RAM-adaptive Parallel generating and minimising the layout file of wafer-scale metalens

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Metalens, a flat optical component with the powerful engineering ability of amplitude, wavefront, and polarisation, has emerged as an attractive device for astronomy observation because of its submillimeter thickness and lightweight [1]. As shown in Fig. 1, the metalens refers to an array of periodically placed subwavelength-scale meta-atoms on a wafer. Currently, the aperture size of a metalens is restricted within a millimetre scale by the layout file sizes. For example, the layout file sizes of a 50mm-diameter metalens, including 6 billion meta-atoms, would be larger than 200Gb, far beyond mask writing tools' handling capability (e.g., e-beam lithography, EBL) [2]. While the square section segmentation and splicing approach has been used for achieving 100mm metalens, this fabrication method highly depends on the C^4 rotational symmetry of the metalens [1]. Meanwhile, a majority of multifunctional metalens don't possess the rotational symmetry [3]. Therefore, it is essential to develop a general way of reducing the layout file sizes and boosting the fabrication of large aperture metalens. In addition, the serial generation process of the layout file, including billions of meta-atoms, would cost a lot of computing time and resources (CPU and RAM).

Here, we propose a RAM-adaptive parallel approach for accelerating the layout file generation of large-aperture metalens and introduce the OASIS format to reduce the layout file sizes effectively. Comparing the commonly adopted GDS format, the OASIS format can reduce file sizes and loading times. Most importantly, the OASIS format is widely accepted by the EBL tools and EDA software (e.g., L-editor and K-Layout) [4]. As shown in Fig. 1, the metalens is divided into several annular rings by setting $0 < AR_1 \leq r_1, r_1 < AR_2 \leq \sqrt{2}r_1, \sqrt{2}r_1 < AR_3 \leq \sqrt{3}r_1, \cdots, \sqrt{n-1}r_1 < AR_n \leq \sqrt{n}r_1$ where $\sqrt{n}r_1$ equals to the metalens's radius R and the r_1 is determined by the available RAM size. Based on this method, the metalens is divided into n annular rings and each ring has a meta-atoms number of $\pi r_1^2/P^2$ (P is the period of the meta-atom). The layout file of each annular ring can be parallelly exported to separate OASIS files with minimised sizes. Finally, each OASIS file can be easily merged into the full OASIS file because we don't need to manipulate the meta-atoms.

Table 1 defines the ratio of layout file sizes to meta-atoms number (Unit: GB/billion) as a figure of merit (FoM) aiming at quantitively illustrating the OASIS format advantage. Table 1 shows that the ratio can be reduced from around 25Gb/billion to 1.4Gb/billion, which indicates that the layout file sizes can be reduced by 94% via using OASIS format. As a result, the layout of a 5cm-diameter metalens with 3 billion meta-atoms can be exported to a 4.3Gb OASIS file within 10 hours based on a multi-core computer. Therefore, layout file sizes of 150mm, 200mm, and 300mm metalens would be only 40Gb, 72Gb, and 160Gb.

Figure 2a demonstrates that our meta-atom width varies from 200nm to 550nm with a period of 800nm, which provides us with a high transmission and 2π phase coverage at the working wavelength of 1550nm. Fig. 2b and 2c illustrate the optical and SEM images of fabricated 50mm metalens based on the 4.3Gb OASIS layout file listed in Table 1. These results demonstrate the feasibility of our method. In addition, as the feature size of our metalens is larger than 200nm (Fig. 2a), our metalens can be massively produced by the DUV and nanoimprint lithography.

[1] Park, Joon-Suh, et al. "All-glass 100 mm Diameter Visible Metalens for Imaging the Cosmos." *ACS nano* 18.4 (2024): 3187-3198.
[2] She, Alan, et al. "Large area metalenses: design, characterization, and mass manufacturing." *Optics Express* 26.2 (2018): 1573-1585.
[3] Sun, Chuang, et al. "Tunable on-chip optical traps for levitating particles based on single-layer metasurface." *Nanophotonics* 0 (2024).
[4] https://sst.semiconductor-digest.com/2020/02/oasis-vs-gds-time-to-switch/

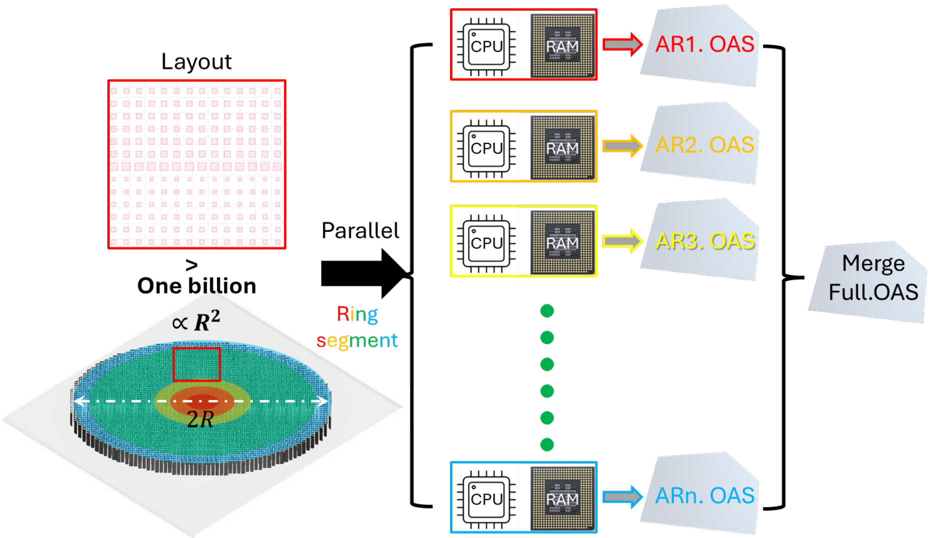

Figure 1. Parallel generation flow of the Layout file in OASIS format.

Table 1. Our metalens Layout file sizes *vs* diameter and comparison with references [1] and [2] are listed in red.

Diameter (mm)	Pillars number	Layout file sizes	Sizes/pillars number
1	1.3 million	2 MB	
2	4.9 million	7.4 MB	
3	11 million	17 MB	
4	20 million	30 MB	
5	31 million	46 MB	
25	0.8 billion	1.1 GB	1.4 GB/billion
50	3.1 billion	4.3 GB	1.4 GB/billion
20 X 20 (square) [1]	0.9 billion	20.3 GB	22.6 GB/billion
50 [2]	6.8 billion	205.7GB	30.3 GB/billion

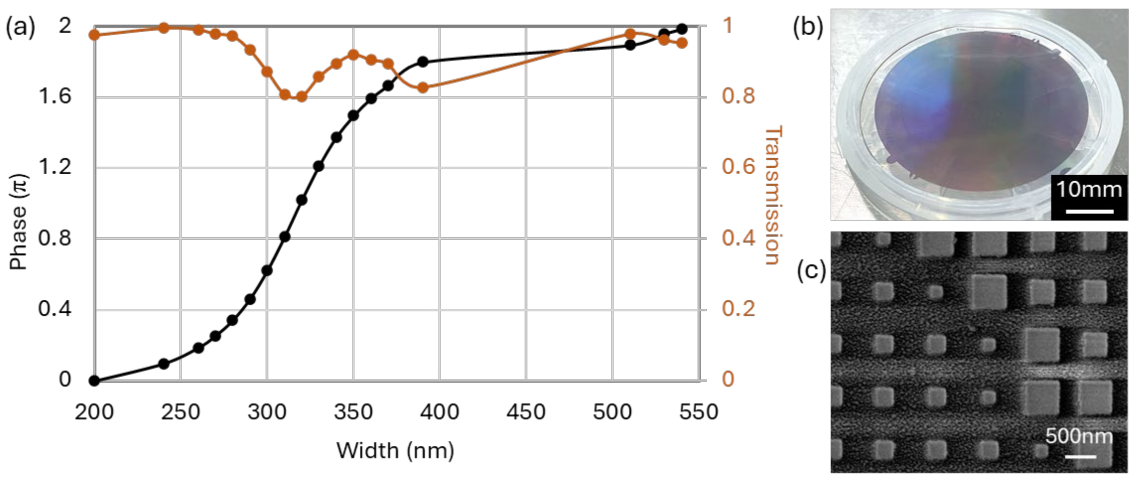

Figure 2. 50mm metalens design and fabrication. (a) The meta-atoms library which is compatible with DUV lithography, (b) optical, and (c) SEM images of the fabricated sample.