Versatile Flat Optics enabled by Grayscale Lithography: Applications from Astrophotography to Microscopy

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Flat optics have many advantages, such as light weight, low cost, and more importantly versatile applications. Recently, we have demonstrated flat optics across a wide field of usage such as astrophotography, microscopy, document security, and extended focusing for metrology and laser-machining.

These flat lenses, which we call multi-level diffractive lenses (MDLs) are comprised of concentric rings of varying heights, with maximum ring height < 3 μm., thereby making them ultra-thin and light weight. These heights are optimized using sophisticated inverse design-based algorithms, adjusted for the specific application that is being addressed by the optic. Following this, we fabricate the MDLs using direct laser write grayscale lithography using a DWL 66+ (Heidelberg Instruments). The lithography process includes a grayscale calibration and pre-optimization step.

Here, apart from the MDL fabrication details, we will report on their applications to different fields. We have demonstrated a 100 mm diameter, f/2, broadband MDL for full-color astrophotography[1], as shown in Fig. 1(a). Next, we demonstrated a 0.99 NA, 3 mm diameter MDL for high-NA microscopy[2], operating at λ =634 nm, as shown in Fig. 1(b), comprised of rings of 0.5 μm width. Here we will also discuss the difference in focusing when the MDL is illuminated in different axial directions. Thirdly, we demonstrated a microlens array (MLA) with 0.88 NA and f/0.27, replicated using nanoimprint lithography into a flexible polymer sheet allowing it to be integrated with offset prints, thereby enabling integral imaging that is used in optical document security (Fig. 1(c)). Lastly, we will report on our recent demonstration of mass-produced (UV casting) extended depth-of-focus (EDOF) MDLs designed to focus 1064 nm laser light over a 5 mm extended focus depth. These are designed for use in metrology and laser machining (Unpublished data, shown in Fig. 1(d)).

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[1] Majumder, Apratim, et. al., "Fresnel zone plate outperforms the metalens at high NA," Optics Express 33 (11), 23313-23321 (2025).

[2] Majumder, Apratim, et. al., "Color astrophotography with a 100 mm-diameter f/2 polymer flat lens," Appl. Phys. Lett. 126, 051701 (2025).

[3] Majumder, Apratim, et. al., "Low-cost, high-volume, manufacturable 0.88 NA multi-wavelength diffractive lens array for optical document security," Applied Optics 64 (7), B1-B5 (2025).

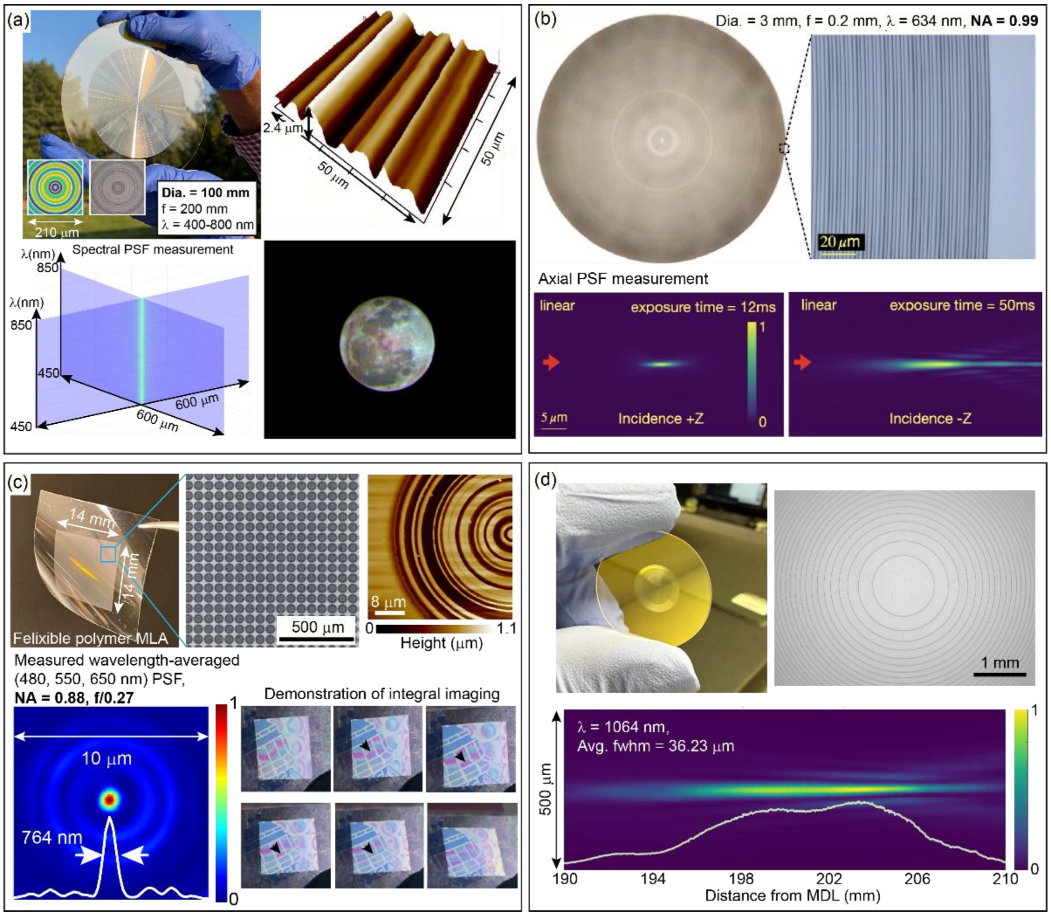

Figure 1: Applications of grayscale lithography enabled flat optics (all sub-panels clockwise from top-left): (a) Photograph of a 100-mm diameter, 200 mm focal length broadband (λ = 400-800 nm) flat lens with design and optical micrographs of the innermost rings shown inset, AFM image of the fabricated rings, a full-color image of the moon captured using this lens, and the measured spectral PSF of the lens showing achromaticity across the designed wavelength range. (b) Photograph of a 3 mm diameter 0.99 NA flat lens with optical micrograph of the outermost rings, measured axial PSF showing drastically improved and near-diffraction limited performance when illuminated from the substrate-lens-air interface direction (+Z). (c) Photograph of a flexible polymer microlens array (MLA) with optical micrograph of the lens array and an AFM image of one of the individual lenses, demonstration of integral imaging when the MLA is combined with an offset print (frame captures from a video showing animation as pointed out by the black arrow), and measured PSF of one of the lenses. (d) Photograph of a mass-produced extended depth of focus (EDOF) flat optic, optical micrograph and the measured axial PSF showing the lens focusing incident light over a 5 mm distance.