Fiber-grating distributed lighting for sensing applications

Paul Westbrook, Kenneth S. Feder, and Gary E. Carver

Novel distributed-light sources employing highly blazed Bragg gratings for efficient scattering enable advances in line-scan sensing.

Line-scan cameras sense the presence of moving objects by reading a row of pixels at uniform temporal increments. Many objects are thus inspected, including foodstuffs, produce, paper, currency, and recyclables. An efficient lighting arrangement should distribute significant power density over a rectangular region conjugate with the row of pixels in the camera. This requires a highly directional distributed source. High-spatial-resolution line-scan cameras require object-plane power densities approaching 1mW/cm² for each pixel to collect useful signals in acceptable integration times. In addition, the power density must be uniform to within a few percent inside the entire rectangle (often 5-25mm high by 1m long). The lighting-distribution optics must function over a wide spectral range and be compatible with practical light-generation devices.

Existing linear-lighting technology includes cylindrical tungsten-halogen lamps, arrays of LEDs and fiber tips, laser-line generators, patterned lightguides, and side-emitting fibers. However, these approaches do not achieve sufficiently intense uniform power density in directional beams without thermal loading. We have developed a fiber-grating-based distributed-light source that meets these requirements. Figure 1 depicts the new distributed-light source which integrates fiber-Bragg gratings and a cylindrical optical element. The key element is a 45° blazed diffraction grating written in the core of an optical fiber. Incident guided light is diffracted from the core at nearly 90° to the fiber axis. The resulting beam is collimated by a cylindrical surface positioned three radii from the fiber.

Gratings were written in standard single-mode fibers using an excimer UV phase-mask system. Diffraction theory relates the outcoupling angle (ξ) to the relevant grating parameters: 

\[
\frac{n_{	ext{eff}}d}{\cos \theta}(1 + \cos \xi) = \lambda,
\]

where \(n_{	ext{eff}} = 1.445\) is the effective index of refraction in the core, \(d = 0.8835\mu m\) is half the phase-mask pitch, \(\theta = 33.3^\circ\) the phase-mask tilt angle relative to the fiber axis, and \(\lambda\) the central wavelength. Because of cylindrical lensing in the fiber, the grating blaze angle is roughly 45°, thus ensuring high outcoupling efficiency. These parameters generate outcoupling at \(\xi\) near 90° for a central wavelength of 1550nm. Similar high-blaze fiber gratings have been used in all-fiber polarimeters. After grating fabrication, fibers are bonded to a 12in-long cylindrical optical element using an optical adhesive.

Figure 2 shows the output of two 5cm-long gratings. The images in Figure 2 were taken with an indium-gallium-arsenide 2D camera focused on a plane 30mm from the fiber axis without the cylindrical optical element. A polarization controller was used to align the input laser’s state of polarization to the blaze angle. The uniformity of the images of the stripe did not

Figure 1. Geometry of the distributed-light source: d is half the phase-mask pitch, θ the phase-mask tilt angle relative to the fiber axis, ξ the outcoupling angle, and φ the azimuthal spread of light emerging from the fiber.

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change as wavelength and polarization were varied. This indicates that grating-induced birefringence is minimal. Low fiber birefringence, high writing concentricity, and post-writing annealing enables good control over polarization evolution, implying a strong potential for light sources in excess of 1m.

We have thus demonstrated a new fiber-grating-based distributed-light source for line-scan sensing with good spatial uniformity (~10%) and spectral bandwidth (300nm). We expect that this approach will provide key improvements in the length, efficiency, brightness, thermal management, and lifetime of lighting solutions for line-scan sensing applications in numerous economic sectors. The long-term potential for this technology includes a low-cost platform for fabrication of meter length or even longer optical fiber-based sources, as well as line sources with specific spectral characteristics spanning the range from IR to visible wavelengths.

**Figure 2.** Measured spatial power distributions for two fiber-Bragg-grating (FBG) light sources (images of both sources are shown at the top and bottom). For both sources, the fraction of light scattered over 1cm is given in the figure legend.

**Author Information**

**Paul Westbrook and Kenneth S. Feder**  
OFS Laboratories  
Somerset, NJ

**Gary E. Carver**  
Omega Optical  
Brattleboro, VT

**References**


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