Silicones: ideal material solutions for the photovoltaic industry

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ABSTRACT

Silicone polymers and resins have been formulated into multiple products that have a long history of successful use in a wide variety of applications and industries. Through chemical modifications of the polymer repeat unit, the optical, mechanical, and thermal properties of the polymers can be extensively varied and tuned to meet the requirements of specific applications. The inherent properties of silicones, such as very low ionic impurities, low moisture absorption, low dielectric constant and broad temperature utility, make them excellent material choices for applications in many of the specialty markets such as automotive, healthcare, electronics and microelectronics. These properties, in conjunction with their excellent optical transparency over a wide spectrum and UV stability, make silicones highly suitable for meeting the materials requirements for encapsulation of photovoltaic cells and other opto-electronic applications. This review will focus on the unique properties of silicones that make them ideal products for the entire photovoltaic (PV) module assembly market.

Photovoltaic module and assembly

The PV industry is growing rapidly as the worldwide demand for cleaner energy increases. As the industry expands, it is critical that suitable material solutions are available to meet the numerous requirements including durability, performance, price, throughput and global availability. Silicones are an ideal product family to meet the needs in the PV module assembly market. Silicones are highly transparent in the UV-visible wavelength region, which makes them ideal candidates for cell encapsulants. They can be formulated to have low modulus and be stress relieving while also having excellent adhesion to the glass and cell substrates. In addition, they can also be constructed into hard/resinous coatings that provide effective durable protection and abrasion resistance while maintaining optical clarity. Silicones can also be employed as PV junction box potting agents. For this application they need to have high reliability, long-lasting protection against environmental ingress and excellent electrical insulation of components. They can be modified to have a thermal conductivity in the range of 0.4-1.34W/mK, or higher if needed. Finally, silicones can be formulated into sealants for frame and junction box sealing. These sealants provide long-term bonding and protection against moisture and environmental attack.

Silicone properties

Silicones can be considered a 'molecular hybrid' between glass and organic linear polymers. As shown in Figure 1, if the Si atom is only bonded to oxygen atoms, the structure is an inorganic glass (called a Q-type Si). If one oxygen atom is substituted by an R group (i.e. methyl, ethyl, phenyl, etc.), a resin or silsesquioxane (T-type Si) material is formed. These silsesquioxanes are more flexible than the Q-type materials.

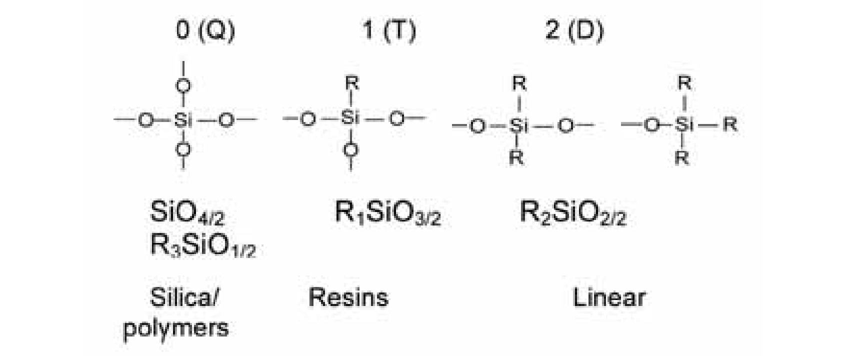

Figure 1. Bonding of an Si atom to various substances and the resulting materials.

Finally, if two oxygen atoms are replaced by organic groups, a very flexible linear polymer (D-type Si) is obtained.

The increased flexibility that is found with decreasing crosslinking results in a low glass transition (T_g) of the linear polymers. The T_g of linear polydimethylsiloxane (if all R groups are methyl units) is -120°C. Due to the T_g, silicones also typically have a low modulus once formulated and cured, especially when compared to organic polymers. The modulus in linear silicones can be quite low due to low crosslink density, and in this form silicones often function to relieve stress due to CTE (coefficient of thermal expansion) mismatch between two components in many applications. Similarly, the modulus is higher in branched, tack-free resin systems; they can be as high as 10MPa at room temperature. It is also

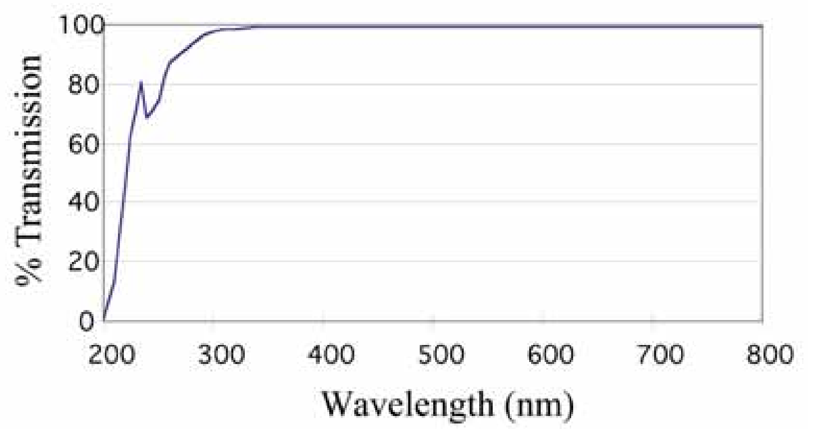

Figure 2. Percentage transmission of a 1mm thick cured PDMS elastomer.

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important to note that the branching vs. linear nature of the silicon polymer also impacts the CTE: as T_g decreases, the CTE increases. Along with a wide range in modulus is a variation in other mechanical properties such as tensile strength and elongation depending upon many formulation variables. For example, frequently reinforcing fillers are added to enhance mechanical properties.

Durability

Many applications and markets have exposed silicones to outdoor weather conditions. For example, construction sealants have proven silicones' ability to withstand UV and other outdoor conditions. These durable materials are virtually unaffected by UV light or ozone and have been successfully tested in many accelerated aging tests. Dow Corning® brand silicones have also been put in PV modules as the cell encapsulant and have withstood 25 years of sun exposure and are still performing satisfactorily. Their wide temperature of use range results in many of their properties remaining virtually unchanged from between -40°C and 150°C, while previous studies have shown little change in transparency and mechanical properties when exposed to temperatures >150 °C for extended times.

Optical properties

The refractive index of silicone polymers can vary from 1.38 to 1.54, depending on the nature of the R groups, while RI tuning can be critical for some optical applications. Silicone polymers are also highly transparent in the UV-Visible wavelengths. In Figure 2, the % transmission of a 1mm thick cured PDMS elastomer is shown, with high transparency present down to <300nm. Silicones are renowned for their UV stability, and require no additional additives to protect against UV degradation.

Further silicone features

Silicones can be formulated to a variety of cure systems. The most common cure system for materials used in electronics applications is the addition cure of Si-H to Si-Vinyl. This reaction is typically catalysed by platinum and can be accelerated with heat and at a variety of temperatures. This type of cure system can be formulated as a one-part or two-part product and it is a neutral cure system that releases no cure by-products.

While silicones are very permeable to gases and liquid vapours, they are also very hydrophobic. These two attributes result in silicones having very low moisture pick-up in damp heat environmental exposure or total water immersion. Often silicones exhibit <0.1 weight % gain in 85%RH/85% °C conditions. This is significantly less than measured for typical organic polymers. Another key component in the performance of silicone sealants is adhesion. The silicones can be formulated to have strong adhesive bonds to multiple substrates. When strong adhesive bonds are formed, the moisture will not have a path to wick into moisture-sensitive components and cause corrosion or other degradation mechanisms. Silicone's ability to transmit water vapour rather than absorb it prevents moisture from being trapped at an interface.

Silicones are very well known for their excellent dielectric strength and high volume resistivity. There are many applications where silicones are used as electrical insulators. They are non-conductive because of their chemical nature, and when compounded with the proper fillers and additives, they can be made to meet a wide range of electrical insulating applications. Because of the low equilibrium moisture content they remain non-conductive even in high humidity conditions.

Silicones are also known as one of the most flame resistant polymers. Certain *Silastic*® brand silicone rubber products inherently possess a profile of fire hazard characteristics which makes them useful for applications where good flame retardation and minimum fire hazard is desired. Silicones can be compounded and fabricated to meet many specifications, including UL-94, V-1 or V-0. They have a low flammability rating and typically do not support or promote flame and do not produce toxic combustion by-product.

Silicones can be formulated with a variety of thermally conductive fillers and have been used successfully in thermal management applications. This is typically an important property for PV junction box pottants for diode temperature control.

Conclusion

Silicones are a unique family of materials that cover a wide range of properties. They can be formulated in a multitude of products depending upon the application needs and requirements, and are an ideal fit for the needs of the PV module assembly market.

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