Optical Diffuser Technologies

In this document we review the properties of four (4) basic diffuser technologies:

1. RPC Engineered Diffusers™
2. "Holographic" Diffusers
3. Diffractive Diffusers
4. Ground-Glass Diffusers.

1. RPC Engineered Diffusers™

RPC Engineered Diffusers™ are refractive, high-efficiency diffusers components with controlled surface properties designed for specific customer applications. These products enables high-performance light management with independent control of both the light distribution pattern and the intensity profile (power vs. angle) within the light distribution pattern. RPC Engineered Diffusers™ go beyond the Gaussian profile provided by common diffusers, such as ground glass and holographic diffusers, to provide users with the controlled light distributions they really need to optimize system performance.

Design

RPC Photonics has developed proprietary modeling and optimization codes to design diffusers that meet specific customer requirements. Important parameters that can be controlled include:

- **Scattering angles (full width)** – from fractions of a degree to Lambertian scatter;
- **Light distribution patterns** – circular, elliptical, square, rectangular, linear, ring, and custom;
- **Intensity profiles** (within the light distribution pattern) – Gaussian, flat top, bat wing, custom.

In addition to supplying custom products upon request, RPC Photonics has a number of stock (off-the-shelf) Engineered Diffusers™ from which to choose. A complete catalog of stock Engineered Diffusers™ can be found on the RPC Photonics website: www.RPCphotonics.com . Examples of our stock Engineered Diffusers™ include:

- **Circular Diffusers** – full-width scattering angles: 0.25 deg. to 120 deg.;
- **Square Diffusers** – full-width scattering angles: 0.16 deg. to 60 deg.;
- **Rectangular Diffusers** – full-width scattering angles: 2 deg. X 1 deg. to 60 deg. X 30 deg.;
- **Line (one-dimensional) Diffusers** – full-width scatterings: 4 deg. to 100 deg.

Fabrication

RPC Engineered Diffusers™ are fabricated using our patented gray-scale lithography system, which is capable of producing deep analog surface-relief profiles (master elements) with depths up to ~80 microns. Arbitrary surfaces structures can be mastered with lithographic precision to attain the theoretically expected performance. The resulting master is used to replicate the Engineered Diffusers™ using a variety of high-volume manufacturing processes and materials.

High-volume manufacturing processes that have been developed for RPC Engineered Diffusers™ include:

- Polymer-on-Glass (or Polymer-on-Film) pattern size up to 228 mm x 228 mm.
- Polymer Injection-Molded Components;
- Hot-Embossed Polymer Sheets – up to 100-mm diameter in a variety of thicknesses;
- Seamless Roll-to-Roll Films – with widths up to 900 mm.

In addition, RPC Engineered Diffusers™ can also be etched directly into the surface of a variety of materials, including: SiO_2, Si , Ge and others; thereby spanning the application wavelength range from 193 nm to 10.6 microns.

Engineered Diffusers™ Features

- Achromatic performance
- Arbitrary/asymmetric scattering angles
- Controlled intensity distribution patterns – Circular, square, rectangular, elliptical, line, ring, etc.
- Controlled intensity profiles – Flat top, Gaussian, batwing, custom
- High optical transmission efficiency – typically > 90%
- Laser, LED, or broadband illumination
- Polarization preserving
- Materials – polymer injection molding; hot embossed polymers, polymer-on-glass components (suitable for re-flow processes); polymer-on-film, fused silica, Silicon, Germanium

Applications

- Gesture-Recognition and Depth-Imaging Systems
- Solid-state (LED) Lighting
- Illumination Systems
- Display Systems
- High-Power Lasers

2. “Holographic” Diffusers

The term “Holographic” diffuser is a name coined to describe the recording of a laser speckle pattern. To record a holographic diffuser, one illuminates a diffuser, typically a piece of ground glass or other suitable diffuser with a laser beam of wavelength λ_0 and width D. A recording material (master element), such as photoresist or film is placed at a distance R from the diffuser, and exposed to the laser speckle pattern. The average size of the recorded speckles ~ λ_0R/D determines the size of the angular spread of light when the exposed speckle pattern (holographic diffuser) is illuminated – the smaller the speckle size, the wider the angular spread of the holographic diffuser.

The intensity distribution patterns produced using holographic diffusers are typically either circular or elliptical in shape, and **the only intensity profile that can be produced within the distribution pattern is a Gaussian profile**. In this sense, while produced using a different manufacturing process, **a holographic diffuser can be regarded as a subset of the intensity distribution patterns and intensity profiles that can be produced using RPC Photonics’ Engineered Diffuser™ Technology.**

Typically, holographic diffusers can produce circular intensity distribution patterns with FWHM angles ranging from 0.5 deg. to 80 deg., and elliptical intensity distribution patterns with FWHM angles from 0.2 deg. x 10 deg. to 35 deg. x 95 deg. Typically, holographic diffusers have a high optical transmission efficiency on the order of 90%.

Holographic Diffuser Features

- Achromatic performance
- Controlled intensity distribution patterns – Circular and elliptical
- Intensity profiles within distribution pattern – Gaussian ONLY
- High optical transmission efficiency – typically > 90%
- Laser, LED, or broadband illumination
- Preserves polarization
- Materials –polymer-on-film.

3. Diffractive Diffusers

Diffractive diffusers are computer-generated diffractive optical elements (DOE) which are produced using either binary- or gray-scale lithography fabrication methods. The maximum scattering angles are determined by the smallest diffraction-grating features on the DOE. Typically, scattering angles for diffractive diffusers are limited to small angles, typically no more than a few degrees.

Diffractive diffusers are capable of generating a wide variety of intensity pattern distributions, together with intensity profile control within the distribution patterns. Diffractive diffusers can produce sharp scattering angle cutoffs, which are desirable in some applications.

There are, however, several difficulties/short-comings associated with diffractive diffusers that limit their use in high-volume commercial applications. First, the DOE must be used at a single design wavelength. Second, it is difficult to eliminate the “zero-order” diffraction order, even at the design wavelength. To eliminate the zero-order (un-diffracted) light, the depth and duty cycle of the surface-relief profile must be controlled with great precision, usually on the order of a few nanometers. If there is a change in the illumination wavelength, a majority of the light lost from the desired diffractive order ends up contributing to the intensity in the zeroth-diffraction order – the result is a “hot spot” on the optical axis. Because of these difficulties associated with sensitivity to the illumination wavelength and wavefront, and the loss of light into higher diffractive orders, and the hot spot associated with the zeroth order, diffractive diffusers have found limited commercial use.

4. Ground-Glass Diffusers

Ground-glass diffusers are produced using various grit sizes of polishing pitch – the finer the polishing pitch, the smaller the surface-relief features on the glass. While ground glass is an inexpensive diffuser, it provides limited control of angular divergence and has issues with repeatability and low optical transmission efficiencies (~40%). In addition, ground glass also can produce only Gaussian scatter distributions. Ground-glass diffusers, accordingly, are generally restricted to laboratory simulations and experiments, rather than wide-spread commercial applications.