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Long-Term Reliability and Performance of Silicone-based Index Matching Gels in No-Epoxy, No-Polish Connectors

Introduction

As fiber optic cable is increasingly deployed in both private and public network applications, including fiber to the x (FTTx), the need to install connectors in the field continues to grow. Corning Cable Systems is an industry leader in field-installable connectors and offers both field-polished and no-epoxy, no-polish (NENP) connectors for these applications. Due to the installation speed, reduced set up/tear down time, deployment velocity, convenience and dramatic labor savings, the adoption of NENP connectors for field termination has shown a significant increase.

NENP fiber optic connectors utilize a factory-polished connector end-face in conjunction with a mechanical splice to provide seamless connectivity. The reliability and performance of the mechanical splice within the connector is enhanced through the use of index matching gel (IMG). IMG refers to a silicone-based gel designed to enhance the performance of mechanical splices and NENP connectors. The gel is formulated to have an index of refraction (IOR) which closely matches the IOR for the glass used in optical fibers. In addition, the physical properties of IMG are carefully controlled to ensure optimum performance in optical communication splices and connectors. The purpose of IMG is to reduce the reflectance between two fibers when they are joined in a mechanical splice. Using IMG allows for greater variation in field cleaves while eliminating the need for expensive fusion splice equipment or extensive training of technicians.[4] In these ways, NENP connectors using IMG are enabling true copper-like optical fiber subscriber connections – with a reel of cable, connectors can be easily installed, and the network connection is established in minimal time.

Although IMG has proven itself to be an enabling technology for more than 30 years,[2] most recently in FTTx applications, misconceptions surrounding IMG persist. These misconceptions include beliefs that the gel will lose optical clarity over time or temperatures, liquefy and leak from the connector, harden or crystallize, absorb liquids, and attract particles or impurities from the air. This paper will address these misconceptions and substantiate the long-term reliability and performance of optical splices and connectors that utilize IMG in their design.

Index Matching Gel: Past and Present

IMG has been an integral part of mechanical optical fiber splicing and termination for over 30 years. Since then, products utilizing IMG have become ubiquitous in the optical fiber splicing and termination market. Despite the historical and market-based confirmation of IMG as a viable enhancement for mechanical splice products, there are several misconceptions based on a small number of early issues with past gel formulations. Gel formulations used up until the early 1990s were not as carefully controlled as IMG formulations used today. For comparison, Table 1 shows the changes to performance parameters of past and present IMG formulations used in mechanical splices and NENP connectors.

Table 1: Changes to IMG Performance Parameters

	Previous Index Matching Gel Formulations	Index Matching Gel of Today
Fluid (Oil) Separation	1.0%	0.2% max, 0.075% average
Evaporation	2.1%	0.2% max
% Transmittance *	79%	97% after 80°C heat aging

** 1 cm optical path*

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From Table 1, one can see that the performance parameters of today's optical gel have improved markedly over gels used as recently as the early 1990s. Fluid separation and evaporation parameters are 5 and 10 times better respectively. In addition, percent transmittance (%T) has been improved as well, from 79% to 97% with modern gel formulations. These individual performance characteristics will be covered in more detail below.

Clarity and Optical Transmission

Optical clarity of IMG is measured using a scanning grating spectrometer in the transmission mode. The percentage of light transmitted through a 1 cm path length gel sample was measured at wavelengths associated with modern optical fiber systems.[6] The percent transmitted was measured before and after a heat aging process where the gel was heated to 80ºC for a period of 136 days. The wavelengths included those commonly used in datacom and FTTx networks. Table 2 shows the change in %T.

Table 2: 80°C Heat Aging for 136 Days

Wavelength (nm)	% Change After Heat Aging
850	-2.7%
1300	0.9%
1310	0.8%
1490	1.2%
1550	-3.0%

From Table 2, we can see that the decrease in the amount of light transmitted is very small at the wavelengths of concern. Additionally, one should note that the path length in a mechanical splice would be on the order of 10 µm. This path length is 1000 times shorter than the path length of 1 cm used in the test. Although % Transmittance can be expressed in terms of dB loss, if one calculates dB loss for the values of %T given in this paper, the losses would be in the ten thousandths of a dB. This is well beyond the measurement capability of available test equipment which may only measure to the hundredth of a dB. For this reason, all optical performance will be expressed in %T.

Another concern is how the clarity of the IMG is affected over the normal operating temperature range of -40º to +70ºC. Recent testing of the IMG used by Corning Cable Systems has confirmed that IMG undergoes very little change in the percentage of light transmitted at temperature extremes. Table 3 shows the test results in terms of change in %T with respect to room temperature (RT).

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Table 3: Test Results in %T

Wavelength (nm)	Baseline RT	70°C	-40°C	70°C re-test	RT re-test
850	0	-5.2%	-0.55%	-3.61%	-0.47%
1300	0	0.06%	-0.17%	1.3%	0.14%
1310	0	-0.06%	-0.31%	1.15%	-0.01%
1490	0	0.63%	0.51%	1.68%	-0.07%
1550	0	0.82%	-0.49%	1.7%	-0.12%

Gel Retention in Mechanical Splice

Another misconception surrounding IMG involves the thought that the gel will liquefy over time or at temperature and leak out of the connector or splice resulting in a device failure. Gel retention in mechanical splices and connectors is ensured through the careful control of two key physical parameters: fluid separation and apparent viscosity. First, fluid separation or "bleed" refers to oil which separates from the IMG over time or at extreme temperatures. Excessive fluid separation could lead to the oil running out of the mechanical splice if the splice was not designed to retain the oil. Past formulations have been tested and found fluid separation values as high as 2%. This has contributed to the misconception that gel may leave the splice by leakage. The IMG used in Corning Cable Systems connectors and splices today is formulated to exhibit less than 0.2% fluid separation during a 24 hour heat soak at 100ºC – the boiling point for water. One should also note that the less than 0.2% value for fluid separation is considered a steady state value. Since fluid separation rate is non-linear over time and temperature, after 24 hours at 100ºC the fluid separation value approaches and "flattens out" at a steady state value. For this reason, one can rest assured that IMG will not leak out of the mechanical splice or connector over time or temperature.

Another carefully controlled physical property of IMG which prevents the gel from leaking out of the connector is the apparent viscosity of the gel. IMG is a thixotropic gel, meaning the viscosity of the gel decreases at higher shear rates. The apparent viscosity of the gel while under sheer is reduced enough so that the gel flows freely from, for example, a syringe during dispensing. Conversely, when the gel is at rest and under no sheer, as is the case when the gel is at rest between two fiber end-faces in a mechanical splice, the apparent viscosity is very high. In fact, the apparent viscosity of the gel in this state is comparable to the viscosity of gum rubber and the gel is essentially in a solid state.[6] With low fluid separation, high apparent viscosity and splice designs which completely enclose and encapsulate splice parts, the IMG used in modern mechanical splice applications will not leak, wick or otherwise leave the optical splice.

Gel Hardening or Crystallization

There are several physical characteristics that determine if a gel will harden or crystallize. These characteristics are fluid separation, evaporation, thermogravimetric stability and glass transition temperature. Because of the relatively high values for fluid separation and evaporation of early IMG formulations, it is easy to understand how the myth of gel hardening or crystallization came about. However, with the improvement to these IMG parameters, hardening or crystallization is simply not a concern for modern IMG formulations.

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In the previous section, we have already seen that the IMG used by Corning Cable Systems is designed to have virtually no fluid separation or bleed. In addition, the IMG exhibits very low evaporation. In accordance with ASTM D-972, the gel was exposed to temperature of 100ºC for 24 hours. During the test, the gel exhibited less than 0.1% mass loss due to evaporation. Like fluid separation, evaporation rate is non-linear and approaches the steady state value of less than 0.1%.

At low and high temperature extremes, the main concerns for IMG are glass transition temperature (Tg) and thermogravimetric stability respectively. The Tg is essentially the temperature at which a liquid or gel becomes a solid. For IMG the Tg is -59ºC. Since even the most demanding applications for IMG in optical connections only require the connectors to withstand temperatures to -40ºC, IMG will easily meet these requirements. At the other end of the temperature extreme, IMG exhibits very good thermogravimetric stability at high temperatures. The thermogravimetric takeoff point was measured using a thermogravimetric analyzer (TGA). The takeoff point was defined as the point where there was mass loss of 1% due to evaporation and chemical oxidation. For the IMG used by Corning Cable Systems, the takeoff temperature was measured to be 279ºC.[6] Modern IMG is designed and tested so that it will remain in a stable gel state throughout the service life of the optical device.

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Gel Contamination

Particle Contaminants

Another common concern is that the IMG used in an optical connector or splice may become contaminated. During manufacturing, the IMG used by Corning Cable Systems goes through a series of proprietary processing steps to ensure optimum performance with respect to particle contamination. For this reason, the initial particle contaminants for practical purposes are non-existent.

While initial particle contaminants are insignificant, some are concerned that IMG will attract, for example dust particles, from the air. Corning Cable Systems follows strict procedures to ensure that no contaminants are introduced to the gel during component manufacturing. The IMG is dispensed into the optical device in a clean room environment. Furthermore, the IMG is contained inside the device and is protected from exposure to dust and other airborne particles through the use of dust caps. Additional protection against a particle compromising a good connection is provided by Corning's new connector installation tool. The installation tool's built-in Continuity Test System (CTS) gives the installer a green light when the fiber is properly installed in the connector and there is no misalignment of the fiber or obstruction at the fiber cleave. Should a particle of dust get introduced between the fibers in an optical device in the short period of time when the fiber is being prepared and inserted into the device, the connector installation tool would give the installer the opportunity to re-clean, re-cleave and re-insert the fiber. Once the connector or device has been activated, even if the particle has been introduced to the gel the particle will not migrate. As we pointed out earlier, the apparent viscosity of the IMG at rest is similar to gum rubber. This means that any particles entrained in the gel during field fiber insertion will not migrate.

Liquid Contaminants

When considering contamination, one must consider liquid contamination. There is some concern that water or other liquids may migrate or diffuse into the IMG at the splice and degrade performance. There have been several studies that address this concern. Several factors affect how severe potential migration may be. These factors include duration of immersion, presence of solvents in the liquid and the containment of the gel-filled splice.

A recent study by a leading IMG manufacturer measured the performance of IMG when exposed to an 85ºC/85% relative humidity (%RH) test and an immersion test. The test measured initial %T, %T after exposure to 85ºC/85%RH for seven days and %T after seven days of immersion in de-ionized water. The gel path length for the tests was 1 cm. The results of the test are given in Table 4. The test data in Table 4 shows practically no change in %T with respect to the tests conducted.

Table 4: IMG Performance Test

Wavelength (nm)	Change in %T after 85°C / 85%RH	Change in %T after 85°C / 85%RH
850	-0.12%	-2.7%
1300	0.2%	0.3%
1310	0.14%	-0.01%
1490	-0.21%	-0.13%
1550	-0.13%	-0.08%

Previous studies also measured index of refraction (IOR) of the IMG following the exposure. The value for IOR before and after the temperature/humidity test and the immersion test was virtually unchanged.[7] This indicated that there was no water diffusion or migration into the gel. Had water contaminated the gel, IOR would have changed significantly. Additionally, percentage weight gain, an indication of water contamination in the gel, was measured. After seven days of immersion the weight gain was less that 0.03%. These tests prove that liquid contamination will not limit the service life of IMG in challenging FTTx applications.

Service Life Study

Many doubts about IMG surround the service life of the IMG when used in optical devices. Naturally, products designed for communication purposes should last for decades rather than years. In order to understand the usable service life of IMG, studies have been conducted by IMG and component manufacturers. In the studies, gravimetric analysis was used to calculate service life for the IMG. The study found the service life of the gel to be 203 years at 40ºC.[1]

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Another study by a leading gel manufacturer placed an IMG sample at 80ºC for 136 days. Based on the findings, a half life calculation was made. The study found a half life of 14.6 years or a full life of 29.2 years at 80ºC.[4] It should be noted that these temperatures are well above room temperature at 25ºC. Based on the studies, it is easy to see that IMG will allow components to provide decades of service.

Market Acceptance

It is clear that the optical components market has accepted and even embraced IMG technology. Virtually every major component manufacturer in the market today offers products that utilize IMG to enhance optical performance. From mechanical splices to NENP connectors, there is a wide selection of products and competitors from which to choose. One of the main factors contributing to the success of IMG-based products can be seen by looking at FTTx deployments around the world. Japan for example, is leading the pack with respect to number of homes connected. Japanese service providers have a target of 30 million homes connected by 2010. They cite mechanical splices with IMG as a technology that is bringing this target to reality.[3] Reports indicate that by using optical components utilizing mechanical splices with IMG versus components requiring fusion splices, initial tooling capital expenditure has been reduced by 90%. In addition, connection speed has doubled and installed costs have been reduced by 50% over fusion splicing.[3] The value that IMG brings to the FTTx and datacom market is easy to see.

Conclusion

With growing bandwidth demand and acceleration of FTTx deployments to meet that demand, IMG will prove to be an enabling technology. With 30 years of innovation and improvement, the index matching gels used today are vastly superior to earlier IMG formulations. Extensive testing has proven the reliability of IMG over a wide temperature range, at a wide variety of wavelengths and for extended periods of time. With the enhanced performance offered by IMG, as well as initial tooling and installation cost reductions, optical components utilizing IMG have proven that they are not only here to stay, but in fact are leading the way.

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