

Optical bonding agents for IR and UV refracting elements

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ABSTRACT

The few coupling materials useable as optical bonding agents in the UV and IR are reviewed. The need for suitable optical cements for the wavelength regions below 250 nm and in the window bands above 3 μm still exists.

1. BACKGROUND

There is an abundance of bonding agents or optical cements for visible-region optics. Gone are the days when the optician needed to travel to the forest in search of Canadian balsam. Cements are commercially available in a variety of refractive indices, rigidities, and thermal properties to satisfy virtually any requirement for glass optics. Outside the visible region, specifically below ~ 350 nm and above ~ 2000 nm, few materials qualify as optical cements because the transition and mechanical bonds of their molecular structure impose absorption bands in the transmission spectra.

The desirability of optically bonding IR components and the problems associated are revisited periodically. The published material for IR cements begins with Ishmuratova and Sergeyev, who in 1967 reported on the transmission spectra of polymer compounds out to 13 μm .¹ The high molecular weight groups have absorption bands throughout the region. The compound found to be the most transparent up to 8 μm was a silicone resin. In 1970, Packard at NASA Electronics Research Center² found that an epoxy resin showed low absorption in the 3.5-6 μm region and acceptably low absorption at 10 μm in thicknesses < 25 μm . His interest was in encapsulating HgCdTe detectors for cryogenic operation. During the years 1972-74, an extensive study was conducted by Williams and Foust at NWC (China Lake). The transmittances of 53 cement candidates were reported³ for the spectrum 200 nm to 15 μm . For the general IR region, members of the cyanoacrylate family ("super glues") were the most transparent. Epoxy resins with either amine or anhydride curing agents (room temp and elevated temp. cure, respectively) showed useable transmission in parts of the IR.

In 1987, Turtle⁴ reexamined many candidate organic compounds and found that when the layer thickness was reduced to < 0.5 μm , the troublesome absorption bands would virtually disappear. Since this thickness is much less than the wavelength of the IR energy, the index mismatch with the high index substrate was reduced in magnitude, thus the interface reflection loss was reduced. A problem encountered with thin layers is the presence of particulates of the same size as the layer thickness. Another disadvantage of layers this thin is that their elasticity is lost and high interface stresses can be generated between dissimilar optical materials when they are thermally cycled.

Recently acquired information from Russian workers reveals their interest in IR cements. Optical glues were studied by the Chernovtsy University Technology Laboratories in connection with HgCdTe detector production. Cement candidates from the GOI (State Institute of Optics), the institute of organic chemistry, and the Chemistry of Colloids Institute were tested by cycling to cryogenic temperatures. Most compounds cracked and delaminated with thermal cycling. Two materials based on epoxy resins (ERN-05 and ED-850) qualified in layer thicknesses near 3 μm .

All of the candidate IR cements and couplers suggested or studied have refractive indices near 1.5. This results in a reflectance value at a Ge/cement surface of 21%, for example. The situation is

better for UV materials whose indices are generally less than 1.8. Candidate cements for the short wavelengths have indices also near 1.5, resulting in coupled surface reflectances <1%. The difficulty encountered when searching for UV cements is that the electronic absorptions are so strong that complete cut off of transmission occurs, with no window bands appearing at shorter wavelengths. This review summarizes the current state of the technology.

2. REQUIREMENTS OF AN OPTICAL CEMENT

For a material to qualify as a cement, or more correctly an optical and mechanical bonding agent, it must provide the following properties. The refractive index must ideally be equal to that of the lenses that are being coupled. This is important not only to eliminate surface reflection, but also to permit aberration correction in multielement imaging lens groups. The bonding agent must maintain a mechanical and optical bond integrity when exposed to thermal stresses, moisture, and in some applications, vacuum. The cement must not introduce mechanical stresses upon curing that would distort the optics or disrupt any coatings that might be present. The thermal expansion coefficient must match that of the optical components over the range of operation. When called upon to couple dissimilar glasses, a certain degree of flexibility or pliability is desired to accommodate differential expansion without the generation of compressional or tensile stresses. From the perspective of the optical assembler, cements must retain a workable viscosity during the centering of the elements, and must be easily cleanable. In special applications, high damage threshold to laser energy and stability to high energy particulate radiation are required.

3. BEYOND THE VISIBLE: THE NEED FOR OPTICAL BONDING

Until the introduction of synthetic compounds such as polyester resins, methacrylates, epoxies, etc., Canadian balsam was the only cement available for visible optics. These compounds satisfy nearly all of the requirements for bonding glass optics. There is no such substance for IR or UV optics. The available optical cements are useable only between ~350 nm and 1000 nm. (The visible cements are covered in the paper 1535-06)

Matching the index of an optical element in the UV and the IR is important to prevent surface losses and stray reflections because the refractive indices of the crystalline and glassy optical materials used outside the visible are relatively large. Dispersion in the UV produces index values increasing to 1.8, which results in an air-surface reflectance of 8%. The most commonly used IR materials have an index between 2.2 and 4, while calcium aluminate and some crystals have indices below 1.6. The surface reflectances can be as large as 36% (uncoated Ge).

Unlike glass optics, IR systems are limited in wide angle performance by the angles of refraction permitted at the surfaces of the lens elements in the absence of a high index cement⁵. Because the elements cannot be cemented, wide angle IR designs cannot be built and wide field coverage for FLIRs, remote sensing spectroradiometers, and other IR systems requires the use of an object space scanning mechanism such as a mirror system. Steep radii are required for field coverage and aberration correction in high f/no systems. The ray angle maximum is limited to the critical angle for the lens-to-air interface. Reduction of the index ratio increases the angular acceptance. Therefore, cements with refractive indices between 2 and 3 are needed for use with ZnSe, Ge, and calcogenide optics.

4. POSSIBLE SOLUTIONS

Suitable materials for optical bonding in the UV and particularly the IR regions are still not available. New compounds need to be developed; the technology is material limited. Given that state of affairs, what is available to the designer and engineer?

A Ultraviolet Materials

Silicone compounds, specifically polysiloxanes, are useable to wavelengths as short as 230 nm for thicknesses $<50 \mu\text{m}$ ⁶. Of the variety of electronic grade silicones, a few have been refined to remove the monomers and other components that might absorb, or for vacuum applications, outgas condensable effluents. These materials have the property of retaining flexibility when cured, which is an advantage in an environment which produces thermal variations. The durometer Shore A hardness is about 45 for a cured mixture containing 10% hardener. The hardness can be reduced with lower hardener percentage. Pliability is maintained to -60°C .

Silicone compounds found one of their first applications as optical cements in balloon- and space-borne UV instruments. They proved especially valuable in bonding calcite crystals whose crossed axes presented asymmetric thermal expansion coefficients. The flexibility of the bond enabled the heat sensitive crystals to survive operation beyond Jupiter⁷, where, additionally, they encountered high energy particulate radiation densities without degradation. The material used was a polymerized methyl silicone compound 93-500 produced by Dow Corning. A similar compound (CV-2500) is produced by McGhan-Nusil Corp. The silicone resins do not form strong bonds as epoxies do, but for lightweight optical components, the bond is sufficiently strong to tolerate shearing forces.

B Infrared Materials

The choices for wavelengths above $3 \mu\text{m}$ carry more limitations than those for UV-VIS regions. Compounds such as Epo-tek 301, Aron Alpha 101 and 201, Eastman 910 (PermaBond), and Eastman Kodak HE-S-1 can be used in thin layers ($<10 \mu\text{m}$ thickness) to provide good transparency in the 3.5 to 5 and 10 to $11.8 \mu\text{m}$ bands. Severe absorption bands appear at other wavelength regions. The HE-S-1 is a modified butyl methacrylate that is shipped refrigerated to prevent polymerization. It has a visible index value of 1.49. An example curve for the HE-S-1 from the NWC study is shown in Fig. 1. Polyimide is another material that is highly transparent between 1 and $12 \mu\text{m}$ with few absorption bands, and deserves further investigation. The choice of material will be influenced by the thermal environment of the application.

A second approach which provides a better index match for the high index IR optics uses transparent low melting materials such as arsenic sulfide or selenide with indices near 2.5. Thick layers of the material are deposited on the surfaces to be bonded, then the assembly is heated to cause softening and reflow. A relatively high temperature is needed to cause plasticity and reflow, therefore, it is necessary to prevent oxidation of the polished lens surfaces from occurring. The obvious negatives are the toxicity of these materials, and the possibility of thermal mismatch and non-wetability with some lens materials. For these reasons, this approach has not developed a following, and has been virtually abandoned.

The third approach incorporates the low index resins and epoxies mentioned above, but reduces the admittance mismatch at the surfaces through appropriate coatings. Figure 2 shows the internal transmission in the 7 to $13 \mu\text{m}$ band of two germanium lenses coupled by a cement of index 1.5. The interference fringes result from the coherent addition of the surface reflections from both Ge lenses. In practice the modulation of these fringes would be reduced as the coherence path is reduced. The cement thickness is $13.4 \mu\text{m}$ in this computation. Better admittance matching through the use of multilayer coatings will also reduce the modulation amplitude of the interference.

Figure 3 shows the effect of adding QW (at $10 \mu\text{m}$) layers of ZnS ($n = 2.15$) to each Ge surface before cementing. Now the admittance matching is improved by the matching layer of ZnS. The average transmission is $\sim 95\%$. The coating index for perfect matching would be

$$n_{\text{film}} = \sqrt{n_{\text{Ge}} \cdot n_{\text{cement}}} = 2.44.$$

Therefore, a ZnSe film layer ($n = 2.35$) would provide an even closer match.

Figures 4 and 5 show the cementing of an AMTIR 1 lens and a Ge lens, with and without matching coating layers on the lens surfaces, respectively. The mismatch with a cement interface only creates a transmission loss of 25% average, Fig 4. When matching QW layers of ZnSe and Y₂O₃ are added to the lens surfaces before cementing, the transmission in the 8 to 12 μm band is increased to ~95%, Fig 5. Not only is the throughput efficiency increased, but a source of ghost images and stray radiation is reduced in intensity.

5. CONCLUSIONS

It is evident from this review that the state of the art for cementing optics for the UV, and especially for the IR, is unsatisfactory. Designers have avoided cemented lens components because there is a serious lack of suitable cements. Alternate solutions have been devised for achieving wide field coverage and for decreasing the losses due to high surface reflectance from IR materials. Instrument cost, complexity, reliability, and size would all benefit from the development of bonding agents for the IR region.

6. REFERENCES

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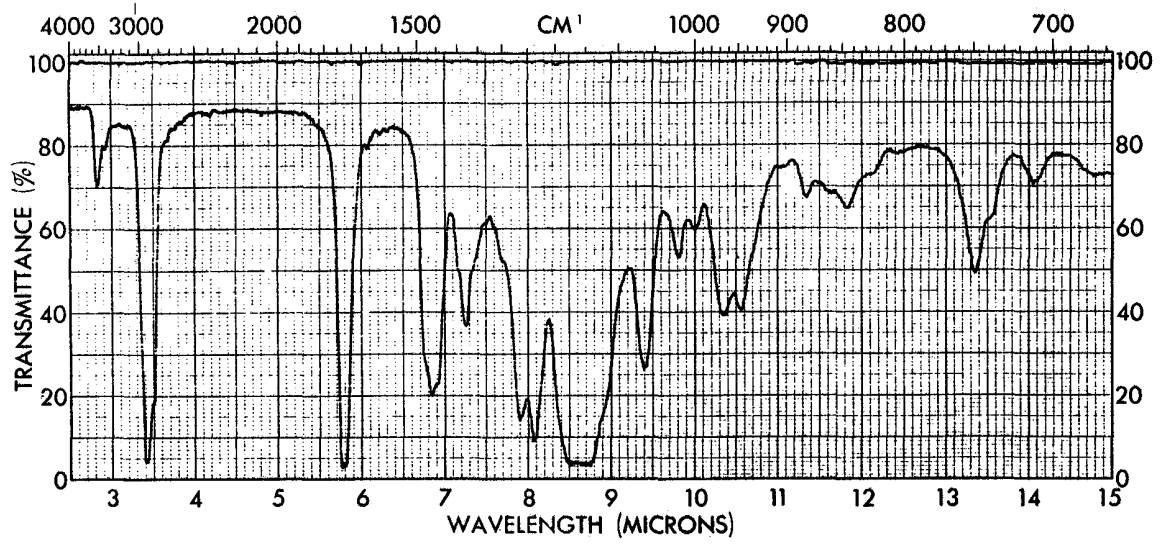


Figure 1. Transmission of a 12 μm layer of Eastman Kodak HE-S-1 used to cement sodium chloride windows. (From the NWC study)

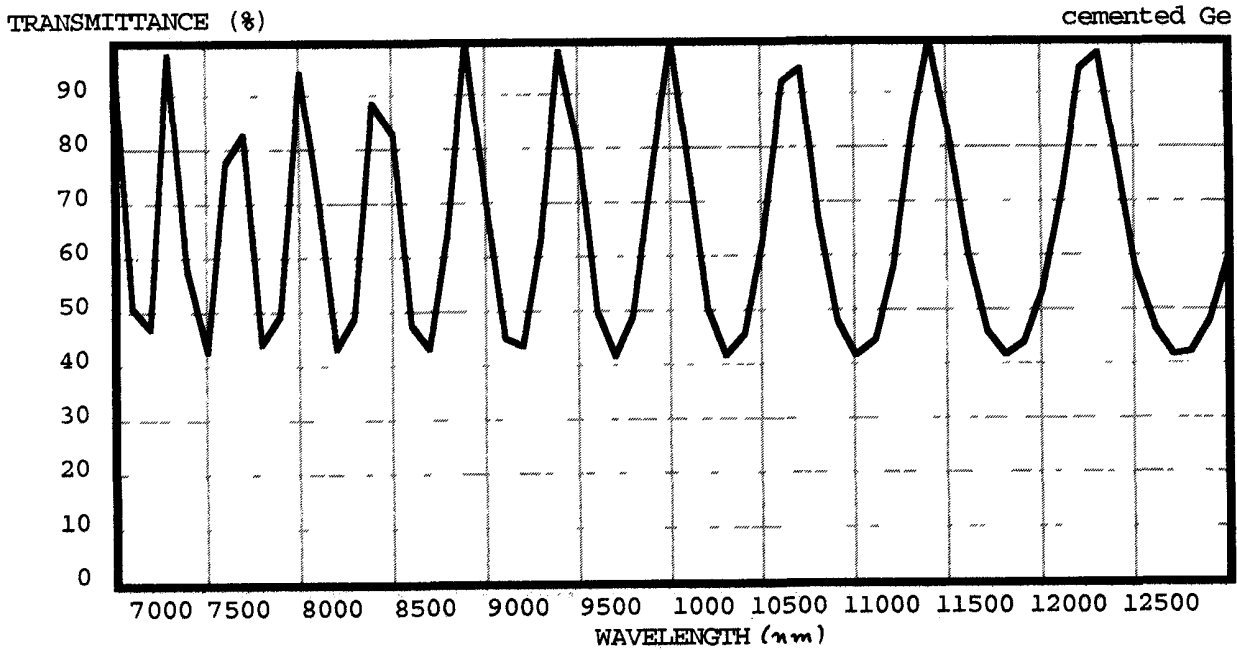


Figure 2 Computed internal transmission of two germanium lenses bonded with an epoxy-type cement of index 1.5. The bond layer is 13.4 μm thick. Interference fringes result from coherent reflections from the interfaces between cement and Ge. The average transmission is $\sim 70\%$.

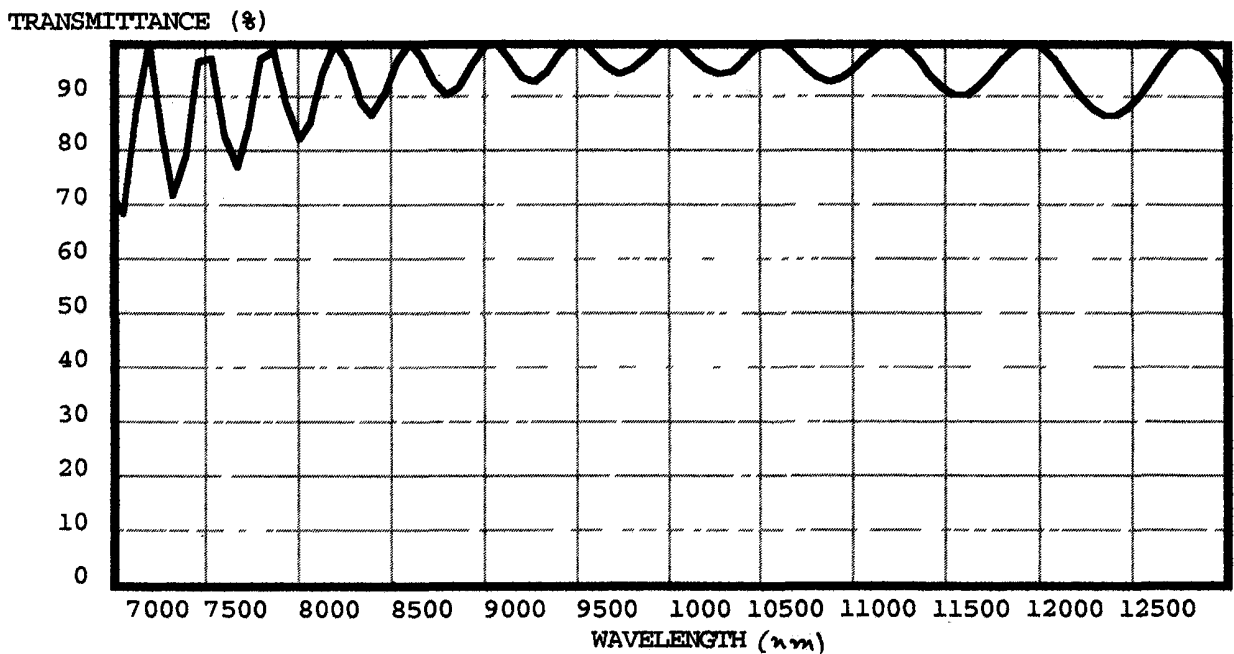


Figure 3 The internal transmission for two Ge lenses whose surfaces are coated with QW layers of index 2.15 before cementing. The improved admittance matching results in lower reflection loss compared with Fig. 1.

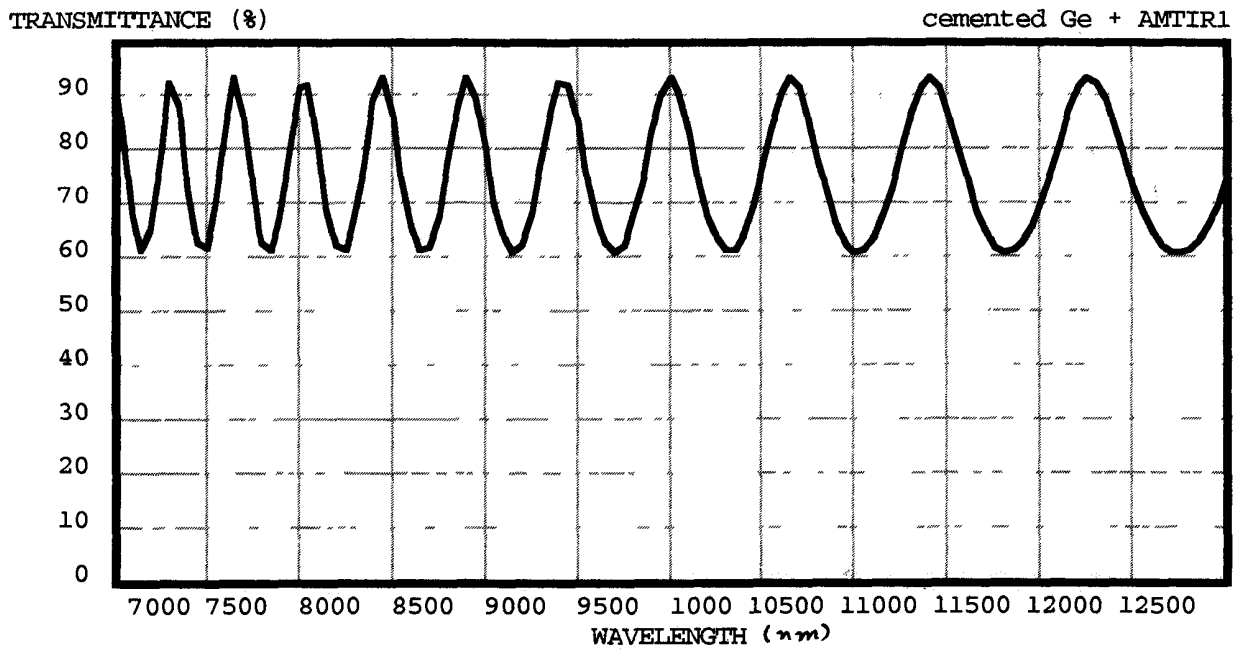


Figure 4 Internal transmission of an AMTIR 1 and Ge lens pair cemented with an epoxy-type material of index 1.5

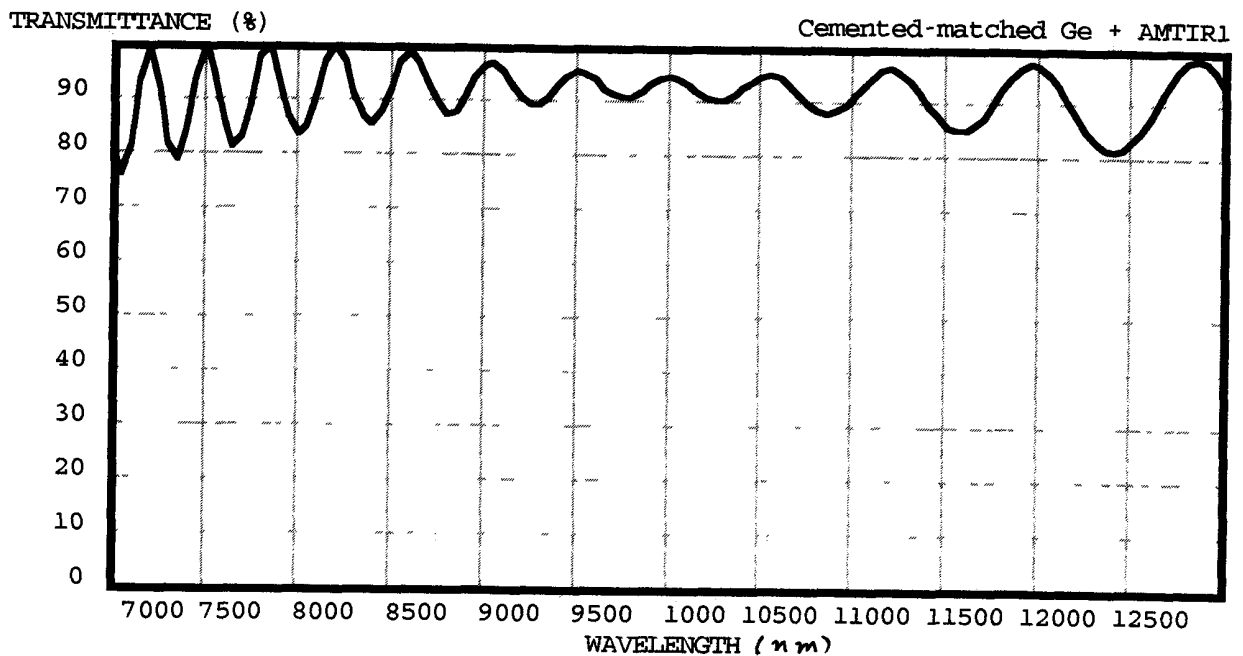


Figure 5 As for Fig 3, but with matching layers applied to the lens surfaces before cementing