BY MIKE WOOD

Non-Gaussian diffusers

A Gaussian diffuser is a light diffuser that scatters light completely randomly. LEDs present a whole new set of desires and concerns for Gaussian diffusers.

YES, YET ANOTHER STRANGE TITLE FOR AN ARTICLE. I struggled to come up with a generic name for this issue's topic and non-Gaussian diffuser was the result. Many of the other names for these items that you may have come across, such as light shaping diffuser or engineered diffuser, are the trademarks of one company or another, and I don't want to restrict the article to a single manufacturer's products. What these various diffusion products all have in common is that they are non-Gaussian.

"The Gaussian distribution . . . implies true randomness and lack of control . . ."

To understand what a non-Gaussian diffuser is and why we should care about it, we first need to know what a Gaussian diffuser is. Fortunately that's simple! It is a light diffuser that scatters light completely randomly. These are the types of diffuser we have long used in entertainment lighting. Standard frost filters, ground glass, and most gel diffusers are all Gaussian diffusers. Their surfaces are randomly diffuse and scatter light in all directions. The output from such a diffuser when a narrow input light beam is directed through it is a wider beam with a typical Gaussian bell-shaped light intensity profile distribution. The Gaussian distribution (the same one we are familiar with from statistics) implies true randomness and lack of control, and that's precisely what a normal frost filter does to light. The best you can do with a Gaussian diffuser is to soften the edges of a light beam in the way we do with a piece of frost gel. We have very little control over this softening and, in fact, all Gaussian diffusers scatter light everywhere, inevitably producing spill light. They are also inherently inefficient, as the random scattering means a lot of the light is wasted. Some gets reflected backwards, and a lot more goes off sideways where you don't want it. With the uses they have been traditionally put to in theatrical lighting, this hasn't mattered that much in the past. We often had light we could afford to throw away, and we dealt with the unwanted spill light with top hats, black wrap, and snoots.

Now along come LED-based luminaires (you just knew I was going to end up talking about LEDs, didn't you?) and a whole new set of desires and concerns. Now we want more out of our diffuser than we can get out of a piece of frosted glass or gel. For example, Gaussian diffusers don't work well for homogenizing light. Put a piece of frost gel in front of an array of red, green, and blue LEDs and what you get is an array of slightly larger red, green, and blue diffuse dots. You don't get the single color, mixed beam you hoped you'd see. Nor do we want to deal with all that scatter and wasted light. We don't have light to waste in the first place and, even if we did, it's more difficult to control the spill from a large array of LEDs than from a single output lens on an ellipsoidal luminaire. Finally, we want some accuracy of control. It's trickier to control the beam angle of an array of 100 individual LEDs than the output of a unit with a single light source. There are now LED-based fixtures that provide arrays of lenses to match the arrays of LEDs, but that isn't always convenient. What would be better would be a diffuser that had reduced scatter, a more defined light distribution, and a range of values that allowed us to pick the beam angle we want. That's where our non-Gaussian diffusers step in.

There are various techniques for producing non-Gaussian diffusers, but the type we see most commonly in entertainment lighting are sometimes called holographic diffusers. Just like a regular piece of frost gel, these start out as a piece of transparent plastic material, often a polycarbonate. However, instead of the completely random application of a texture, the surface is stamped or printed with an epoxy layer with a very fine pseudo-random pattern that has been generated holographically on a master plate or drum. Some manufacturers impress the pattern into the material, while others build it up as surface relief. However it is applied, the end result is the same. The pattern consists of tiny ridges and valleys that behave as a huge array of micro lenses. It isn't really random at all; it is very carefully designed to provide the precise optical qualities desired. The pattern is deliberately kept pseudo-randomized, with no repeating patterns, so the structure won't generate moiré patterns or produce color fringing. The goal is to have the pattern controlled, but random enough that we eliminate direct lens aberrations by overlapping multiple, subtly different, lenses. These surface features are tiny, with sizes of the order of a few micrometers. **Figure 1** shows a scanning electron micrograph of the surface of a 5° diffuser. It's almost flat, but you can see the small dimples and hills.

They are much more obvious in **Figure 2,** which is a 50° diffuser. In these small photographs of a small part of the material, the pattern looks completely random, but, taken as a whole, there is an overall structure and layout that behaves as if it were millions of tiny lenses.

The output of these diffusers isn't the bell-shaped Gaussian distribution of a simple piece of frost. Instead, they are designed to produce a flat beam with well-defined edges and beam size. The wide range of sizes of the micro structures mean that they work equally well at all wavelengths of visible light, from deep blue through red, and thus behave achromatically, with no color fringing. **Figure 3** shows the result of passing a collimated beam of light through one of these materials, in this case a 20° symmetrical diffuser. The output beam has a good flat distribution with a soft edge and a well-defined beam size. No scatter and no spill.

You get a similarly well-defined result from a regular non-collimated light source. **Figure 4** shows a holographic diffuser being used with a Maglite. This time the diffuser has been designed to have differing

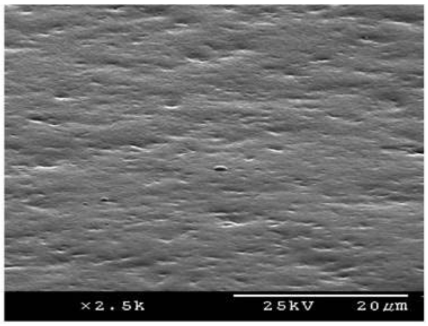


Figure 1 - 5° diffuser

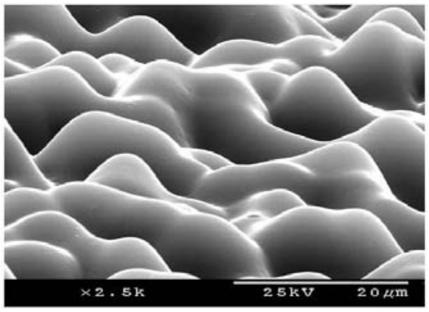


Figure 2 – 50° diffuser

distribution in the vertical and horizontal planes and so produces an elongated 60° x 10° elliptical beam. The beam is again flat and well defined, and the diffuser has done a good job of smoothing out the hot spot you inevitably get with a Maglite or any system using simple ellipsoidal optics.

Holographic diffusers are also very efficient. The vast majority of the light ends up where we want it, with very little stray scatter and reflected light. It's not unusual to see holographic diffusers with efficiencies around 90%. That's incredibly good, and is better than you would get from a single uncoated lens. With wider beam angles, they also do an excellent job of homogenizing multiple light sources, which is why you see them so commonly used in LED luminaires that use arrays of differently colored emitters to produce a single colored output beam.

Note: a holographic diffuser can actually be more efficient than a clear piece of the same plastic. For example, clear polycarbonate is around 89% transparent, whereas the same material with a holographic diffuser layer can be 92 or 93% transparent. This seemingly paradoxical result is achieved by the diffuser layer reducing surface reflections that are the main cause of loss in flat, uncoated materials.

"In this case, one plus one does not equal two."

The final product is a piece of diffusing material that looks, at first glance, just like a piece of frost gel. They are becoming very common in LED units, and I'm sure you have used them in a wide range of angles and distributions in luminaires over the last few years, both to shape and to homogenize beams.

All the theory I talk about above is all very well, but there are some practical points that might assist you in using these

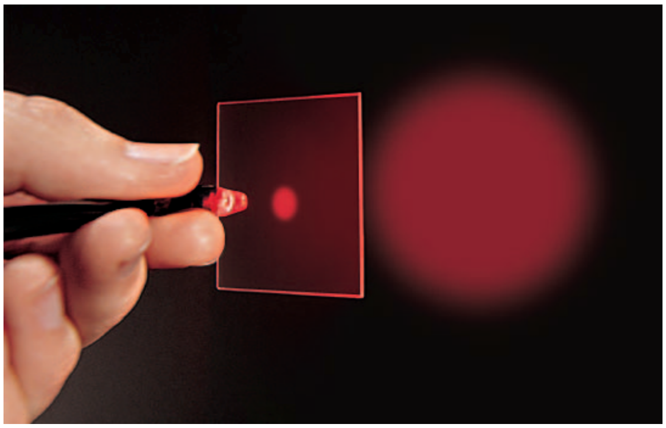


Figure 3 – Flat well defined beam

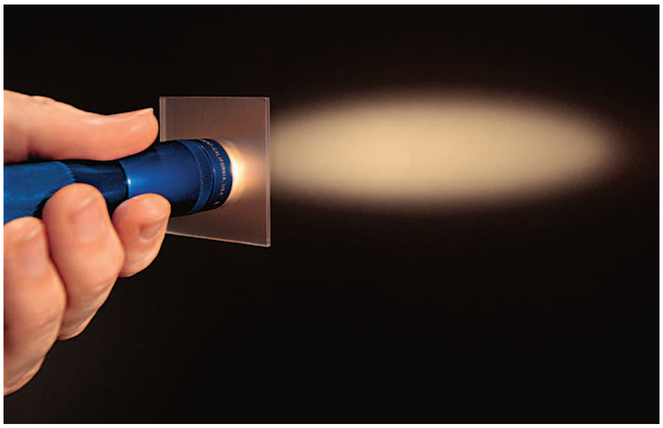


Figure 4 – Asymmetric diffuser

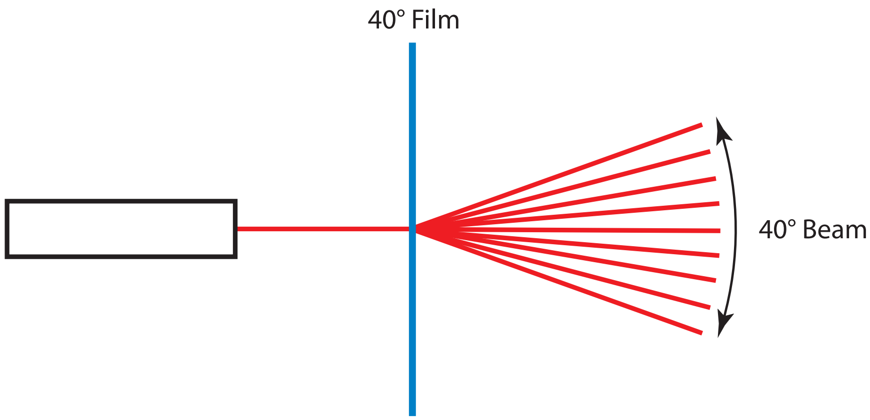
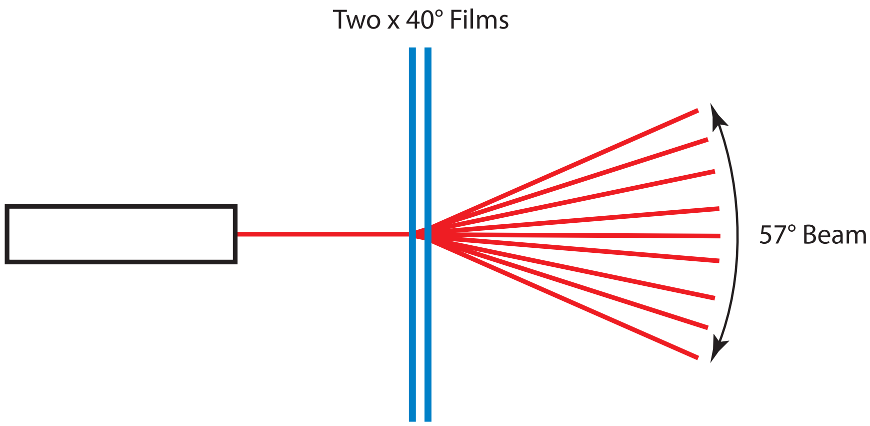
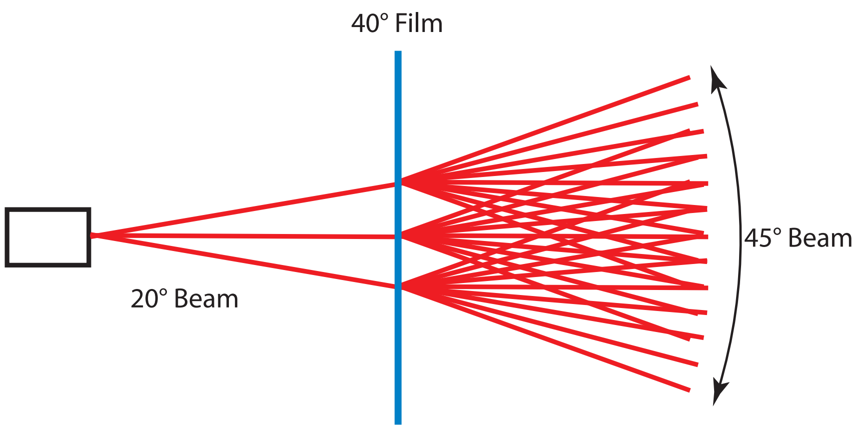


Figure 5 – Single 40° diffuser



$$\text{Output angle} = \sqrt{(40^2 + 40^2)} = 57°$$

Figure 6 – Twin 40° diffusers



$$\text{Output angle} = \sqrt{(20^2 + 40^2)} = 45°$$

Figure 7 – 20° luminaire plus 40° diffuser

products. Firstly, and somewhat sadly, holographic diffusers always behave like a negative, diverging, lens, never a converging one. Thus, once more, our dreams of a negative frost filter have been dashed! They will always make a beam larger and wider, never smaller. It's that darn etendue problem again (see the *Protocol* Winter 2012 issue for a discussion of etendue). Secondly, the angle specified given for a particular diffuser nearly always refers to the full beam width produced. That is the angular width from one side of the beam to the other (not to the middle) where the output drops to 50% of the center. Finally, it's also useful to know how these diffusers work when you use more than one on the same light, or add them to a light with an existing beam angle. **Figure 5** shows the simplest situation, a collimated laser beam with effectively zero beam angle passing through a piece of 40° non-Gaussian diffuser.

The result is, precisely as one might expect, a beam with a 40° beam angle. However, what happens if we add a second 40° filter in? Do they add up and give us 80°? No, they don't! In this case, one plus one does not equal two. Instead they give us a beam of approximately 57°. **Figure 6** shows how the math works.

We have to add the two beam angles together by squaring each value, adding them, and then taking the square root of the result. (Although the basis behind the math is completely different, you will be familiar with the same equation as expressed in Pythagoras' theorem.) The same technique can be used if we use a diffuser in front of a regular, non-collimated light source. **Figure 7** shows the same single 40° diffuser in conjunction with a conventional light source with a 20° beam angle. This could be an LED or an ellipsoidal luminaire.

The net result is not simply 40° + 20° = 60°, but is instead 45°, calculated through the square root of the sum of the squares. The point to remember here is that, if you add multiple holographic diffusers, or add them to a light source with a known beam angle, the final result will always be less than the simple sum of the beam angles,

What are gel theatrical frost filters made from?

For readers who are old enough to remember when drawings were done by hand and not on a computer screen, gel theatrical frost filters started out as the same material used for drawing film: polymer films coated with a thin slurry of titanium dioxide. You might know titanium dioxide (TiO_2) better as the primary ingredient of white paint. Although the base material might have changed to polycarbonate, much gel frost is still made that way to this day. It is scattering from and within those TiO_2 particles that cause the diffusion in frost gel. The scattering is completely random, and somewhat inefficient.

much less in many cases. For asymmetric holographic diffusers you can do the same math for each direction separately.

Note: The described method of summing the squares and then taking the square root of the result is an approximation, but is accurate enough for our application.

With LED-based units, this addition method means that we get the widest range of beam angle control (and the highest efficiency of the LED optics) when the native beam angle of the LED with its primary optic is as narrow as possible. This puts all the final beam angle control within reach of a range of non-Gaussian diffusers. You can always make a light beam wider, but it's much tougher to make it narrower again. ■

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