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DIFFRACTIVE OPTICAL ELEMENTS FOR LIDAR BEAM SCANNING

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1. Introduction

Wind measurement from space can provide critical data for understanding weather patterns and large-scale storm phenomena. An instrument of providing such measurements is currently under development at NASA's Marshall Space Flight Center.[1] The instrument utilizes a pulsed coherent lidar system operating at a wavelength of 2.06 μm in order to achieve decreased weight, size, and cost compared to systems operating at longer wavelengths, and it is being developed to be compatible with the capabilities of small satellites.

A key aspect of such an orbital lidar system is that the beam must be conically scanned after it exits the final beam expansion telescope. Previous work indicates that the aperture of the beam expansion telescope should be 50 cm with a scanner half-angle of 30° and a rotation rate of 10 RPM.[1,2] Such a scanner is illustrated in Fig. 1, in which a beam deflection element is rotated to achieve the conical scan. The critical requirements for the beam scanning element include a 50 cm aperture, an induced wavefront error of less than $\lambda/10$, and high efficiency deflection (i.e., 95+ % of the incident light is deflected).

This report is intended to provide a brief overview and discussion of potential technologies for space-borne laser radar (lidar) beam scanning.

2. Scanner Approaches

2.1 Prism Beam Scanner

The most straightforward method of achieving the beam deflection function is to simply use a prism as illustrated in Fig. 2. The prism material should have a high refractive index to minimize the wedge angle of the prism and hence the prism's volume and weight. This necessitates a material such as germanium (wedge angle ~9° to achieve a 30° beam deflection). However, it is difficult to grow germanium crystals of the requisite size to provide a 50 cm prism aperture. In addition, the mass of such an element is substantial. For example, using a 6:1 diameter to thickness rule, the mass would be 275 lb. Using a more aggressive 15:1 rule the mass is reduced to a

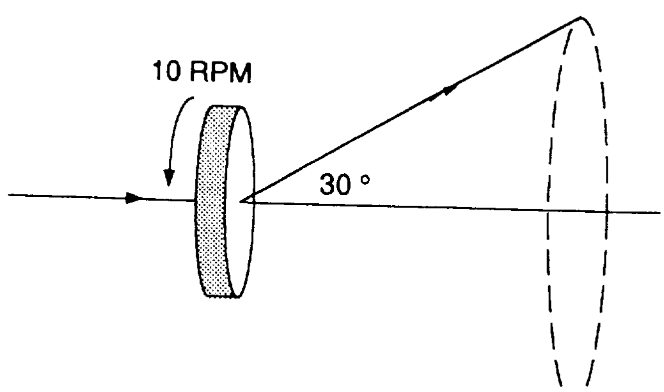

Figure 1. Schematic representation of rotating conical beam scanner.

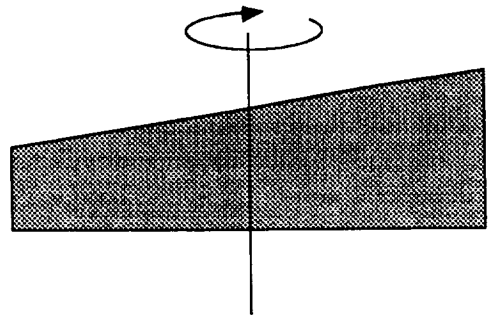

Figure 2. Simple prism beam scanner.

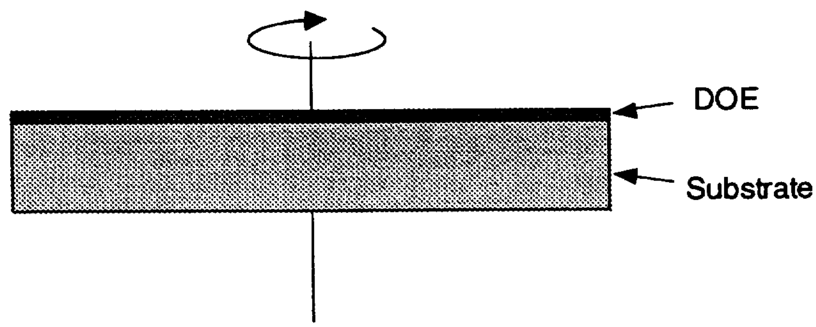

Figure 3. Schematic representation of a DOE beam scanner.

still hefty 160 lb. A further drawback of the prism approach is its asymmetric mass distribution, which complicates balancing the spacecraft dynamics.

2.2 DOE Approaches

A potentially attractive alternative to the prism approach is to use a very thin diffractive optical element (DOE) on top of a lightweight transparent substrate as illustrated in Fig. 3. The DOE would perform the 30° beam deflection function, while the substrate could be made from a low index material such as fused silica. Using the 6:1 rule for the substrate, the mass of the element would be 95 lb (a factor of three less than the corresponding Germanium prism case), while a 15:1 rule yields a mass of 38 lb (a factor of four improvement). A further advantage is that the element's mass is symmetrically distributed about its rotational axis.

2.3 Volume Diffraction Grating

As illustrated in Fig. 4, a volume diffraction grating is an attractive DOE technology because of the potentially high diffraction efficiency that can be achieved. Candidate volume holographic materials include dichromated gelatin, silver halide photographic emulsions, and DuPont's holographic photopolymer. The DuPont photopolymer is particularly attractive because of its dry development process and its availability in thicknesses suitable to achieve high diffraction efficiency. Based on preliminary experiments at a wavelength of 2.06 μm with 10 μm thick

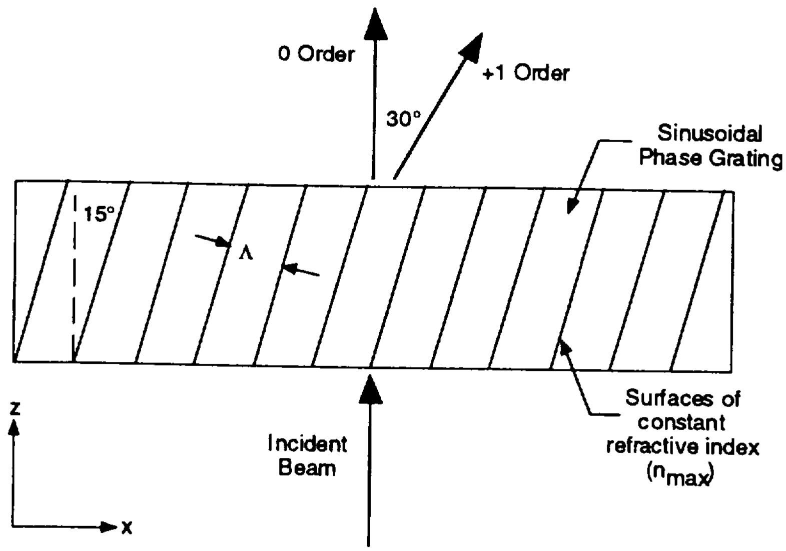

Figure 4. Volume diffraction grating beam scanner.

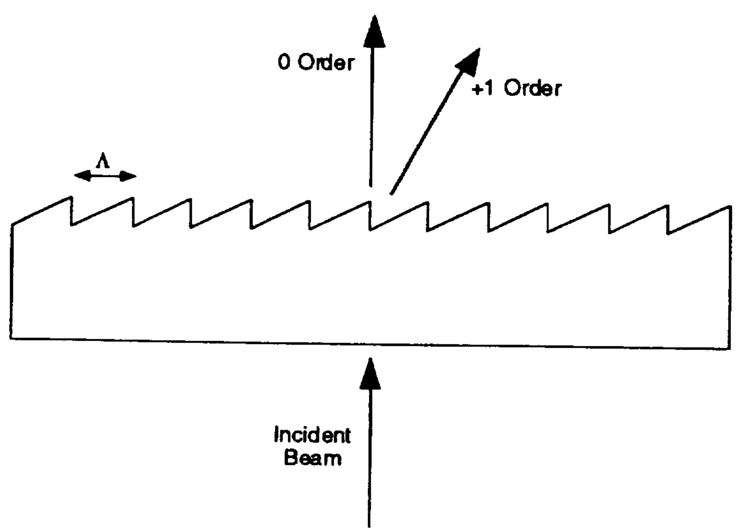

Figure 5. Schematic diagram of a blazed grating.

photopolymer samples, nearly 100% diffraction efficiency should be achievable with 70 μm thick films. Further issues that need addressed include film shrinkage, availability of large exposure optics, polarization sensitivity, and uniformity.

2.4 Blazed Grating

Another attractive high efficiency DOE technology is that of blazed gratings. As illustrated in Fig. 5, a blazed grating is a surface relief profile that is etched into the substrate. By an appropriate choice of blaze angle for a given grating period, Λ, the diffraction efficiency into the +1

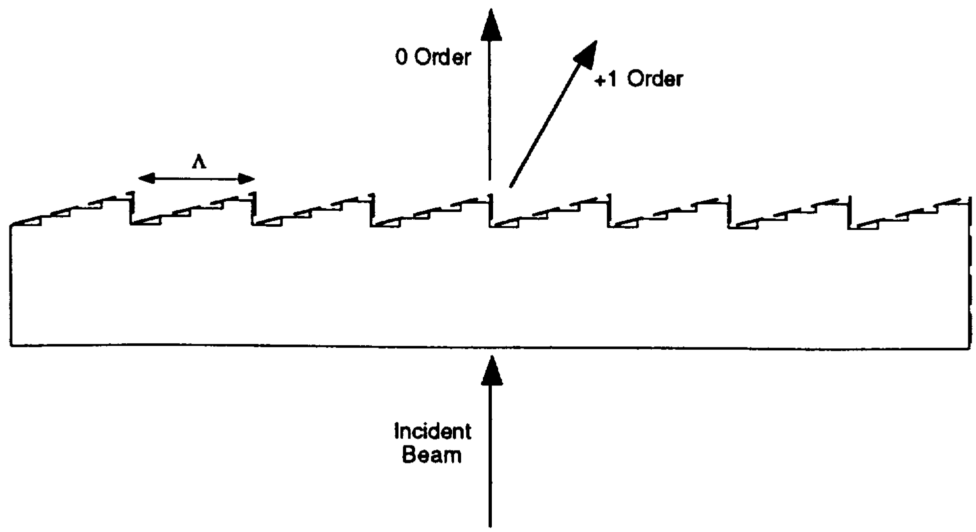

Figure 6. Multilevel diffractive optical element.

Table 1. Multilevel DOE DE and minimum feature size for a given number of phase levels

N	DE (%)	Feature Size (μm)
2	41	2.06
4	81	1.03
8	95	0.52
16	99	0.26

order can be nearly 100%. However, we have yet to locate a vendor who is able to fabricate such a structure over a 50 cm aperture with the required feature size and uniformity.

2.5 Multilevel DOE

As illustrated in Fig. 6, one can approximate the surface relief profile of a blazed grating through the use of a multilevel diffractive optical element. Such profiles are fabricated using a repeated photolithographic patterning and etch process. To achieve large diffraction efficiencies (the column labeled DE in Table 1), the number of phase levels in the surface relief profile needs to be relatively large. For example, 16 phase levels are required to achieve 99% diffraction efficiency. However, the minimum feature size in this case is 0.26 μm, which is too small to fabricate and align over the large area required for this project. Multilevel DOE's are therefore not an option.

3. Summary

There are compelling reasons to look at DOE beam deflection technologies to replace a heavy prism element for conical beam scanning in space-borne 2.06 μm lidar wind measurement systems. Due to its simplicity, the most attractive DOE technology is that of blazed gratings. Since the fabrication of such an element is uncertain at this point, other alternatives are being explored, including volume diffraction gratings and other novel structures that are not discussed in this brief report.

References

1. M. J. Kavaya, G. D. Spiers, E. S. Lobl, J. Rothermel, and V. W. Keller, "Direct global measurements of tropospheric winds employing a simplified coherent laser radar using fully scalable technology," Proc. of SPIE International Symposium on Optical Engineering in Aerospace Sensing, Technical Conference on Space Instrumentation and Dual-Use Technologies, 2214-31, April 6, 1994.

2. R. G. Frehlich and M. J. Yadlowsky, "Performance of mean-frequency estimators for Doppler radar/lidar," J. Atmospheric and Oceanic Technology 11, October 1994.