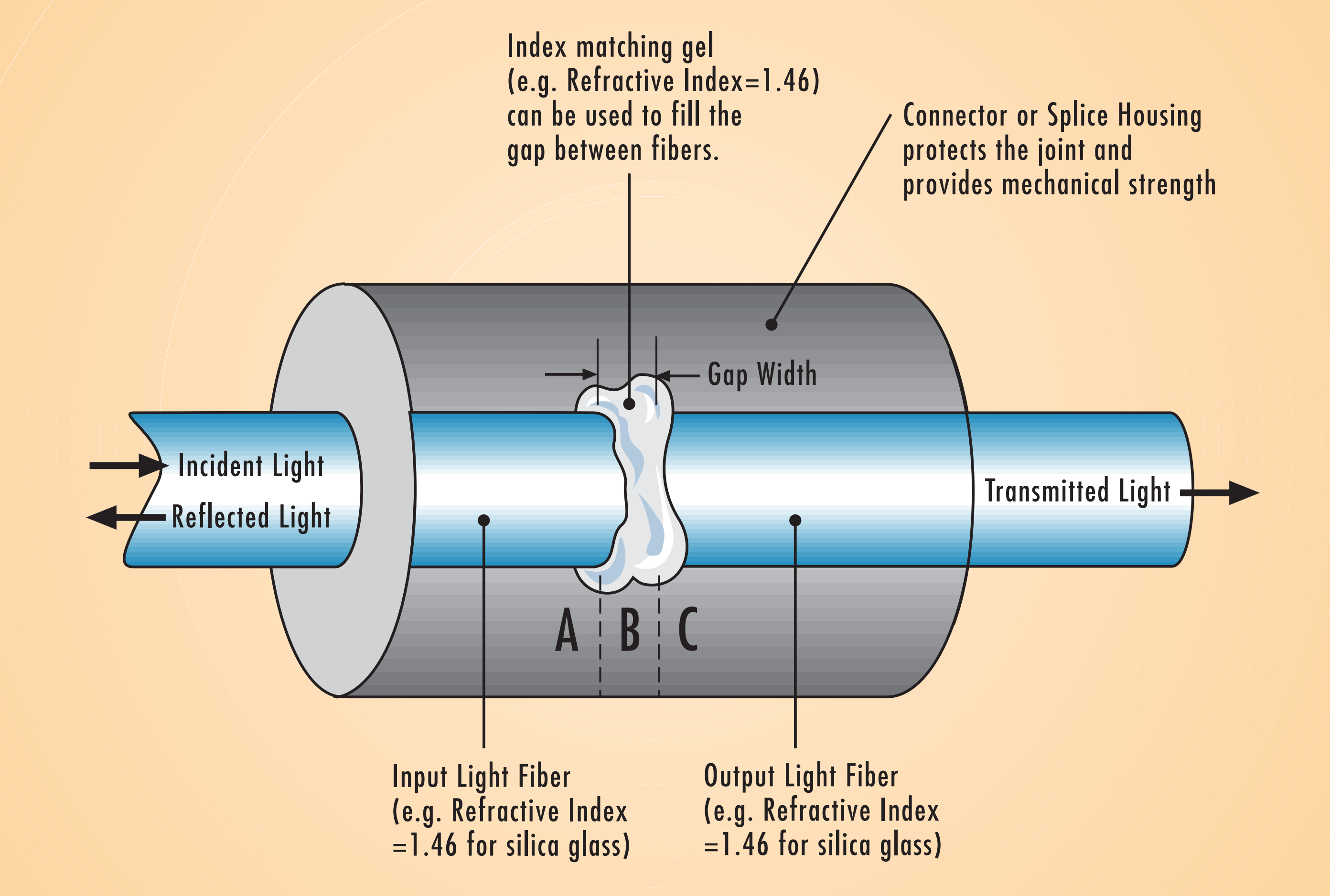
Optical Gels:

A Light Bridge to the Future



Design engineers throughout the photonics industry are discovering something that 3M, Lucent Technologies, and other manufacturers of fiber optic splices learned in the 1980s: Index-matching gels are a cost-effective way to simplify design, improve reliability, and extend operating life.

When fiber optic cables were adopted by the telecommunications industry, necessity mothered the invention of an "optical splice." Unlike metal wires, splicing strands of glass required precise alignment and an electric arc to form a "fusion

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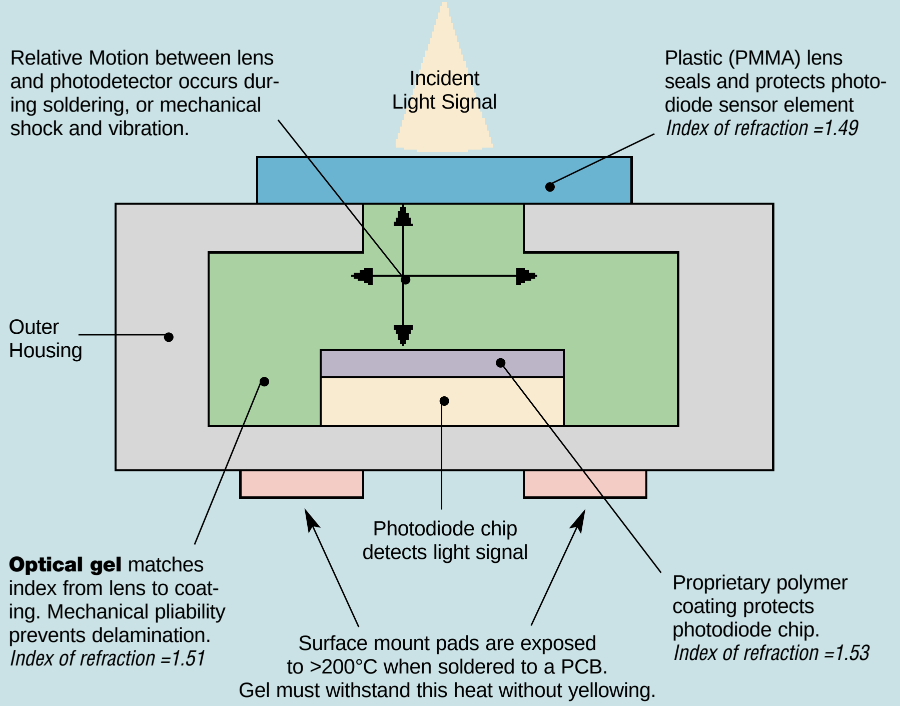
Interconnect Geometry

A lightwave flows from the left through silica fiber, which has index of refraction of 1.46. It encounters the gap at the end of the silica fiber at the A/B interface. If the gap (B) contains air whose index of refraction equals 1, a fraction of the light is reflected back to the left while the balance of the light signal continues on through the gap to the right. Here it encounters the second fiber (C) and undergoes a second reflection. When the light signal emerges from the interconnect at the right side, it will have suffered a significant net reflection. Since the amount of signal reflected depends on the difference in refractive indices between the gap and the fiber, an index-matching gel in the gap, equal to the refractive indices of the two fibers, is very effective at minimizing reflections.

Using an Optical Gel in a Photonic Device



Using an Optical Gel in a Photodetector

The lens in this example is an engineering plastic with an index of refraction of 1.49. The photodiode element has an outer polymer coating with an index of refraction of 1.53. A curing optical gel is chosen to fill the space between the lens and the photodiode. In order to optimize light transmission, a gel with an index equal to the geometric mean of the two adjoining materials is ideal, or, mathematically,

$$n_{GEL} = \{1.49 \times 1.53\}^{1/2} = 1.51.$$

The designers of this device also expect large dimensional excursions when this component is subjected to wave-soldering temperatures on a printed circuit board. In order to prevent delamination or damage to wire bonds, they specify the gel for ample pliability, in this case, a Shore 00 hardness of 15, like a slightly rigid version of gelatin pudding.

splice.” This was a tricky process that required extensive technician training and costly “fusion splicer” gear. Enter the “mechanical splice,” which skirted the cost and complexity issues encountered with fusion splices. Cleaved fibers were inserted into either end of the mechanical splice until they touched in the center of the housing. To minimize reflection at the unavoidable air gap between fiber end faces, the gap was filled with an optical fluid whose refractive index matched the silica glass. Since the amount of signal reflection depends on the difference in refractive indices, displacing air in the gap with the index-matching optical fluid allowed the light to flow from one cable to the other with minimal reflection. However, because fluids are prone to leakage, evaporation, and mechanical instability, their effectiveness was compromised. They were soon replaced with optical gels — crystal-clear, stable, index-matching, synthetic gels with wide-temperature serviceability and a 30-year service life, which are now the industry standard in mechanical optical splices.

GELS OR EPOXIES

Today, index-matching gels are finding their way into a growing number of electro-optic devices, including optical sensors, photodiodes, laser packaging, medical instruments, and flat panel displays. Sometimes they replace more traditional optical epoxies. While many optical epoxies provide excellent dimensional stability, adhesion, and tensile strength, their rigidity can literally be the undoing of an optical device. Optical epoxies can trap stresses in an optical assembly. At low stress levels, birefringence can be induced in nearby optical glasses and plastics, degrading performance of polarization-sensitive designs. Over wide service temperature ranges or under thermal shock or excessive vibration, epoxies can induce actual damage by fracturing or delaminating from glass or plastic. In a photonic assembly, such fractures often decrease light output, reduce sensitivity, increase reflection, or even cause catastrophic electronic failure. Under similar operating conditions, optical gels present a rugged alternative to

Nye Optical Gels

The Nye Optical Coupling Kit contains three optical coupling products: a non-curing gel (Bellcore GR-2919, Refractive Index=1.46) used in many optical splices; a 2-part curing gel (Refractive Index =1.51) suitable for many electro-optic components; and a non-curing gel (Refractive Index=1.62) for higher index glass or plastic components. The kit is intended for design engineers who are prototyping new fiber optic or photonic products.

epoxies. While optical gels cannot assure high dimensional stability, their viscoelasticity provides strain relief between precision optical parts as they undergo small dimensional changes caused by thermal expansion, mechanical shock, or vibration. The ability of gels to move slightly in response to these stresses prevents the build-up of those stresses in adjacent optical parts. Nonetheless, optical gels, like epoxies, are non-migrating once they are in place. They will not wick or flow out of the assembly.

Optical gels come in two forms: curing and non-curing. Curing gels consist of an optical fluid and soluble thickening agents. Mixing and/or applying heat to the two components causes a chemical reaction that produces a soft cured elastomeric gel. Prior to curing, these products have a low pre-cure viscosity (100 to 1000 cP, the viscosity of motor oil), which enables them to be rapidly dispensed on an automated production line and wick into tight spaces within small optical assemblies. Once fully cured, these gels are chemically stable to temperatures in excess of 200°C. Because they are chemically reactive materials until cured, curing gels have a limited shelf life in their uncured form, typically about six months. Further, manufacturer’s mixing ratios and cure conditions must be adhered to strictly to achieve repeatable properties in the cured materials.

Non-curing gels are ready-to-use materials with no mixing regimens or shelf-life limitations. Because the consistency of non-curing gels ranges from that of toothpaste to hard putty, they are unsuitable for applications where the material must wick into tight spaces under surface tension alone. As with curing gels, once the non-curing gel material is dispensed and is at rest its thixotropic nature prevents it from flowing or migrating out of the optical assembly. Non-curing gels also remain chemically stable at 200°C and above.

SPECIFYING AN OPTICAL GEL

Once the decision is made between curing and non-curing gels, the key to an optical gel’s success in a photonic device is to match the gel’s properties to the design. There are 10 such “customizable” properties:

- Index of refraction of the gel optimizes light transmission. Ideally, the index of the gel equals the index of the mating glass or plastic, for example, 1.46 for fused silica or 1.66 for polyetherimide. If the gel is used to couple dissimilar materials, the gel index should equal the geometric mean of the indices of the two materials: ngel=(n1 x n2)1/2. Gel index values to 1.67 are available, with standard tolerances specified to ±0.005. Tolerances of ±0.0005 can be achieved.

- Apparent viscosity of non-curing gels is measured in centipoises, where soft putty measures around 1 million cP. Softer gels are recommended when modest gel movement is required during device assembly. A stiffer gel is more appropriate for devices that are subject to high mechanical shock.

■ Hardness, which is measured on the Shore 00 durometer scale, refers to the stiffness of a curing gel in its cured state. The consistency of curing gels ranges from gelatin-like with self-healing characteristics to a hard rubber. Harder gels allow higher dimensional stability, while softer gels provide better strain relief.

■ Set time, which applies only to curing gels, is the length of time a gel will flow before taking on its final consistency. Sometimes called "pot life," set time can be specified from minutes to hours. Set time is dependent on temperature, as is the "full cure time" that is, the time when there are no further significant changes in the gel's mechanical properties.

■ Temperature service range for non-curing and curing gels ranges from below –65°C to +250°C. Note that viscosity, set time, and refractive index are all intrinsically related to temperature, so the full operating temperature range should be determined before specifying an optical gel.

■ Evaporation rate is often overlooked as a critical specification. Lower is better. Low evaporation rate prevents micro-bubble formation and "dry-out," which might not become apparent in the field until months or years of service. For applications extremely sensitive to outgassing, also specify the vapor pressure of the gel.

■ Thermooxidative stability, another often overlooked parameter, affects a gel's resistance to yellowing, hardening, or softening due to chemical changes over time.

■ Cleanliness refers to the amount of microscopic particulate contamination within the gel. Maximum particle count should be no more than 300 particles/cc for particle sizes 1 to 34 microns in size with no particles greater than 34 microns.

■ Clarity of the gel refers to the maximum allowed optical absorption per unit path length at the wavelength of intended use. For example, in fiber optic splices where the gel path is approximately 10 microns, optical absorption is less than 0.1%. Photonic devices do not usually require more than a few millimeters in gel path length, where optical absorption of a few percentage points or less is the norm.

■ Material compatibility ensures that base fluids and thickeners in the gel are compatible with plastics, elastomers, coatings, and adhesives specified in the design. ■

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