



Diamond Grade™

DG³ Reflective Sheeting Series 4000

Product Bulletin 4000

August 2006

Description

3M™ Diamond Grade™ DG³ Reflective Sheeting is a super-high efficiency, full cube retroreflective sheeting designed for the production of traffic control signs and delineators that are exposed vertically in service. DG³ sheeting is designed to have the highest retroreflective characteristics at medium and short road distances as determined by the R_A values at 0.5° and 1.0° observation angles in Table B. Performance at these observation angles represents the most common nighttime viewing geometries encountered by the driving public. During the daytime, Diamond Grade DG³ fluorescent reflective sheeting provides higher visibility than ordinary (non-fluorescent) colored sheetings. Applied to properly prepared sign substrates 3M Diamond Grade DG³ reflective sheeting provides long-term retroreflectivity and durability. Series 4000 sheeting is available in

Color	Product Code
White	4090
Yellow	4091
Red	4092
Blue	4095
Green	4097
Brown	4099
Fluorescent Yellow - FY	4081
Fluorescent Yellow Green- FYG	4083
Fluorescent Orange - FO	4084

Photometrics

Daytime Color (x,y,Y)

The chromaticity coordinates and total luminance factor of the retroreflective sheeting conform to Table A.

Color Test - Fluorescent Sheetings

Conformance to standard chromaticity (x, y) and luminance factor (Y %) requirements shall be determined by instrumental method in accordance with ASTM E 991 on sheeting applied to smooth aluminum test panels cut from Alloy 6061-T6 or 5052-H38. The values shall be determined on a HunterLab ColorFlex 45/0 spectrophotometer. Computations shall be done for CIE Illuminant D65 and the 2° standard observer.²

Color Test - Ordinary Colored Sheeting

Conformance to standard chromaticity (x,y) and luminance factor (Y %) requirements shall be determined by instrumental method in accordance with ASTM E 1164 on sheeting applied to smooth aluminum test panels cut from Alloy 6061-T6 or 5052-H38. The values shall be determined on a HunterLab ColorFlex 45/0 spectrophotometer. Computations shall be done for CIE Illuminant D65 and the 2° standard observer.²

Table A - Daytime Color Specification Limits¹

Color	x		y		x		y		Daytime Luminance Limit (Y%)	
	x	y	x	y	x	y	x	y	Min.	Max.
White	.303	.300	.368	.366	.340	.393	.274	.329	40	
Yellow	.498	.412	.557	.442	.479	.520	.438	.472	24	45
Red	.648	.351	.735	.265	.629	.281	.565	.346	3	15
Blue	.140	.035	.244	.210	.190	.255	.065	.216	1	10
Green	.026	.399	.166	.364	.286	.446	.207	.771	3	12
Brown	.430	.340	.610	.390	.550	.450	.430	.390	1	6
FY	.479	.520	.446	.483	.512	.421	.557	.442	45	
FYG	.387	.610	.369	.546	.428	.496	.460	.540	60	
FO	.583	.416	.535	.400	.595	.351	.645	.355	25	

¹The four pairs of chromaticity coordinates determine the acceptable color in terms of the CIE 1931 Colorimetric System.

²The instrumentally determined color values of retroreflective sheeting can vary significantly depending on the make and model of colorimetric spectrophotometer as well as the color and retroreflective optics of the sheeting (David M. Burns and Timothy J. Donahue, Measurement Issues in the Color Specification of Fluorescent Retroreflective Materials for High Visibility Traffic Signing and Personal Safety Applications, Proceedings of SPIE: Fourth Oxford Conference on Spectroscopy, 4826, pp. 39-49, 2003). For the purposes of this document, the HunterLab ColorFlex 45/0 spectrophotometer shall be the referee instrument.

Coefficients of Retroreflection (R_A)

The values in Table B are minimum coefficients of retroreflection expressed in candelas per lux per square meter (cd/lux/m²).

Test for Coefficients of Retroreflection

Conformance to coefficient of retroreflection requirements shall be determined by instrumental method in accordance with ASTM E-810 "Test Method for Coefficient of Retroreflection of Retroreflective Sheeting", and per E-810 the values of 0° and 90° rotation are averaged to determine the R_A in Table B.

Table B - Minimum Coefficient of Retroreflection R_A for new sheeting (cd/lux/m²)

-4° Entrance Angle ³	Observation Angle ⁴		
	0.2°	0.5°	1.0°
White	570	400	120
Yellow	425	300	90
Red	114	80	24
Green	57	40	12
Blue	26	18	5.4
Brown	17	12	3.6
Fluorescent Yellow	340	240	72
Fluorescent Yellow Green	460	320	96
Fluorescent Orange	200	140	42
30° Entrance Angle ³	0.2°	0.5°	1.0°
White	215	150	45
Yellow	162	112	34
Red	43	30	9
Green	22	15	4.5
Blue	11	6.8	2
Brown	6.5	4.5	1.4
Fluorescent Yellow	130	90	27
Fluorescent Yellow Green	170	120	36
Fluorescent Orange	75	52	16

³ Entrance Angle - The angle from the illumination axis to the retroreflector axis. The retroreflector axis is an axis perpendicular to the retroreflective surface.

⁴ Observation Angle - The angle between the illumination axis and the observation axis.

Screenprinted Colors and Overlay Films

For screenprinted transparent color areas on white sheeting when processed according to 3M recommendations, the coefficients of retroreflection shall not be less than 70% of the value for the corresponding color in Table B. For white sheeting covered with 3M™ ElectroCut™ Film Series 1170 when processed according to 3M recommendations, the coefficients of retroreflection shall not be less than 100% of the value for the corresponding color in Table B.

Entrance Angularity Performance in Regard to Orientation

3M™ Diamond Grade™ DG³ Reflective Sheeting is designed to be an effective wide angle reflective sheeting regardless of the orientation on the substrate or ultimate orientation after installation. However, because the efficiency of light return from cube corner reflectors is not equal at all application angles, especially with increasing entrance angles, it is possible to get the widest entrance angle light return when the sheeting is oriented in a particular manner. 3M has designed a special feature into Diamond Grade DG³. This special feature takes advantage of increased performance at high entrance angles (>50°). When high entrance angle performance is a requirement for your signs (e.g. Keep Right Symbols) you can obtain this performance easily by specifying the application angle of your completed signs. In these situations the completed sign should have the sheeting positioned at the 0° application angle (downweb direction perpendicular to the road).

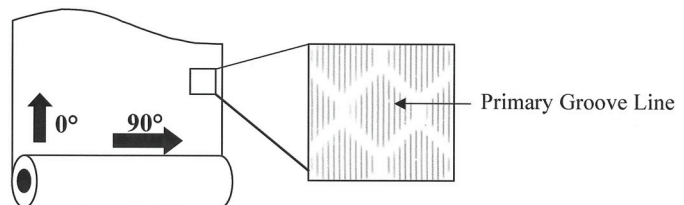


Figure 1

When the "primary groove line" (or, flat side of the diamond shape) is vertical in the completed sign, sheeting is said to be at a 0° application angle. When the "primary groove line" (or, flat side of the diamond shape) is horizontal in the completed sign, the sheeting is said to be at a 90° application angle. (See Figure 1)

Unless the location and/or position calls for extra-wide entrance angularity performance, signs can be fabricated and installed using the application angle that most efficiently utilizes the reflective sheeting.

Fabrication Lines

The manufacture of prismatic sheeting results in lines being present in the product. In 3M Diamond Grade DG³ sheeting these lines are slightly thicker than the seal pattern legs. Fabrication lines are noticeable in shop light but are not observable on the road either in daylight or at night under typical use conditions (Figure 2).

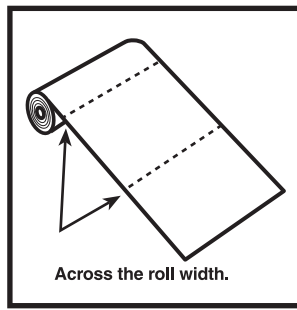


Figure 2 - Fabrication Lines

Adhesive

Series 4000 sheeting has a pressure-sensitive adhesive that is recommended for application at temperatures of 40°F (4°C) or higher.

Test Methods for Adhesive and Film Standard Test Panels

Unless otherwise specified herein, sheeting shall be applied to test panels in accordance with ASTM D4956-05, section 7.2 and test conditions shall conform to ASTM D4956 section 7.1.

Standard Conditioning - all mounted and unmounted test specimens shall be conditioned for 24 hours at 73°F ± 2°F (23°C ± 1°C) and 50% ± 4% R.H. before testing.

Properties

1. Adhesive

The retroreflective sheeting shall comply with the liner removal and adhesion requirements contained in ASTM D4956-05 sections 7.10 and 7.5 respectively.

2. Impact Resistance

Test Method - Apply sheeting to a standard panel 3" x 6" (7.6x15.2cm) and condition. Subject sheeting to a 50 inch-pounds (5.7Nm) impact in accordance with ASTM D2794. Requirement - No separation from panel or cracking outside immediate impact area.

3. Shrinkage

The retroreflective sheeting shall comply with the shrinkage requirements contained in ASTM D4956-05 section 7.8.

4. Gloss

Test Method - Test in accordance with ASTM D523 using a 60° glossmeter. Requirement - Rating not less than 50.

5. Optical Stability

Test Method - Apply a 3 inch x 6 inch sample to a test panel. Measure R_A then place it in an oven at 71° C ± 3° C (160°F ± 5°F) for 24 hours followed by conditioning at standard conditions for 2 hours. Remeasure R_A.

Requirement - The sheeting shall retain a minimum of 85% and a maximum of 115% of the original coefficient of retroreflection.

Sign Fabrication Methods

Application

Diamond Grade DG³ sheeting Series 4000 incorporates a pressure sensitive adhesive and should be applied to the sign substrate at temperature of 40°F/4°C or higher by any of the following methods:

Mechanical squeeze roll applicator - see Information Folder (IF) 1.4. Application to extrusions that are wrapped require sufficient softening of the sheeting. This can be accomplished by directing additional heat to the "next to last" edge roller. This practice will increase productivity and avoid any cracking.

Hand squeeze roll applicator - see IF 1.6

Hand Application

Hand application is recommended for legend and copy only. All direct applied copy and border MUST be cut at all metal joints and squeegeed at the joints. Application of Diamond Grade sheeting for complete signs or backgrounds must be done with a roll laminator, either mechanical or hand. See Information Folder 1.5 for more details.

Hand applications will show some visual irregularities, which are objectionable to aesthetically critical customers. These are more noticeable on darker colors. To obtain a close-up uniform appearance, a roll laminator must be used.

Splices

Series 4000 sheeting should be butt spliced when more than one piece of sheeting is used on one piece of substrate. The sheeting pieces should not touch each other. A splice gap of up to 1/16 inch is acceptable. This is to prevent buckling as the sheeting expands in extreme temperature and humidity exposure.

If a slight gap is undesirable, the following procedures must be followed:

1. Overlap the sheeting at least one inch, with or without the liner attached.
2. Using a straight edge and a sharp utility knife, cut through both layers of reflective sheeting.
3. Peel back and remove cut remnants. If liner was left on, remove and roll down remaining sheeting.

Double Faced Signs

Series 4000 sheeting on the first side must be protected by liner paper and FR-2 sponge rubber to prevent damage from contact with bottom rollers on squeeze roll applicators.

Substrates

For traffic sign use, product application is limited to properly prepared aluminum (see Information Folder 1.7) and High Density Overlay Plywood (HDOP). Extrusions are to be wrapped and flat panel signs are to be carefully trimmed so that sheeting from adjacent panels does not touch on assembled signs.

Users are urged to carefully evaluate all other substrates for adhesion and sign durability. 3M™ Diamond Grade™ DG³ sheeting is designed primarily for applications to flat substrates. Rivets or bolts should also support any use that requires a radius of curvature of less than five inches. Plastic substrates are not recommended where cold shock performance is essential. Sign failures caused by the substrate or improper surface preparation are not the responsibility of 3M.

Screen Processing

Series 4000 sheeting may be screen processed into traffic signs before or after mounting on a sign substrate, using 3M Process Colors Series 880I (see Product Bulletin 880I) or Series 880N (see Product Bulletin 880N). Series 880I or 880N process colors can be screened at 60-100°F (16-38°C) at relative humidity of 20-50%.

A PE 157 screen mesh with a fill pass is recommended. See Information Folder 1.8 for details. Use of other process colors series is not recommended. 3M assumes no responsibility for failure of sign face legends or backgrounds that have been processed with non-3M process colors or 3M process colors other than those listed above.

Care should be taken to avoid flexing Series 4000 sheeting before and especially after screening to eliminate the possibility of cracking from improper handling techniques.

Electronic Cutting

Programmable knife cut (electronic cutting)

1. Flat bed plotters can either die cut or kiss cut and offer the most consistent reliable performance.
2. Friction Fed plotter. Kiss cut only. Success has been achieved using plotters that have 600 grams of down force and a 60° cutting blade.

Letter heights less than 3 inches and stroke widths less than 1/2 inch should not be used. Additional drive wheels may need to be added to improve tracking. An alternative procedure is to cut sheeting from the liner side. Blade force and knife depth must be set to score but not cut through the topfilm. Break apart individual copy or apply premask to retain spacing.

Note: It is recommended to fabricate all but the largest signs using 1170 electronic cuttable overlay film (ECOF) instead of direct applied copy.

Cutting

The sheeting may be hand cut or die cut one sheet at a time, and band sawed or guillotined in stacks. Series 4000 sheeting can be hand cut from either side with a razor blade or other sharp hand tool. Cutting equipment such as guillotines and metal shears, which have pressure plates on the sheeting when cutting may damage the optics. Padding the pressure plate and easing it down onto the sheets being cut will significantly reduce damage. Maximum stack height for cutting Series 4000 sheeting is 1½ inch or 50 sheets. Details on cutting can be found in Information Folder 1.10. Edge sealing DG³ sheeting is generally not required.

Following extended exposure, airborne dust particles may become trapped within the row of cut cells along the sheeting edge. This should have no adverse effect on sign performance. If the user chooses to edge seal, series 880I toner should be used.

Health and Safety Information

Read all health hazard, precautionary and first aid statements found in the Material Safety Data Sheet and/or product label of chemicals prior to handling or use.

General Performance Considerations

The durability of 3M™ Diamond Grade™ DG³ Reflective Sheeting Series 4000 will depend upon substrate selection and preparation, compliance with recommended application procedures, geographic area, exposure conditions, and maintenance. Maximum durability of Series 4000 sheeting can be expected in applications subject to vertical exposure on stationary objects when processed and applied to properly prepared aluminum according to 3M recommendations provided in Information Folder 1.7 on Sign Substrate Surface Preparation. The user must determine the suitability of any non-metallic sign backing for its intended use. Applications to unprimed, excessively rough or non-weather-resistant surfaces, or exposure to severe or unusual conditions can shorten the performance of such applications. Signs in mountainous areas that are covered by snow for prolonged periods may also have reduced durability. 3M process colors, when used according to 3M recommendations, are generally expected to provide performance comparable to colored reflective sheeting, except for certain lighter colors, such as yellow, gold, or heavily toned colors or blends containing yellow or gold, whose durability depends on how much of each color is used. Dilution of color and atmospheric conditions in certain geographic areas may result in reduced durability.

Periodic sign inspection and regular sign replacement are strongly recommended in order for agencies to establish their own effective service life expectation, beyond the warranty period.

Cleaning

Signs that require cleaning should be flushed with water, then washed with a detergent solution and bristle brush or sponge. Avoid pressure that may damage the sign face. Flush with water following washing. Do not use solvents to clean signs. See Information Folder 1.10.

Storage and Packaging

3M™ Diamond Grade™ DG³ Sheeting should be stored in a cool, dry area, preferably at 65-75°F (18-24°C) and 30-50% relative humidity and should be applied within one year of purchase.

Rolls should be stored horizontally in the shipping carton. Partially used rolls should be returned to the shipping carton or suspended horizontally from a rod or pipe through the core. Unprocessed sheets should be stored flat. Finished signs and applied blanks should be stored on edge.

Screen processed signs must be protected with SCW 568 slipsheet paper. Place the glossy side of the slipsheeting against the sign face and pad the face with closed cell packaging foam. Double-faced signs must have the glossy side of the slipsheet against each face of the sign.

Unmounted screened faces must be stored flat and interleaved with SCW 568 slipsheet, glossy side against the sign face. Packages of finished sign faces must include sufficient nylon washers for mounting.

Avoid banding, crating, or stacking signs. Package for shipment in accordance with commercially accepted standards to prevent movement and chafing. Store sign packages indoors on edges.

Panels or finished signs must remain dry during shipment and storage. If packaged signs become wet, unpack immediately and allow signs to dry. See Information Folder 1.11 for instructions on packing for storage and shipment.

Installation

Nylon washers are recommended.

Warranty - Ordinary Colored Sheeting

3M warrants that 3M™ Diamond Grade™ DG³ Reflective Sheeting to be sold by 3M to be used as components for traffic control and guidance signs in the United States and Canada will remain effective for its intended use and meet the stated minimum values for coefficient of Retroreflection for twelve years, for colors used in permanent sign applications. The warranty is subject to the following provisions in Table C.

Table C - Percentage of Table B Initial R_A Minimums Guaranteed Over 12 Year Warranty Period (Colors: white, yellow, red, green and blue)

Warranty Period	Minimum Percentage R _A Retained
1-7 Years	80%
8-12 Years	70%

R_A percentage retained above apply to all entrance and observation angles presented in Table B, and shall be measured per ASTM E 810.

All measurements shall be made after cleaning according to 3M recommendations. If a 3M Diamond Grade DG³ sign surface is processed and applied to sign blank materials in accordance with all 3M application and fabrication procedures provided in 3M's product bulletins, information folders, and technical memos (that will be furnished to the agency upon request), including the exclusive use of 3M matched component systems, process colors, clear coatings, electronic cuttable films, protective overlay films, and recommended applications equipment; and

If the sign deteriorates due to natural causes to the extent that: 1) the sign is ineffective for its intended purpose when viewed from a moving vehicle under normal day and night driving conditions by a driver with normal vision, or 2) the coefficient of retroreflection after cleaning is less than the minimums specified in Table C, 3M's sole responsibility and purchaser's and user's exclusive remedy shall be:

If the failure occurs within the first 7 years from the date of fabrication, 3M will, at its expense, restore the sign surface to its original effectiveness. If the failure occurs within the 8th through the 12th year from the date of fabrication, 3M will furnish the necessary amount of 3M Diamond GradeTM DG³ sheeting to restore the sign surface to its original effectiveness.

Warranty - Fluorescent Sheeting

3M warrants that 3MTM Diamond GradeTM DG³ Fluorescent Reflective Sheeting to be sold by 3M to be used as components for traffic control and guidance signs in the United States and Canada will remain effective for its intended use and meet the stated minimum values for coefficient of Retroreflection for up to 10 years. The warranty is subject to the following provisions in Table D.

Table D - Warranty Period for Fluorescent Colors.

Color	Warranty Period
Fluorescent Yellow	10 Years ⁵
Fluorescent Yellow Green	10 Years ⁵
Fluorescent Orange	3 Years

⁵ Due to climatic conditions, the warranty for Alabama, Florida, Georgia, Hawaii, Louisiana, Mississippi, New Mexico, South Carolina and Texas will be 7 years.

If a Diamond Grade fluorescent sign surface is processed and applied to sign blank materials in accordance with all 3M application and fabrication procedures found in 3M's product bulletins, information folders and technical memos (which will be furnished to the agency upon request), including the exclusive use of 3M matched component systems, process colors, clear coatings, electronic cuttable films, protective overlay films, and recommended application equipment; and if the sign deteriorates due to natural causes to the extent that: (1) the sign is ineffective for its intended purpose when viewed from a moving vehicle under normal day and night driving conditions by a driver with normal vision; or (2) the coefficient of retroreflection, after cleaning, is less than 70% of the initial minimum values in Table B; or (3) the total luminance factors after cleaning, are less than the minimums specified in Table A; 3M's sole responsibility and purchaser's and user's exclusive remedy will be:

For those states with a 10 year warranty (see Table D), if the failure occurs within the first 7 years from the date of fabrication, 3M will, at its expense, restore the sign surface to its original effectiveness. If the failure occurs in the 8th through the 10th year from the date of fabrication, or year 1-3 for fluorescent orange, 3M will furnish the necessary amount of Diamond Grade fluorescent sheeting to restore the sign surface to its original effectiveness.

For those states with a 7 year warranty (see Table D), if the failure occurs within the first 5 years from the date of fabrication, 3M will, at its expense, restore the sign surface to its original effectiveness. If the failure occurs in the 6th or 7th year from the date of fabrication, or year 1-3 for fluorescent orange, 3M will furnish the necessary amount of Diamond Grade fluorescent sheeting to restore the sign surface to its original effectiveness.

Conditions for Warranties

Failure must be solely the result of design or manufacturing defects in the Diamond Grade™ DG³ reflective sheeting and not of outside causes such as: improper fabrication, handling, maintenance or installation; use of process colors, thinner, coatings, or overlay films and sheetings not made by 3M; use of application equipment not recommended by 3M; failure of sign substrate; exposure to chemicals, abrasion and other mechanical damage from fasteners used to mount the sign; snow burial; collisions, vandalism or malicious mischief.

3M reserves the right to determine the method of replacement. Replacement sheeting will carry the unexpired warranty of the sheeting it replaces.

Claims made under this warranty will be honored only if the signs have been dated at the time of sheeting application, which constitutes the start of the warranty period.

Claims made under this warranty will be honored only if 3M is notified of a failure within a reasonable time, (reasonable information requested by 3M is provided, and 3M is permitted to verify the cause of failure.)

Limitations of Liability and Remedies

3M's liability under this warranty is limited to replacement as stated herein, and 3M assumes no liability for any incidental or consequential damages, such as lost profits, business or revenues in any way related to the product regardless of the legal theory on which the claim is based. THIS WARRANTY IS MADE IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE IMPLIED WARRANTIES OF MERCHANTABILITY, OF FITNESS FOR A PARTICULAR PURPOSE, AND ANY IMPLIED WARRANTY ARISING OUT OF A COURSE OF DEALING OR OF PERFORMANCE, CUSTOM OR USAGE OF TRADE.

Literature Reference

Instructions for Squeeze Roll Applicator	IF 1.4
Hand Application Instructions	IF 1.5
Instructions for Hand Squeeze Roll Applicator	IF 1.6
Sign Base Materials	IF 1.7
Color Application Instructions	IF 1.8
Cutting, Matching, Premasking, and Prespacing Instructions	IF 1.10
Storage Maintenance, and Removal Instructions	IF 1.11
Sign Fabrication Guidelines for Maximizing Legibility and for High Entrance Angle Signs	
Process Colors	PB 880I
3M™ Process Color	PB 880N

ASTM Test Methods are available from ASTM International, West Conshohocken, PA.

FOR INFORMATION OR ASSISTANCE

CALL:

1-800-553-1380

IN CANADA CALL:

1-800-265-1840

Fax-on-Demand in the U.S. and Canada:

1-800-887-3238

Internet:

www.3M.com/tss

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Traffic Safety Systems Division

3M Center, Building 0225-05-S-08
St. Paul, MN 55144-1000
1-800-553-1380
www.3M.com/tss

3M Canada Company

P.O. Box 5757
London, Ontario N6A 4T1
1-800-3MHELPS

3M México, S.A. de C.V.

Av. Santa Fe No. 55
Col. Santa Fe, Del. Alvaro Obregón
México, D.F. 01210