

Optical Contacting: Changing the Interface of Optics

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Figure 1: Optical contacting is used to manufacture micro-optic assemblies, cubes and etalons.

Micro-optic systems consisting of prisms, beamsplitters and other optical components are used across a variety of industries from telecommunications to biophotonics. **[Fig 1]** They can increase the efficiency of fiber-optic and endoscopic imaging systems in medical and biophotonic applications, lock the wavelength of telecommunications transmitters, and increase the lasing efficiency in high-power lasers. The optics in these micro-systems are bonded together so that no extra fixturing is required.

Various processes such as epoxy bonding, frit bonding, diffusion bonding, and optical contacting, have been employed. The quality of the bond/interface is judged on several criteria including: precision, mechanical strength, optical properties (scattering, absorption, index mismatch, and power handling), thermal properties, and chemical properties, along with the simplicity and manufacturability of the process itself.

One of the most common methods to adhere two pieces of optical glass is epoxy bonding. The two pieces are coated with epoxy, brought together, and cured (time, temperature or UV exposure). Epoxy bonding is reliable and manufacturable because it is an inexpensive

process with high yield. However, because it leaves an often thick and variable film, it is inappropriate for applications requiring precision thickness control. Scattering can occur in these optically thick interfaces introducing loss. And, because the epoxy is often made from organic material, these bonds cannot withstand high-intensity optical powers or UV exposure. Moreover, epoxy bonds are not particularly heat resistant or chemically robust. Because the pieces are “floating” on a sea of epoxy, the pieces can move under various thermal conditions. The epoxy can also dissolve with chemical exposure. In a vacuum environment, the epoxy can outgas and contaminate other optics. For these reasons, there is great interest in epoxy-free bonding technologies.

Frit bonding, a process that uses a low-melting-point glass frit as an intermediate bonding agent, is widely used for both optical and MEMs applications. It is an epoxy-free process, where the substrates are polished, cleaned, and coated with a glass frit. The pieces are baked together at high temperatures (in the range of 400-650°C) and with moderate pressure. The benefit is that the bond is mechanically strong and chemically resistant. However, there are several drawbacks. Because the melted glass frit bonds the parts together, the frit must be able to flow between the parts. In some cases, the parts are grooved to enable the frit to flow evenly, increasing scattering in the final interface. Moreover, the process is expensive due to the requirement that the fixtures must withstand extremely high temperatures. And, these high temperatures can cause changes in the physical and chemical properties of the materials themselves, including changes in dopant concentrations and or structural changes.

Another epoxy-free bonding process is diffusion bonding. Here, the two optical pieces are heated and then pressed together. Since the bonding process relies on the atomic diffusion of elements at the interface, the required temperature can be up to 80% of the melting temperature of the substrates themselves (often greater than 1000°C). In the diffusion process, the atoms

migrate through the solid, either by the exchange of adjacent atoms, the motion of interstitial atoms, or the motion of vacancies in the lattice structure. Developed as a cost-effective method for the fabrication of titanium structural fittings (instead of costly machining) for military aircraft systems including the B-1 bomber and the Space Shuttle, the two substrates of glass, ceramic or metal must be in very close proximity for the diffusion process to take place. Initial surface flatness and cleanliness are essential. Because the material is heated up, expensive fixturing is required, and chemical changes can occur (dopant concentrations can be altered). Onyx Optics uses diffusion bonding as part of their patented AFB[®] (Adhesive-Free Bond) process.

A room-temperature bonding process that results in an optically transparent, precision bond is optical contacting. In traditional optical contacting, the surfaces are polished, cleaned and bonded together with no epoxies or cements and no mechanical attachments. Optical contacting has been used for years in precision optical shops for blocking optics for polishing because it removes the dimensional uncertainty of wax or adhesives. Because it is not very robust and can be easily “broken”, the parts must be sealed around the edges to prevent breaking the contact. Today variations on traditional optical contacting, however, can create precision, optically transparent bonds that are robust and mechanically strong.

Optical contacting has a long history. The adhesion of solids was first observed two centuries ago. Desagulier in 1792 first demonstrated the bonding of two spheres of lead when pressed together. [i] Because the sphere deformed in the process, this could not be used for rigid materials such as quartz and fused silica. About a century ago, German craftsmen used the technique “Ansprenge”, meaning “jumping into contact” to adhere two optically polished bulk pieces of metals for precision measurements. They used an analogous technique with optically polished glasses for making precision prisms. Nonetheless, it was not until 1936 that a systematic investigation took place with Lord Rayleigh’s studies of the room-temperature adhesion mechanism between two optically polished glass plates. [ii]

To create robust and strong optical contact bonds, a number of companies perform a modified “adhesive-free” or “epoxy-free” optical contact bonding. These

epoxy-free processes result in a bond as strong as if the entire structure had been made from a single piece of material, and bonds have even passed Telcordia’s stringent requirements for durability, reliability and environmental stability. Because these parts are epoxy free, they can withstand high optical powers and low temperatures.



Figure 2: Optical contacting is used in the manufacture of composite high-power optics structures.

There is no scattering or absorptive losses at the interfaces, and no out-gassing; the bond is chemically resistant and can be used with a wide variety of materials—both similar and dissimilar crystals and glasses can be bonded. Thus, modern day uses of optical contacting include composite high-power laser optics (structures that have a doped “core” with a different cladding material), micro-optics, cryogenic optics, space optics, underwater optics, vacuum optics and bio-compatible optics [Fig 2].

Almost all modern-day optical contacting processes use a variation of “wafer bonding”—an analogous process in the semiconductor industry. These processes include an extra step to create covalent bonds across the interface—a bond that is significantly stronger than that formed from traditional optical contacting. This extra step can be increased pressure, chemical activation and/or thermal curing. For example, one “solution-assisted” process uses an alcohol-based optical cleaning solution (isopropyl alcohol or similar) so the parts can be aligned before the alcohol evaporates. [iii] This facilitates alignment of the optical components and eliminates one disadvantage of conventional optical contacting: it is

difficult or impossible to adjust the alignment once the components have bonded [Fig 3]. The solution forms a weak bond that strengthens as the alcohol evaporates, typically about one minute. While this solution-assisted process addresses the alignment issue, there are still tight requirements on the flatness and cleanliness of the pieces.

Another epoxy-free optical contacting process is “Chemically Activated Direct Bonding” (CADB). Developed by Precision Photonics Corporation, it is a highly repeatable and manufacturable process that relies on a well-studied chemical activation. CADB results in a bond as strong as bulk material, as precise and transparent as optical contact bonds, and as reliable as high-temperature frit bonding. Most importantly, it can be performed with high yields, and with a variety of materials, including dissimilar materials.

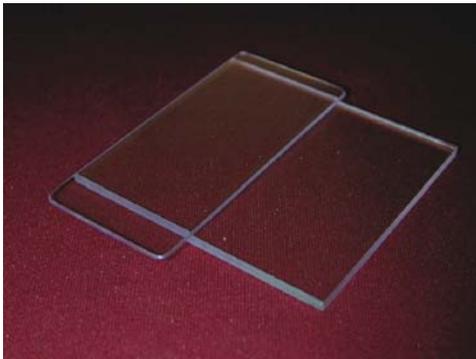


Figure 3: Today’s modified “solution-assisted” processes relax the incoming requirements, enabling optical contact bonding over large areas without any voids.

In CADB, the parts are polished, and physical and chemical contaminants are removed. The surfaces are chemically activated to create dangling bonds. The two parts to be bonded are brought into contact with each other and the outer molecules from each surface bond together through hydrogen bonding. The parts are then annealed at a temperature specific to the substrate materials. During annealing (at temperatures well below melting temperatures), covalent bonds are formed between the atoms of each surface, often through an oxygen atom. CADB has been successfully used for a variety of applications including composite bonding of

dissimilar materials where it is typically only limited by the mismatch of the coefficient of thermal expansion of the materials. Materials combinations that have been bonded together successfully include YAG/sapphire, quartz/BK7, and fused silica/Zerodur®.

CADB can also be used to bond coated materials. Ion-beam-sputtered (IBS) and ion-assisted (IAD) coatings are hardy enough to withstand the bonding process. IBS is a repeatable and controllable high-energy process that results in dense, durable, dielectric thin films. Because the molecules in the IBS process are deposited at a high average energy (unlike evaporative or ion-assisted processes that are low energy), the molecules form covalent bonds. The resulting films are extremely uniform and non-porous, and offer superior adhesion. The deposited molecules in the IBS process have energies of approximately 10 eV, or 100 times their thermal energies.

In summary, optical contacting, since it was first observed over 200 years ago, has evolved from “black art” to a highly manufacturable and repeatable process used in the manufacture of a variety of components from wavelength lockers for telecommunications to composite laser structures for high-power applications. Optical contacting results in epoxy-free optical paths that are 100% optically transparent with negligible scattering and absorptive losses at the interfaces. Today’s optical contacting methods offer increased robustness and flexibility than traditional optical contacting. For example, CADB can be used to bond a variety of materials including crystal, glass and ceramic (fused silica, LaSFN9, Zerodur®, BK7, ULE, YAG, ceramic YAG, sapphire, YVO4, and doped phosphate glasses), and can also be used over large areas for high-volume applications, even on ion-beam-sputtered and ion-assisted dielectric thin films.

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- i. D. Dawson, *History of Tribology*, Longman, London, 1979.
 - ii. Lord Rayleigh, “A study of glass surfaces in optical contact,” *Proc. Phys. Soc.*, A156, 326 (1936).
 - iii. Daniel Shaddock and Alexander Abromovici, *NASA Tech Briefs*, March 2004, “Solution-Assisted Optical Contacting: Components in optical contact can be adjusted for about a minute.”



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