lasers, the benefit of tweaking up the system is not available so the mounting hardware capability is just extra volume in the box and extra weight as a payload. The solution to this problem is to use bond in place optics as shown in Figure 1. Imagine the dimension growth of the assembly shown if each of the optics were held with standard mounts. It should be noted that 1 and 2 part epoxies are not suitable for this purpose because the optics are actively aligned.

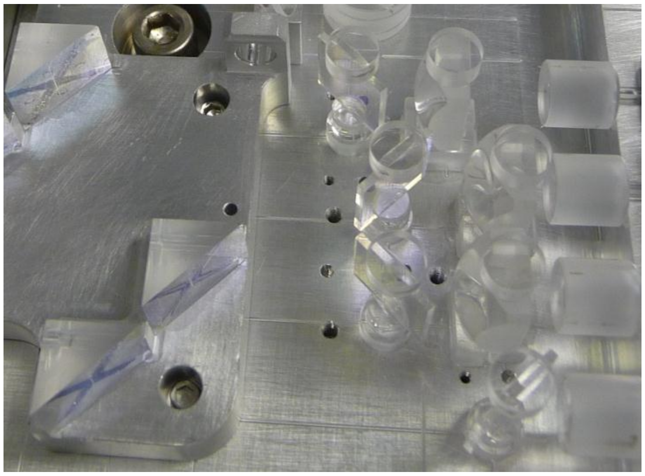

Figure 1: Example of Bond in Place Optics

UV Cure Epoxy Selection

Application of the laser assembly, which has embedded environmental issues, is the primary driver for material property selection of various UV curing epoxies available. For example, a laser mounted on a terrestrial vehicle will mostly need high tensile strength whereas a laser mounted on a satellite will need shock resistance to survive launch and low out-gassing to protect the optics from contamination. There are many suppliers that offer UV curing epoxy products. The most common ones are listed table 1 below.

Supplier	**Contact Information**
3M Adhesives	www.3m.com
Ablestik Electronic Materials & Adhesives	www.ablestik.com
Armstrong Products	http://www.ellsworth.com/ArmstrongEpoxy.html
Dow Corning	www.dowcorning.com
Dymax Corporation	www.dymax.com
Eastman	www.eastman.com
Emerson and Cuming	www.emersoncuming.com
Epoxy Technology	www.epotek.com
Extreme Adhesives	www.extremeadhesives.com
Fiber Optic Center (distributor of AngstromBond)	www.focenter.com
GE	www.ge.com
Loctite Corp.	www.loctite.com
Master Bond, Inc.	www.masterbond.com
Norland Products	www.norlandprod.com
Summers Optical	Http://www.emsdiasum.com/summers/optical/cements/default.htm

Table 1: List of UV EPOXY Suppliers

Table 2 displays a selection of five products that Norland offers. The full range of products available can be found at the website listed in table 1. The range of material stiffness is quite broad and shown with corresponding elongation at failure. This parameter is critical when considering mechanical stress and thermal cycling. The value of this characteristic will be shown in the example to follow in section “Stress Analysis”. NOA 88 is clearly the choice epoxy for low pressure environments due to the low out-gassing characteristic. While NOA 60 is declared as the general purpose adhesive, many optical engineers prefer NOA 71 as the general purpose adhesive for optics in laser systems above the mW regime because the optical clarity ensures transmission and not absorption of stray light. Optical systems built for the military must adhere to specific requirements that define performance over time. These qualifications are very time consuming and expensive so it is useful to the consumer when a vendor already has a qualified product. For this vendor, the military spec is satisfied with NOA 61.

The room temperature viscosities of the epoxies in table 2 are all very similar. The 200-300 CPS range is thick enough to support a bubble for tacking, but thin enough that it will quickly wick in between two very close surfaces for a much stronger bond. Some other important characteristics that are not listed here, but should be addressed before purchase are curing shrink percentage, long term creep, thermal conductivity, and resistance to moisture. Each of these parameters will affect the performance of bond in either the short term or as degradation over time.

		ADHESION TO:		TYPICAL PROPERTIES				
Type	Description	Glass	Metal	Viscosity at 25 Degrees C	Modulus PSI	Tensile PSI	Elongation at Failure	Shore D Hardness
NOA 60	General purpose adhesive for bonding doublets, prisms or mounting components.	Good	Good	300 CPS	135,000	2,800	35%	81
NOA 61	Preferred adhesive for military optics. Meets MIL-A-3920. Used for optics exposed to temperature extremes. Low shrinkage.	Excellent	Excellent	300 CPS	150,000	3,000	38%	85
NOA 71	Provides a strong bond to glass surfaces and has excellent clarity for light guides and other applications.	Excellent	Excellent	200 CPS	55,000	1,300	43%	86
NOA 86	Low viscosity adhesive that meets Bellcore specification of 85C/85RH for bonding glass.	Excellent	Good	200-300 CPS	360,400	7,834	2.80%	75
NOA 88	Low outgassing adhesive for aerospace or electronic applications. Excellent transmission in UV range.	Excellent	Excellent	250 CPS	112,000	1,900	43%	90

Table 2: Norland Products

Mechanical Glass Selection and Geometry Options

The material used for the mounting structures is most commonly fused silica. For the knob, a much stronger material, sapphire, is used. The reason for choosing sapphire is that it allows a very strong clamping force for precision positioning without risk of chipping or cracking of the knob. Figure 2 shows an optical component being held by a jig during alignment before curing. The geometry of the mounting glass depends on the optic being held. For most mirrors, a split ring base with piston is sufficient to allow the necessary degrees of freedom. For lenses, a ball and socket will be more appropriate to allow more freedom in beam steering. If all six degrees of freedom are necessary for appropriate positioning, a combination of piston and ball and socket may be used. While this solution offers the most flexibility in positioning, more often a set of fused silica shims will be used to control the optic height instead of a piston assembly.

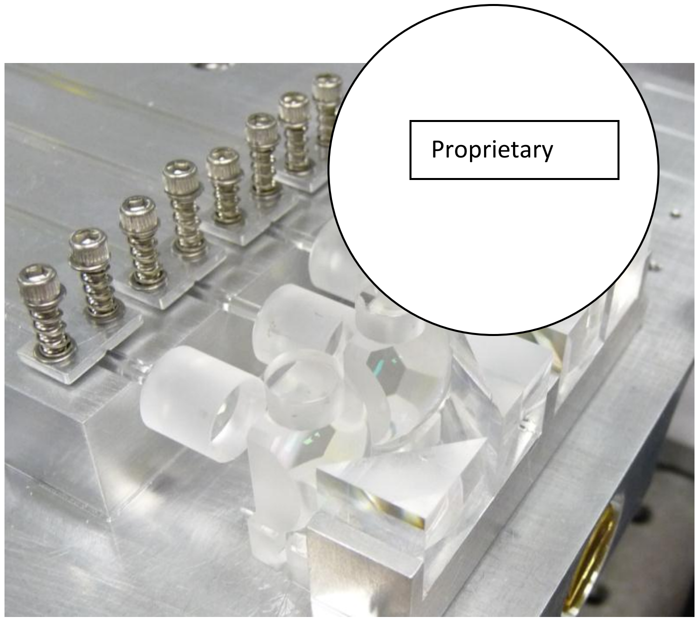

Figure 2: Mechanical Glass Example

Figure 3 shows an example split ring and piston assembly. Figure 4 shows an example split ball and socket assembly. Grinding of optics may be necessary to provide a strong bond as shown in figure 5. A much simpler solution for low mass optics that does not require precision positioning is to do a face bond, figure 6.

Figure 3: Split Ring and Piston Mount

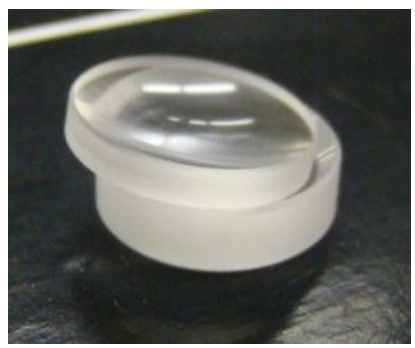

Figure 4: Ball and Socket Mount

Figure 5: Edge Ground Optic for Mounting

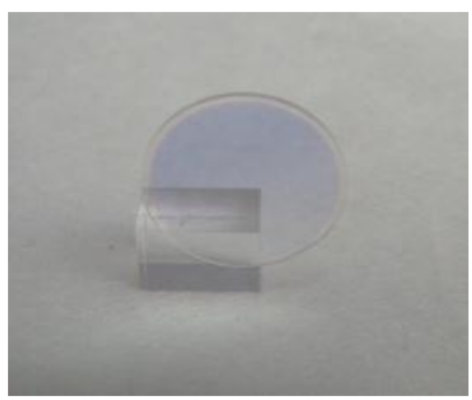

Figure 6: Face Bonded Filter

Other geometries for positioning of optics require some finesse when working in extremely tight spaces. See figures 7 and 8.

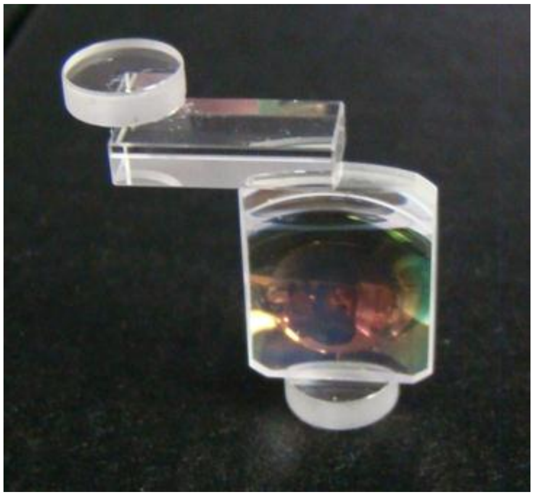

Figure 7: Odd Positioning Geometry Example 1

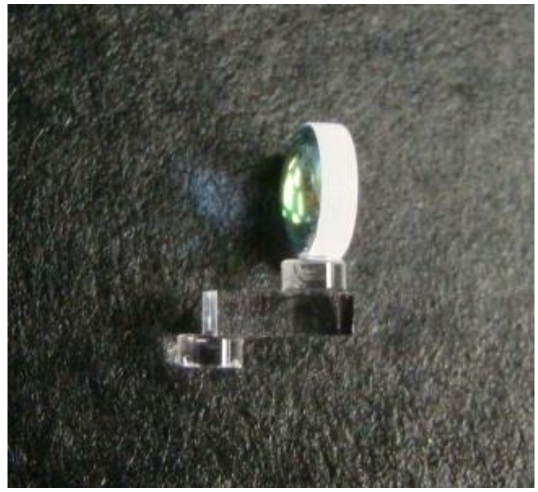

Figure 8: Odd Positioning Geometry Example 2

UV Lamps

Once the epoxy has been applied and the optic aligned, it is time to cure. Several UV curing lamps are available from the various suppliers of UV curing epoxy as well as other optical technology companies. Norland Products currently offers 9 options for lamps. A basic outline of their lamps with performance is shown in table 3.

Light Source	**Cure Area**	**Intensity** (*microwatts*/sq. cm)	**Recommended Distance**
4 Pole Multi-Pole LED	0.5" diameter	10,000,000	0.5 inches
Opticure LED	0.5" diameter	1,000,000	0.5 inches
Opticure 4	0.5" diameter	40,000	0.5 inches
Polylux 500	4"x5"x2"	8,000	N/A
Black Lamp (spot bulb)	2" diameter	14,500	6 inches
Black Lamp (flood bulb)	7" diameter	6,000	6 inches
Splice Lamp	1.5" x 2"	2,500	1.5 inches
Mini Lamp	5/8" x 4"	2,000	1.5 inches
Bench Lamp	4" x 15"	2,000	4 inches

Table 3: UV Curing Lamp Options from NOrland Products

Stress Analysis

The example shown in figure 9 represents two common considerations when determining suitability of an optical assembly for space applications. The first consideration is survivability within a specified temperature range and the second is survivability of the random shock and vibration forces experienced during launch.

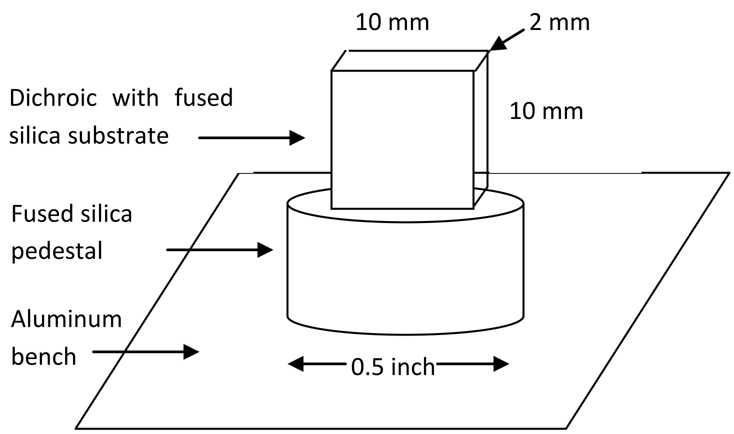

Figure 9: Dichroic bonded to pedestal bonded to Aluminum substrate

Based on standard specifications from NASA, the temperature range is +/- 20 C and the max shock force is 1200 g's. The full analysis shown in the Appendix reveals that each of the five candidate epoxies from table 2 will satisfy the requirements. The total elongation of epoxy under the temperature range is 0.72% and the total stress when shocked in the weaker dimension of the dichroic is 450 psi. All of the epoxies available satisfy these requirements so NOR 88 is selected as the most appropriate epoxy for its low out-gassing feature.

Conclusion

With the multitude of UV curing epoxies available, it is very important to select a product that most closely resembles the ideal epoxy for the assembly. Some characteristics are "nice to have" such as low shrink curing volume with a stiff epoxy to reduce internal and external stresses. These types of features may help distinguish one product after other mechanical requirements are met. Some characteristics are "need to have" such as low out-gassing for low pressure optical systems or qualification of military or telecom standards. In this case, the bond line thickness or other potting geometry must be engineered to accommodate the significant properties of the epoxy chosen. As there is no value in reinventing the wheel, it is advisable that every epoxy evaluated for an assembly be catalogued for advantages and disadvantages regardless of being selected for the current project.

References

http://www.norlandprod.com/

Andrew Clements, “Selection of Optical Adhesives”, Technical Paper, University of Arizona, 2006.

J. Burge, Course notes, OPTI 521 Introduction to Optomechanics, University of Arizona, 2011.

Appendix

al : aluminum
fs : fused silica
ep : epoxy
D: dichroic
P: pedestal
DD: density

```
Eal = 69 * 10^9;
Efs = 73 * 10^9;
Eep71 = 3.8^10^8;
Eep86 = 2.5 * 10^9;
Eep88 = 7.7 * 10^8;
CTEal = 23.6 * 10^-6;
CTEfs = 0.55 * 10^-6;
CTEep = 100 * 10^-6;
Dl = 10;
Dw = 10;
Dth = 2;
Pdia = 12.7;
Ph = 6.4;
DDfs = 2.201;
```

Temp Excursion

Note that the substrate of the dichroic mirror is fused silica.
The common temperature survival range for a launch payload is 0 to 40 C so with room temp at around 20 C,
$\Delta T = \pm 20°\ C$
The vendor recommended bond line thickness is 25 um.

$$\Delta T = 20;$$

$$\Delta al = \frac{Pdia}{2} * CTEal * \Delta T;$$

$$\Delta bs = \frac{Pdia}{2} * CTEfs * \Delta T;$$

$$Elongation = \left(\frac{\sqrt{0.025^2 + \Delta al^2}}{0.025} - 1\right) 100;$$

Radial aluminum growth is 3 um
Radial fused silica growth is 70 nm, we can ignore the thermal expansion of the fused silica
The elongation of the epoxy is 0.72%.

Shock Force

```
g  = 9.8;
g1 = 1200;
```

Optic to Pedestal (force along short edge)

```
Voptic = Dl * Dw * Dth;
Moptic = Voptic / 1000 * DDfs;
```

$$F1 = g * g1 * \frac{Moptic}{1000};$$

$$\sum M = F1 * Dl / 2 - Mal = 0$$

$$\sum F = F1 - Fal = 0$$

```
Mal = F1 * Dl / 2;
Fal = F1;
TotalForce = Mal + Fal;
TotalStress = TotalForce / 0.00001;
TotalStressPSI = TotalStress * 0.000145038;
```

The total stress on the epoxy under the weakest condition is 450 psi. This gives a safety factor of 3 for the weakest of the considered epoxies.