Scattered-Light Analysis of Birefringent Coatings for Distributed Polarization Rotators

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Abstract: Novel, birefringent thin-film coatings have been developed for improved irradiation uniformity by polarization smoothing in direct-drive fusion. Forward scatter distribution of 351 nm radiation is characterized and its operational impact analyzed.

1. Introduction

To achieve spherical direct-drive implosions at the National Ignition Facility at Lawrence Livermore National Laboratory, beam-smoothing techniques, such as illumination with different polarization states, are employed to avoid beam modulation on target [1]. Efforts have been made at the Laboratory for Laser Energetics (LLE) to create a distributed polarization rotator (DPR) to accomplish this goal [2]. Although they have many benefits, birefringent thin films can have appreciable scatter from their microstructure, which can create amplitude modulation at the target, reducing the efficacy of the DPR. Collaboration between LLE and the National Institute of Standards and Technology (NIST) has begun to measure scattered light fields at 351 nm. To help optimize DPR manufacturing, it is necessary to understand the source of the scattered radiation and the directions in which it radiates.

The birefringent coatings are fabricated using glancing angle deposition (GLAD), whereby material is deposited at very high angles onto a substrate. The coatings are deposited in alternating directions through the layer thickness—a method known as serial bideposition—to suppress column broadening and extinction, creating vertical columns of material with elliptical cross sections [3]. Figure 1(a) shows a typical scanning electron microscopy (SEM) image of a cross section. The optical properties of the coating will change based on the density of the columns, the material used, the ellipticity of the columns, and the angle at which the material is deposited [4]. The goal is to create a quarter-wave coating and to pattern that coating with alternating optical axes. The coating will be index-matched to the substrate to minimize inter-reflections. Currently, magnesium oxide (MgO) is the material of choice because of its refractive index, stress, and deposition properties.
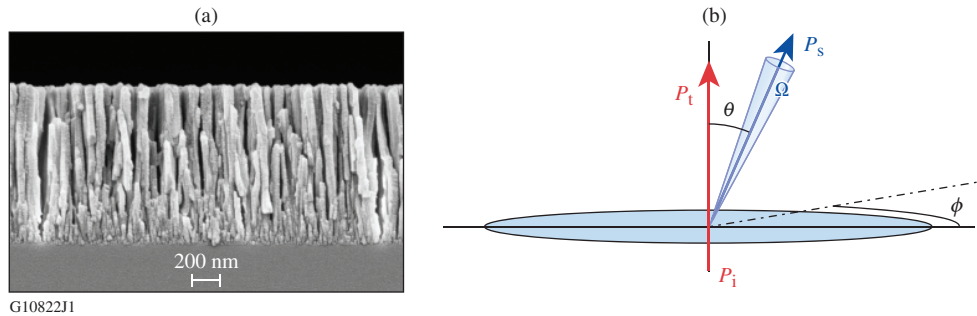

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Fig. 1. (a) SEM image of an optic similar to Sample C and (b) the geometry of the scattered-light measurements.

2. Scatter measurements

A goniometric optical scatter instrument [5] was used to measure optical scatter and polarization effects of a variety of GLAD coatings. The instrument measures both the forward and backward scattered radiation. Figure 1(b) shows the geometry of the measurement for reflection and transmission.

The scatter was measured over many directions in both polar angle θ and azimuthal angle ϕ. The reported bidirectional scattering distribution function (BSDF) is $f_r = P_{\mathrm{i}} / \left(P_{\mathrm{s}} \, \Omega \cos \theta \right)$ where the incident power is P_{i}, the scattered power is P_{s}, and the solid angle subtended by the detector is Ω. Data were taken such that the incident power direction was normal to the substrate surface and the polarization was oriented 45° to the deposition direction. These conditions match the geometry and polarization for which the DPR will be used. The BSDF can be integrated to yield the total hemispherical scatter level.

3. GLAD DPR scatter measurements

Table 1 describes some of the manufacturing parameters of each sample measured. The main difference between Sample A and Sample B is the dipped sol-gel antireflective (AR) coating, which changed the retardance properties and likely contributed to the increase in scattered light. Figure 2 shows the transmitted BSDF as a function of projected cosine space. The center of each image corresponds to the normally transmitted beam, and the detector is blocked by parts of the instrument in the dark corner points. It is noted that the larger retardance of Part C did not correlate to more scatter, as originally expected. Overall, scatter in the backward hemisphere was very low (less <1%) and showed minimal directionality. The standard uncertainties in the BSDF and integrated measurements are expected to be below 2% of the stated values.

Table 1. Sample information and integrated scatter results.

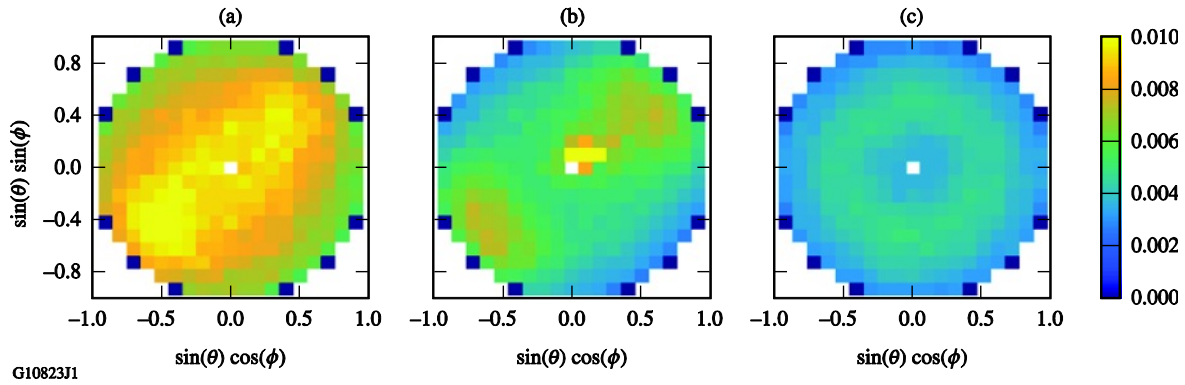| Part	Deposition Angle	Estimated Film Thickness	Retardance	Sol-gel antireflective coating	Transmitted Scatter
A	73°	1.14 μm	55 nm	yes	2.77%
B	73°	1.14 μm	89 nm	no	1.65%
C	58°	1.15 μm	96 nm	no	1.69%

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Fig. 2. BSDF in the forward, transmitted hemisphere projected on a 2-D plane for (a) Part A, (b) Part B, and (c) Part C. Data are shown in BSDF units (sr^{-1}), and the axes are defined by the direction cosines.

Future work will focus on ellipsometry of the birefringent MgO GLAD coatings and modeling of the interaction of the electric field with serial bideposition columnar structures. More exploration is needed to correlate scattered light with variations in deposition angle, film thickness, and retardance.

4. References

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