Deposition of a Discontinuous Coated Surface to Form a Phase-Stepped Reflected Wavefront

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Advancements in spatiotemporal control of laser intensity have enabled new approaches to manipulating laser–plasma interactions and applying these developments in unique ways.[1–4] The "flying focus" scheme uses a chromatic focusing system together with chirped laser pulses to create a laser focus that can propagate at a speed that is decoupled from the group velocity of the laser light.[5,6] The spectral separation of this system extends, however, the minimum pulse duration and limits its usefulness for applications that require ultrashort laser pulses.[7] Recently, a novel achromatic concept was proposed to overcome this limitation.[8] This "achromatic flying focus" uses a radial echelon together with an axiparabola[9] to generate a small focal spot that can propagate over extended distances while maintaining an ultrashort temporal duration.

The goal of this effort is to develop an optical component with a wavelength-scale stepped-surface relief; the axiparabola and the reflective echelon together can produce a focal spot that propagates at the speed of light over a distance of 1 cm without temporally stretching a 15-fs laser pulse. Deposition of a silicon-dioxide thin film via electron-beam evaporation through a mask[10] was used to form the surface structure shown in Fig. 1(a), followed by dc magnetron sputtering of a reflective aluminum layer. The deposited surface structure was formed on a 100-mm-diam × 9-mm-thick glass substrate rotating behind the mask shown in Fig. 1(b) to create an azimuthally uniform thickness.

The mask design uses 23 concentric annular rings with progressively larger angular widths as a function of the radial position on the optic to achieve the profile shown in Fig. 1(a). This required a deposited thickness of 24.2 μm since the maximum open

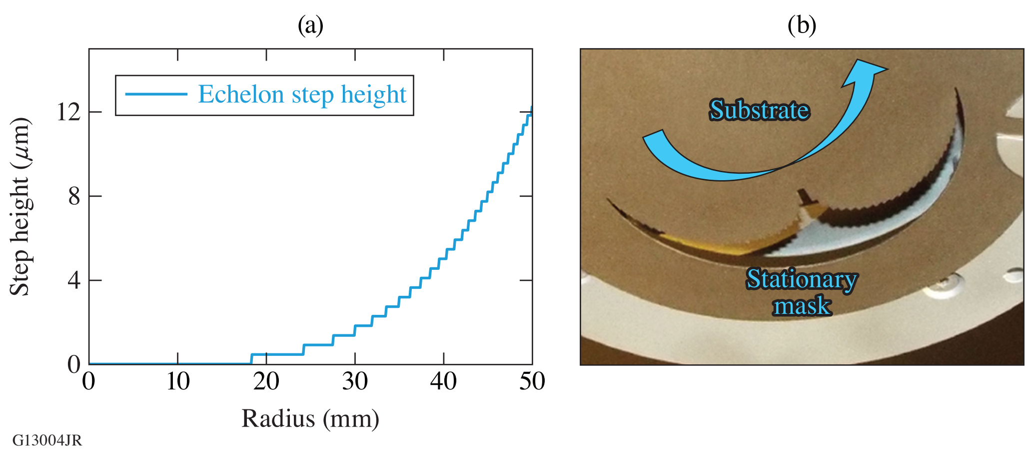

Figure 1
(a) Desired deposition profile to achieve discrete steps of 0.53 μm over the surface of the component. Such a physical step on the surface yields a phase step of π or 2π in reflection. (b) The mask placed in front of the rotating optic has a series of discrete, discontinuous steps to yield the specified profile, with thinner layers near the optic center and thicker layers near the periphery.

space in the mask design is 50%. Each successive mask opening was designed to provide a stepped surface with 0.526 μm less height, using a mask-design scheme similar to the design for continuous surface profiles.[11] The optic center, which is coincident with the substrate-rotation axis, has no deposited thickness. The aluminum layer deposited over the structured surface was limited to approximately 20-nm thickness to minimize degradation of the surface profile while achieving >90% reflectance.

The substrate surface relief was measured using stitching white-light interferometry as shown in Fig. 2. The flatness and transitions of the steps indicate that an accurate duplication of the desired surface profile was achieved with minimal blurring between steps in a manner that should quickly diverge light incident on the transitions out of the optical system. The transitions are of the order of 150 μm in width, representing 5% to 10% of the total substrate area.

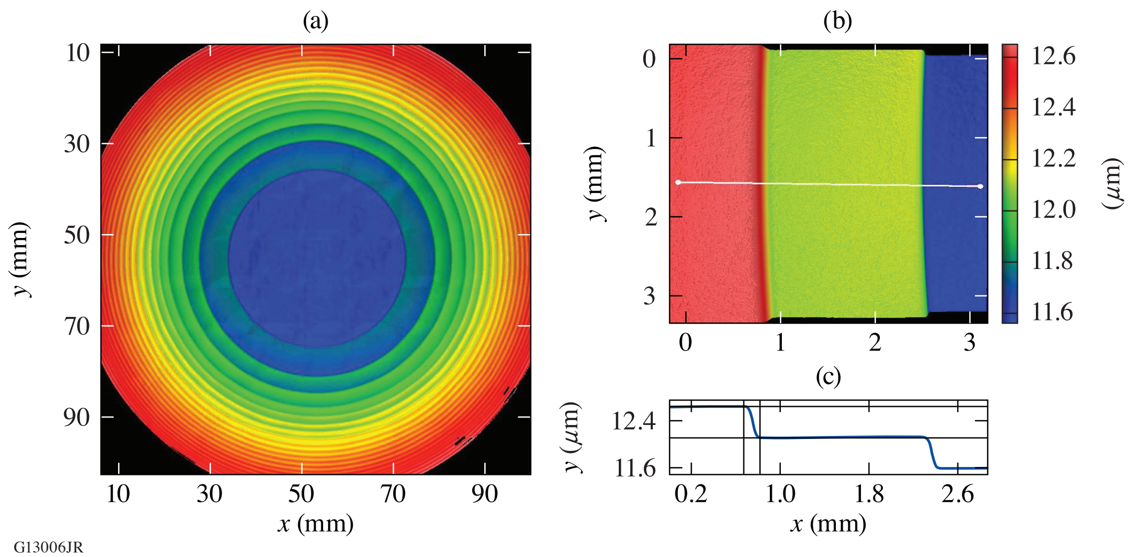

Figure 2
The surface profile of the echelon component as measured with a Zygo NexView white-light interferometer. (a) The overall optic surface is based on a series of stitched measurements. The (b) higher-magnification image and (c) corresponding lineout provide greater detail on the step shape and linear extent of the transition between steps. The step heights differ from nominal by <3%, while the transitions between steps are of the order of 0.15 mm.

This work showed it is possible to vapor deposit a reflective echelon component for use in an achromatic flying focus. The resulting film structure provides accurate steps to yield the desired discontinuous reflected-wavefront phase profile. Future work may focus on reducing the lateral extent of the transitions by increasing the source-to-substrate distance and further shrinking the mask/substrate separation. Alternative deposition materials may potentially be explored, as well as collimation of the vapor source.[12]

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1. D. Turnbull *et al.*, Phys. Rev. Lett. **120**, 024801 (2018).

2. D. Turnbull *et al.*, Phys. Rev. Lett. **120**, 225001 (2018).

3. P. Franke *et al.*, Opt. Express **27**, 31,978 (2019).

4. D. H. Froula *et al*., Nat. Photonics **12**, 262 (2018).

5. A. Howard *et al*., Phys. Rev. Lett. **123**, 124801 (2019).

6. A. Sainte-Marie, O. Gobert, and F. Quéré, Optica **4**, 1298 (2017).

7. D. H. Froula *et al*., Phys. Plasmas **26**, 032109 (2019).

8. J. P. Palastro *et al*., Phys. Rev. Lett. **124**, 134802 (2020).

9. S. Smartsev *et al*., Opt. Lett. **44**, 3414 (2019).

10. J. B. Oliver and D. Talbot, Appl. Opt. **45**, 3097 (2006).

11. J. B. Oliver, J. Spaulding, and B. Charles, Appl. Opt. **59**, A54 (2020).

12. J. B. Oliver *et al*., presented at SVC Techcon 2014, Chicago, IL, 3–8 May 2014.