ThreeBond TECHNICAL NEWS

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63

Resins for Optics

1. Light-Curing Resin
2. Heat-Curing Resin

Introduction

As the word "optoelectronics is popular," the fields of electronics and optics now have a close relationship each other. Optical field includes precision components such as optical pickup devices, liquid crystal devices, micro lenses, prisms, and optical wave guides. The resin materials that are used for these components require peculiar optical properties that have not been needed in the electric and electronic fields. In this issue, we summarize and introduce our newly developed products that are applicable to these optical components.

Contents

1. Light-Curing Resin

1-1. Brief Description of the Refractive Index

The refractive index shows the optical density of a material and it is generally represented by “n”. In other words, the refractive index is the resistance under which light passes through a material. A greater resistance results in an increased refractive index, while a smaller resistance results in a decreased index.

Light has a property, which is traveling straight in a single material, but deflecting the path at the surface if entering different material. As shown in the example in Fig. 1, when the light emitted from the light source (A), travels straight through the air and reaches the surface (B) of the water, it enters the water in a deflected direction and then travels straight through the water as well.

As discussed above, the property in which the travel direction is deflected when the light enters a different material is called "refraction." Degree of refraction differs by material, and numeric representation of this is the refractive index

As the refractive index changes depending on the wavelength of the light, the standard value is measured using a sodium lamp, which is called a "D ray" (wavelength: 589 nm), as the light source. A refractive index measured using this D ray is expressed in units of "nD." The calculation formula for nD is as follows.

$$nD = \frac{\sin\theta 1}{\sin\theta 2} = \frac{i}{r}$$

The refractive index nD in the air (or in a vacuum) is 1.0, while it is 1.3 in water. A higher nD results in a larger refractive index.

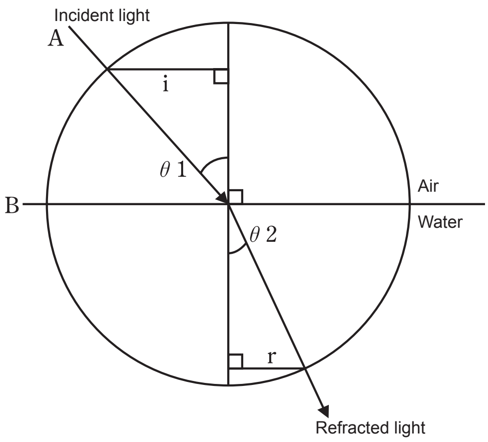


Fig. 1 Refractive Index

Table 1 lists the general refractive indexes.

Table 1 General Refractive Index

Material	nD
Air	1.0
Water	1.3
Glass	1.5

The ThreeBond (hereinafter referred to as "TB") 3078 series includes UV-curing resins that the refractive index is controlled. The TB3078 series covers nD 1.41 to 1.59, and it is also possible to minutely control the refractive index to the desired value.

To control the refractive index, the chemical composition of the UV-curing resin is changed. The UV-curing resin consists of various molecules, each having a unique refractive index.

The refractive index can theoretically be calculated from the following Lorentz-Lorentz formula, without conducting actual measurement.

Lorentz-Lorentz formula

$$n = \sqrt{\frac{1+2\,[R]/V}{1-[R]/V}}$$

R : Molecular refraction

V : Molecular volume

Atomic refraction determines the molecular refraction, and the refraction index can be obtained from the sum of these refractions.

It can be seen from the above formula that enlarged molecular refraction results in an increased refraction index, while an increase in molecular volume results in a decrease in the index. Therefore, the refraction index of the entire resin compound can be controlled.

Application designs of UV-curing resins for optics are broadly classified into two categories: one is to match the refractive index with that of the part material (to be bonded), and the other is to utilize the difference in the refractive indexes by using a resin with the bonded material that has significantly different refractive index.

Table 2 summarizes the refractive indexes of various polymers.

Table 2 Refractive Indexes of Polymers

Polymer	Refractive index, nD	Polybenzyl methacrylate	Refractive index, nD
Polytetrafluoroethylene	1.35 to 1.38	Stylene-acrylonitrile copolymer	1.57
Poly-4-methylpentene-1	1.47	Polyphenylene methacrylate	1.57
Polymethyl methacrylate	1.50	Polydiallyl phthalate	1.57
Polyvinyl alcohol	1.49 to 1.53	Polyethylene terephthalate	1.57
Diethylene glycol bis allyl carbonate	1.50	Polystyrene	1.58
Polycyclohexyl methacrylate	1.51	Polyvinyl chloride	1.59
Polyethylene	1.51	Polyvinyl naphthalene	1.63
Polyacrylonitrile	1.52	Polyvinyl carbazole	1.68
Nylon 6	1.53		1.68

Table 3 Various characteristics of UV-Curing Resins for Optics

Item	Unit / examination method	TB3078	TB3078B	TB3078C	TB3078D
Appearance	Visual	Transparent	Transparent	Transparent	Transparent
Viscosity	mPa•s	150	180	300	100
Hardness	JIS	D 80	D 80	A 74	A 80
Refractive index (before curing)	nD 25°C	1.56	1.47	1.44	1.39
Refractive index (after curing)		1.59	1.51	1.46	1.41
Coefficient of linear expansion (α1)	ppm/°C	53	75	201	142
Coefficient of linear expansion (α2)		220	135	278	280

1-2. Dispersion of the Refractive Index

1) Dispersion by wavelength

Fig. 2 plots the refractive indexes of TB3078 at various wavelengths. It can be seen that a longer wavelength decreases the refractive index. The refractive index depends on the wavelength. In optical systems, this dispersion is desired to be small, and by reducing this dispersion, optical aberration can be decreased.

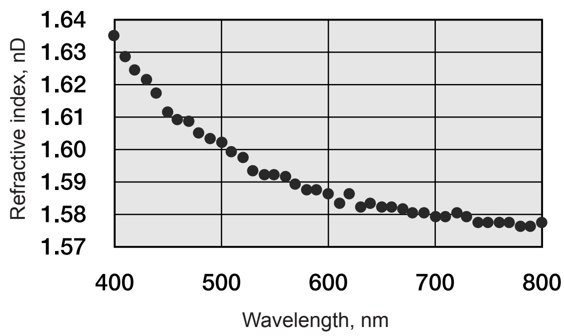


Fig. 2 Characteristic of TB3078 - Dispersion by Wavelength

2) Dispersion by temperature

Fig. 3 plots the refractive indexes of TB3078 at various temperatures. It can be seen that a higher temperature decreases the refractive index. This demonstrates that the refractive index depends on the density of the medium, as previously discussed. When the temperature is increased, the density drops then, as a result, the refractive index is decreased.

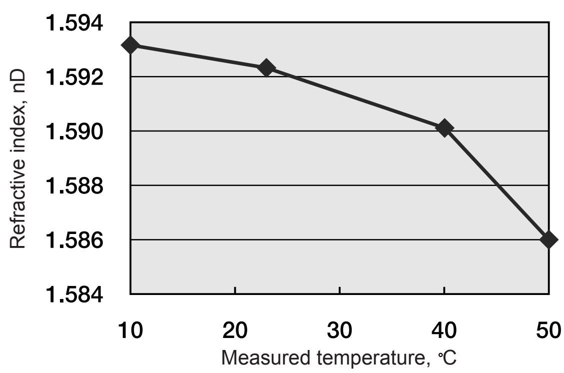


Fig. 3 Characteristic of TB3078 - Dispersion by Temperature

The TB3078 series can be used as a 2P molding material.

1-3. Brief Description of the 2P Molding Method

"2P" is an acronym for Photo Polymerization. Photo polymerization is a molding process utilizing the light-curing property. Fig. 4 simply illustrates this process.

(1) The optically designed stamper (casting mold) is filled with UV-curing resin (TB3078 series).

(2) Press bond a base plate such as a transparent acrylic plate against the die, then,

(3) Irradiate ultraviolet rays through the transparent plate to polymerize-cure the resin.

(4) Any pattern on the stamper can be copied to the transparent base plate.

The size of the patterns on the casting mold generally ranges from submicrons to several hundred microns.

Advantages of 2P molding

- UV-curing resins can be polymerized at lower temperatures than those used in the heat polymerization method, minimizing the optical distortions.
- The light curing process provides excellent productivity.
- The stamper (mold) is fabricated in an easy manner, resulting in lower costs compared to metallic molding dies.

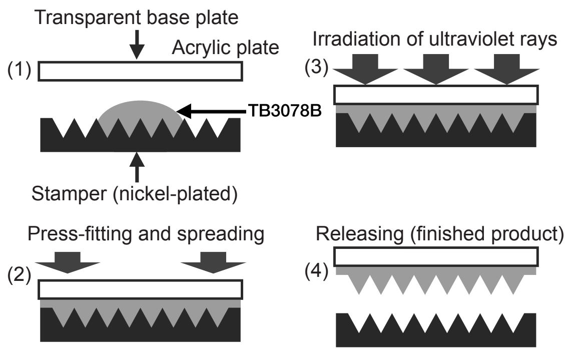


Fig. 4 2P Molding Process

1-4. Light Transmittance

The TB3078 series features high light transmittance and superior heat resistance. Fig. 5 plots the light transmittances measured on TB3078 samples cured and aged at various test temperatures. Within the wavelength range at or above 400 nm, the light transmittance is significantly decreased with aging at 250°C, while it remains constant with aging at or below 200°C.

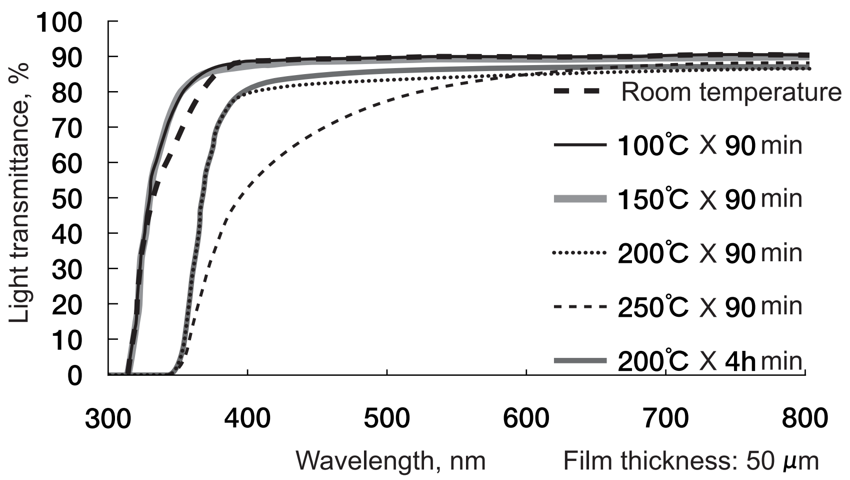


Fig. 5 Characteristic of TB3078 - Light Transmittance

2. Heat-Curing Resin

The Internet is now entering into broadband era, and progressing day by day. Optical fiber cables are indispensable components for the popularization of broadband Internet services. Communications using fiber optics cables require devices that control amplification, wave division, and switching of optical signals. In the optic communications, the optical characteristics are impaired with humidity, therefore, effects of external moisture must be shut off. Three Bond developed TB2960 and TB2960B, which are sealants for optical components.

2-1. Brief Description of the Optical Components

Optical fiber has been developed as a communication medium to replace metallic cables, and it is expected to be used in various fields. Signal attenuation of optical fiber is small and it allows long distance and large capacity, compared to conventional metallic cables. Therefore, if optical fiber cables are connected to general houses, its advantages are inestimable. To complete fiber-optic networks that covers general houses, it is necessary to install a splitter that divides optical signals, and an optical device that sends and receives optical signals (i.e., a terminal). For example, the optical device consists primarily of the following components.

- Optical waveguide

Same as electrons flow through electric circuits, optical waveguides lead optic signals to optic circuits formed on base boards by utilizing differences in refractive indexes. The principals are same as fiber optics, but the optical waveguide is plain surface structure while fiber optics is fabric.

- Optical switch

The optical switch is a device for switching optic signals, as it is, without converting into electrical signals.

- Photocoupler

Photocoupler is a device to branch optical power that transmits on a optical fiber, with set ratio.

- Optical transceiver

Optical transceiver is a device that integrates optical transmitter and receiver, converting electric and optic signals in both directions.

Lenses, optical glasses, and prisms which are used in optical equipment such as cameras, are also optical components.

2-2. Requirement Characteristics of Sealants for Optical Components

Optical components such as an optical fiber can transmit light without attenuation. However, light is affected and attenuated in moisture, which causes transmission loss. Sealants are used to protect the devices, discussed earlier, from the degradation caused by external moisture and to enhance the durability. (See Fig. 6.)

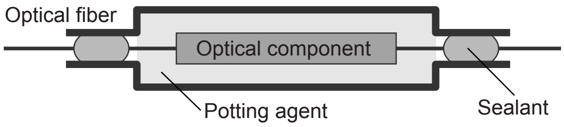


Fig. 6 Application Example of Sealant

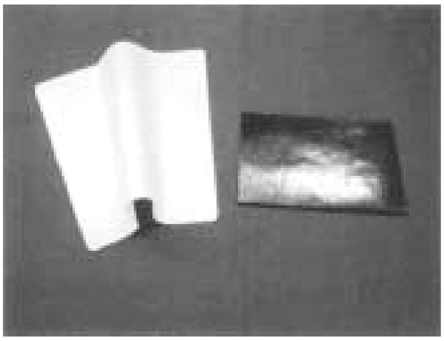
Conventionally, UV-curing resins and epoxy resins have been used as sealants. However, Shrinkage of UV-curing resins are large during curing, and internal stress remains inside the component. Epoxy resins, due to their higher hardness, occasionally suffer from cracking during the heat cycle. Taking into consideration these drawbacks of current resins, we have been developing resins for optical components, aiming following items as requirement characteristics.

- Low permeability:
  Preventing penetration of moisture into optical components and maintaining their original performance
- Flexibility:
  Reducing internal stress during the heat cycle
- Low curing shrinkage:
  Mitigating damages to optical components during curing

2-3. Characteristics of TB2960 and TB2960B

Three Bond investigated and researched new materials that satisfy the requirements items described in the previous section, and ultimately developed TB2960 and TB2960B. These sealants consist primarily of polyolefine polymers that have a reaction group at both ends and, this component is polymerized and bridged to form elastic rubber, when heated, Generally, resins with high gas-sealing performance are often hard, and it is a cause of internal stress and the cracks that occur when exposed to heat cycle. TB2960 and TB2960B are flexible and low-permeable sealants. (See Photograph 1.)

Table 4 shows the physical properties of both TB2960 and TB2960B. As the permeability is temperature dependent, a higher temperature results larger permeability. Table 5 shows the permeability of TB2960 and TB2960B, and their temperature dependency.



Photograph-1 Cured Objects of TB2960 and TB2960B

Table 4 General Characteristics of TB2960 and TB2960B

Item	Unit	TB2960	TB2960B	Test method
Application	-	Sealant	Potting agent	-
Appearance	-	White	Black	3TS-201-02
Viscosity	Pa•s	280	14	3TS-210-02
Specific gravity	-	0.96	0.98	3TS-213-02
Standard curing conditions	-	100°C × 30 min	120°C × 30 min	-
Hardness	-	A 20	C 25	3TS-215-01, 02
Peeling property	MPa	1.6	0.5	3TS-320-01
Elongation	%	290	120	3TS-320-01
Cure contraction	%	1.0, max.	1.0, max.	3TS-228-02
Glass transition point	°C	-58.7	-55.0	3TS-501-04
Coefficient of linear expansion	ppm/°C	$\alpha 1$ 57.4 $\alpha 2$ 260.7	$\alpha 1$ 51.9 $\alpha 2$ 271.9	3TS-501-05
Volume resistivity	Ω•m	1.8×10^{13}	6.6×10^{13}	3TS-401-01
Surface resistivity	Ω	8.5×10^{14}	1.2×10^{11}	3TS-402-01
Dielectric loss tangent	-	0.009 1kHz 0.004 1MHz	0.008 1kHz 0.002 1MHz	3TS-405-01
Dielectric breakdown voltage	kv/mm	32.3	17.5	3TS-406-01

Table 5 Permeability Measurements

Test conditions	Unit	TB2960	TB2960B	Test method
40 °C × 95%RH	$g/m^2/24h$	0.9	1.1	JIS Z 0208
60 °C × 95%RH		1.9	1.8	
85 °C × 85%RH		2.9	2.4	

Resin thickness: 3 mm

Studying the resistances of the cured object under various environment conditions shows any degradation of the tension strength with dumbbell property on any of them, including humidity resistance (85°C × 85 %RH) (see Fig. 9), heat-cycle resistance (40°C × 2 h ⇔ 120°C × 2 h) (see Fig. 10), acid resistance (90°C, pH-1 sulfuric-acid solution) (see Fig. 11), alkali-resistance (90°C, 10 % sodium hydroxide solution) (see Fig. 12), and heat resistance (120°C) (see Fig. 13). It can keep stable rubber material properties for a long time

TB2960 is designed for sealing and TB2960B is for potting applications in order to meet the usage of each component. TB2960B is blackened so that it will be suitable for light-shielding applications.

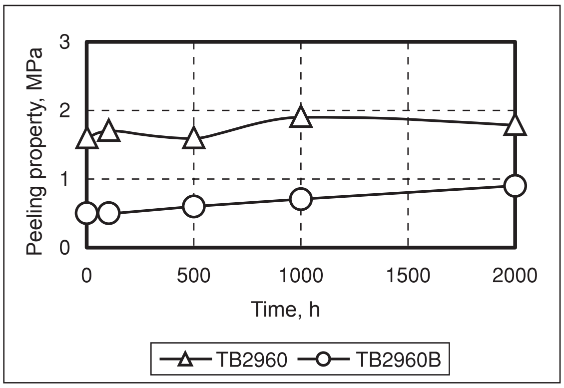


Fig. 9 Moisture Resistance

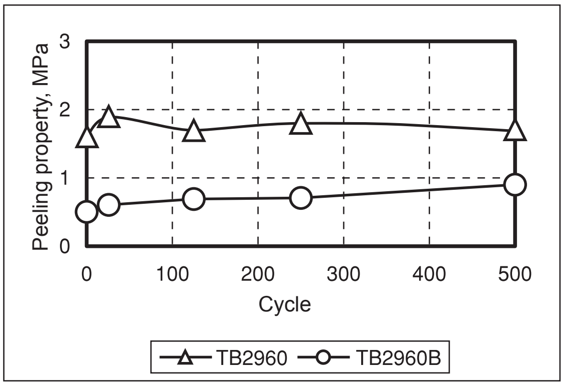


Fig. 10 Heat-Cycle Resistance

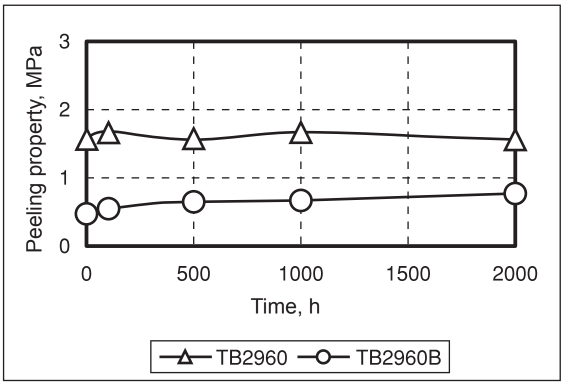


Fig. 11 Acid Resistance

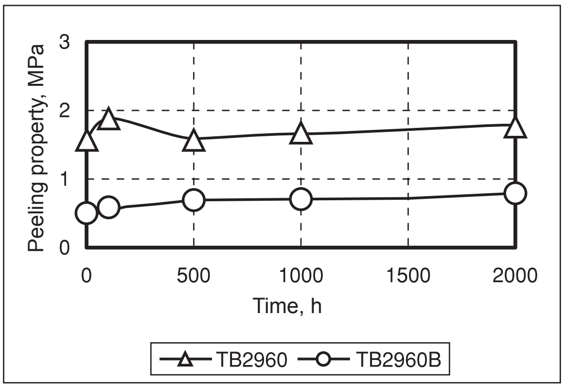


Fig. 12 Alkali Resistance

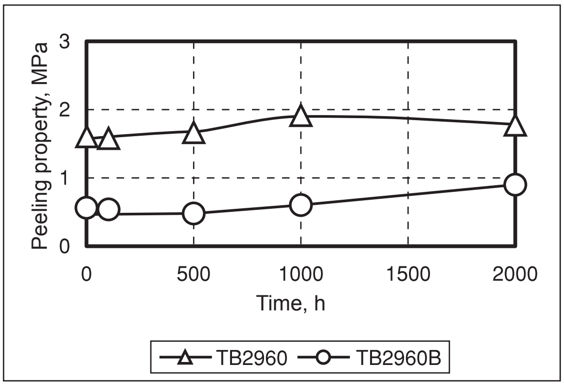


Fig. 13 Heat Resistance

3. Conclusion

Recently, the optics related business has been developing remarkably. We have developed new materials to meet the requirements of the market. We hope that the resins for optics introduced in this issue contribute to the development of the optoelectronics field.

Photograph-2 TB3078-Series UV-Curing Resins for Optics

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