Broadband Imaging with Metasurfaces

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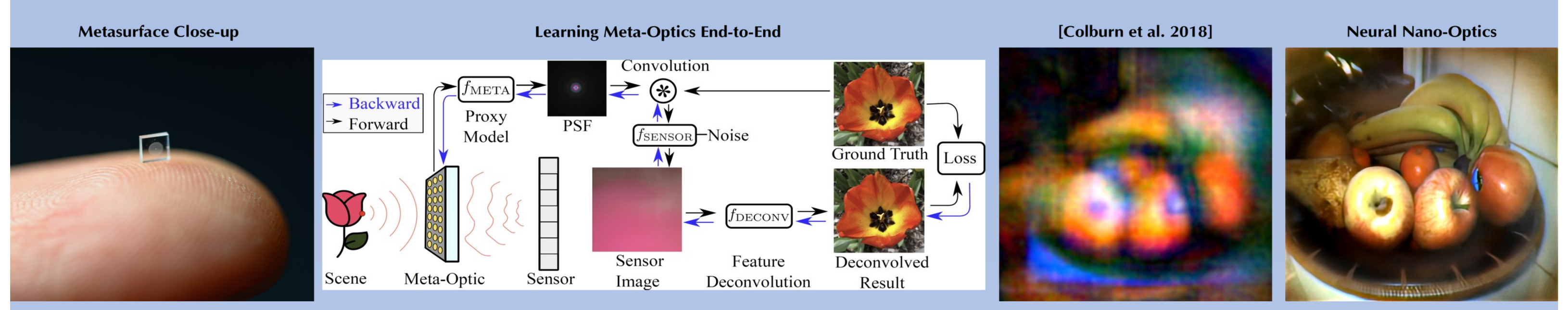
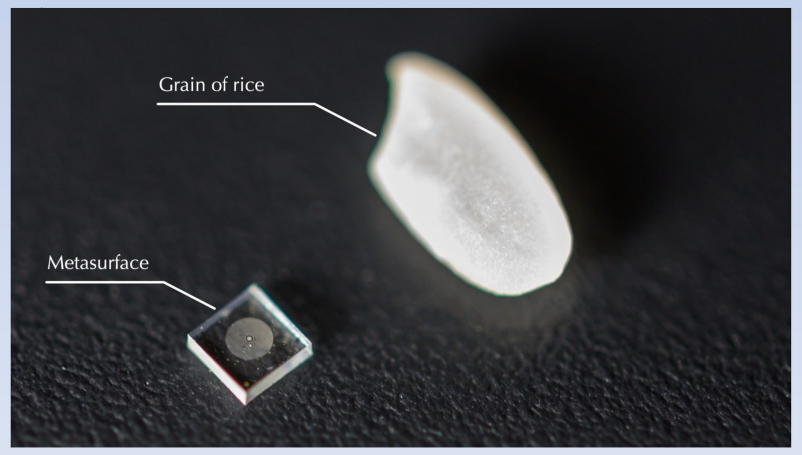
Neural Nano-Optics



- We present neural nano-optics, offering a path to ultra-small imagers, by jointly learning a metasurface optical layer and neural feature-based image reconstruction. Compared to existing state-of-the-art hand-engineered approaches, neural nano-optics produce high-quality wide-FOV reconstructions corrected for chromatic aberrations [1].

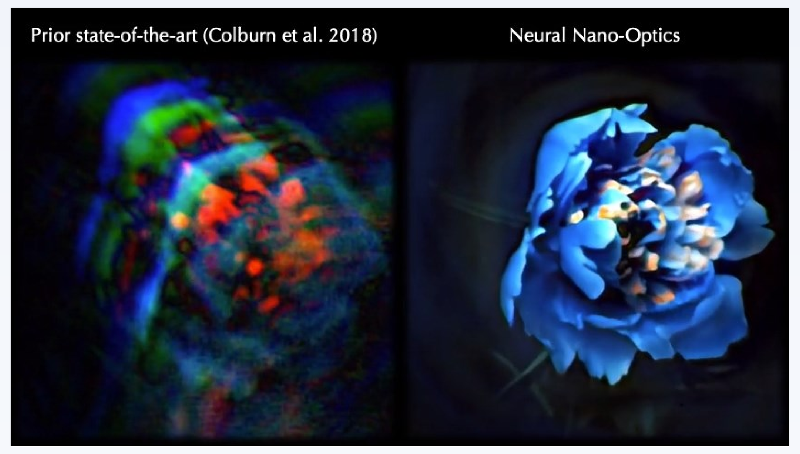
Salt Grain-sized Cameras

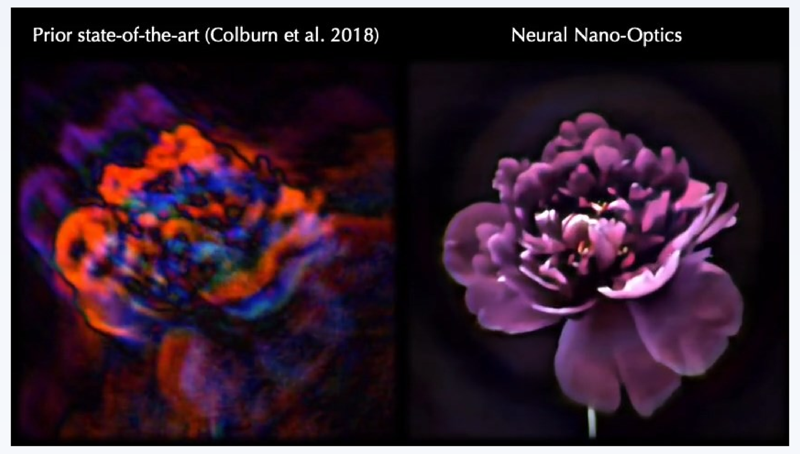
- The ultracompact camera we propose uses metasurface optics at the size of a coarse salt grain and can produce crisp, full-color images on par with a conventional compound camera lens 500,000 times larger in volume.



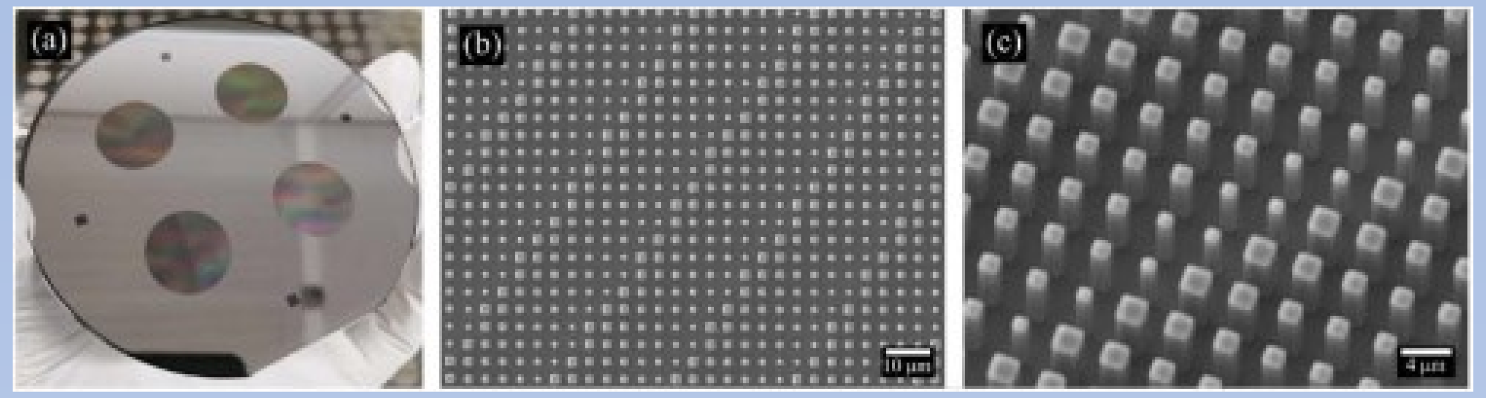
Achromatic Imaging Capabilities

- Our optimized meta-optic design meets several criteria that were not met by previous methods. The nano-camera allows us to capture full-color images over a wide field-of-view (see below)
- our aperture is the largest demonstrated for meta-optics at 500 microns, allowing for increased light collection. Our optic also exhibits a low f-number, allowing for the optic to be placed extremely close to the camera sensor.
- No previous metasurface has demonstrated imaging with this combination of large aperture, large field-of-view, small f-number, and large fractional bandwidth. Previously, achieving any one of these metrics came at the cost of some other, for example, one could achieve a low f-number by sacrificing the aperture size.





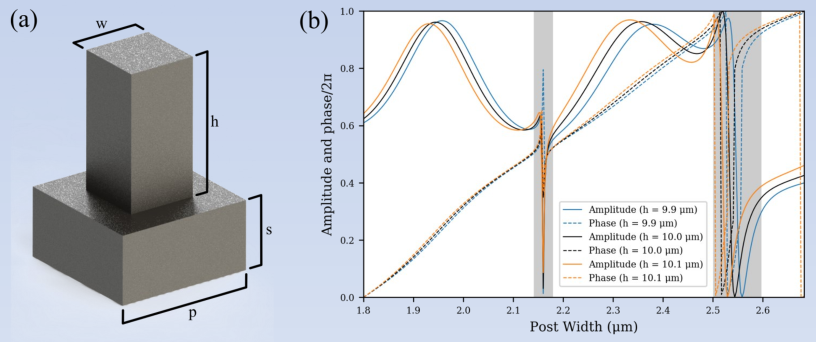
Thermal Meta-optical Imaging



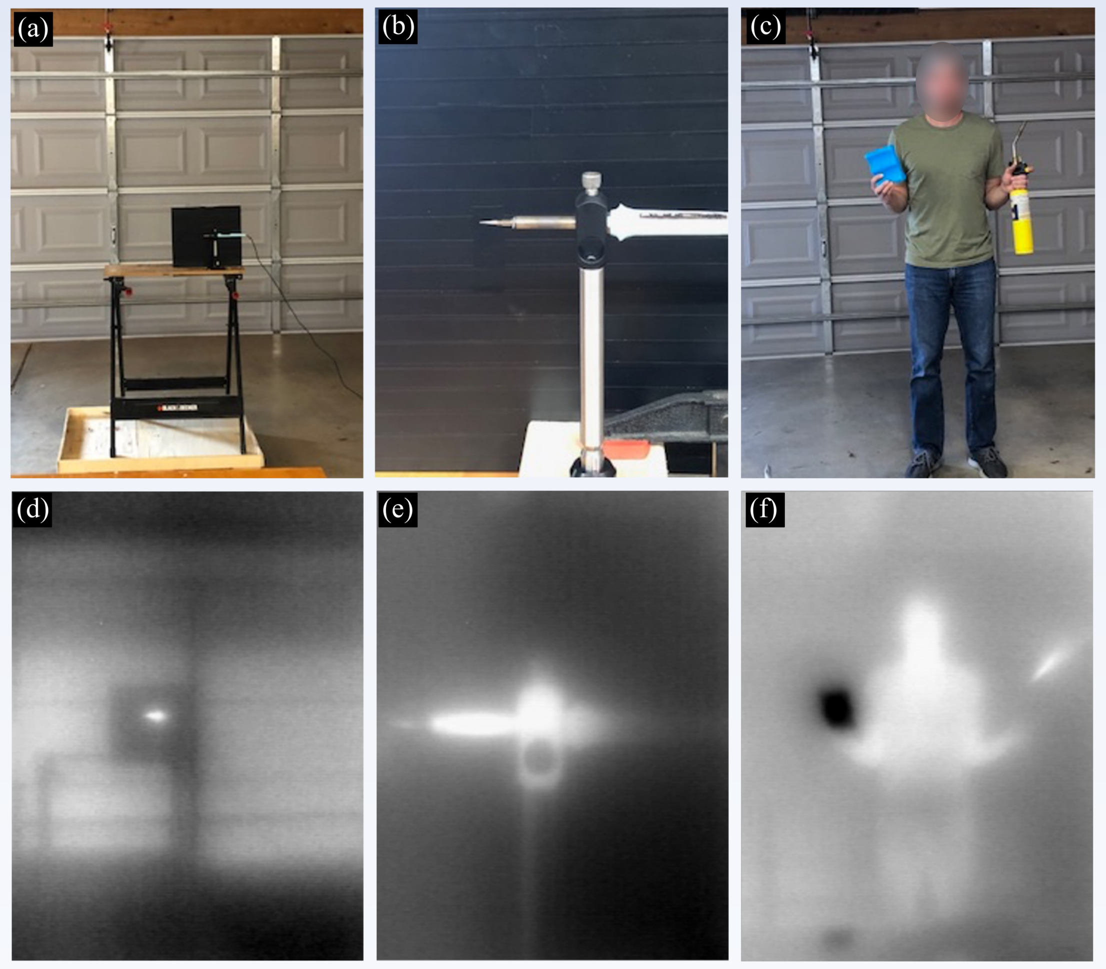
- We extend meta-optics to the long-wave infrared (LWIR) regime and demonstrate imaging with a 2 cm aperture f/1 all-silicon metalens (see above) under ambient thermal emission. We showed that even with the strongly chromatic nature of the metalenses, we can perform ambient light imaging, primarily due to the lack of wavelength discrimination in the sensor, as is the norm for an RGB-camera in the visible [2].

Design

- The metalens is designed by placing appropriate scatterers in a square lattice. The schematic of a unit cell of the nanopost is shown on (a). By adjusting the widths of these square nanoposts, we can modify the effective index of the nanoposts and thus change the transmission coefficient (both amplitude and phase) of the incident light. We perform rigorous coupled-wave analysis (RCWA) to map the nanopost width to the respective transmission coefficient shown on (b).



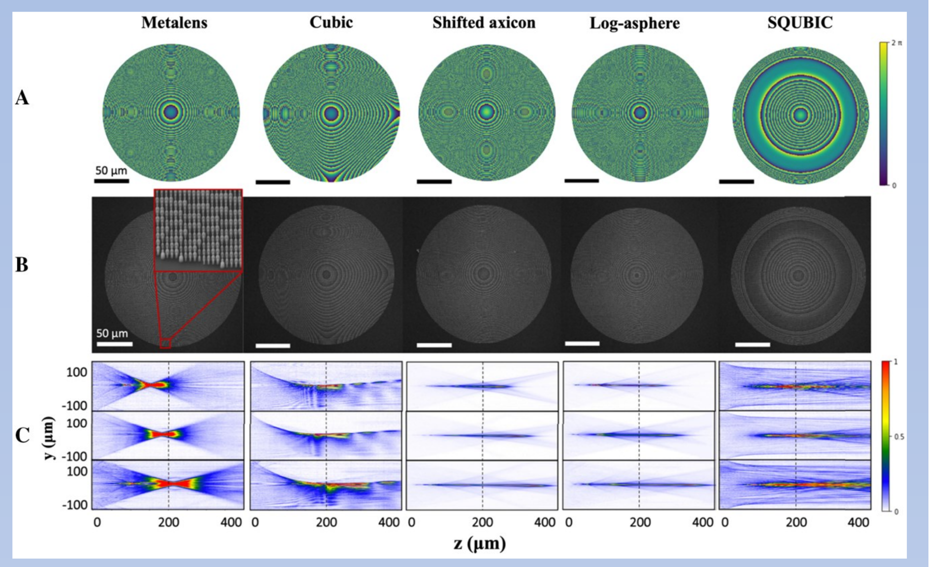
Ambient Temperature Imaging



- We are the first to demonstrate LWIR imaging using the simple metalens "in the wild", outside of the laboratory environment.
- The black-body radiation spectrum differs at different temperatures. To further characterize the performance of the metalens imaging system under more extreme temperatures

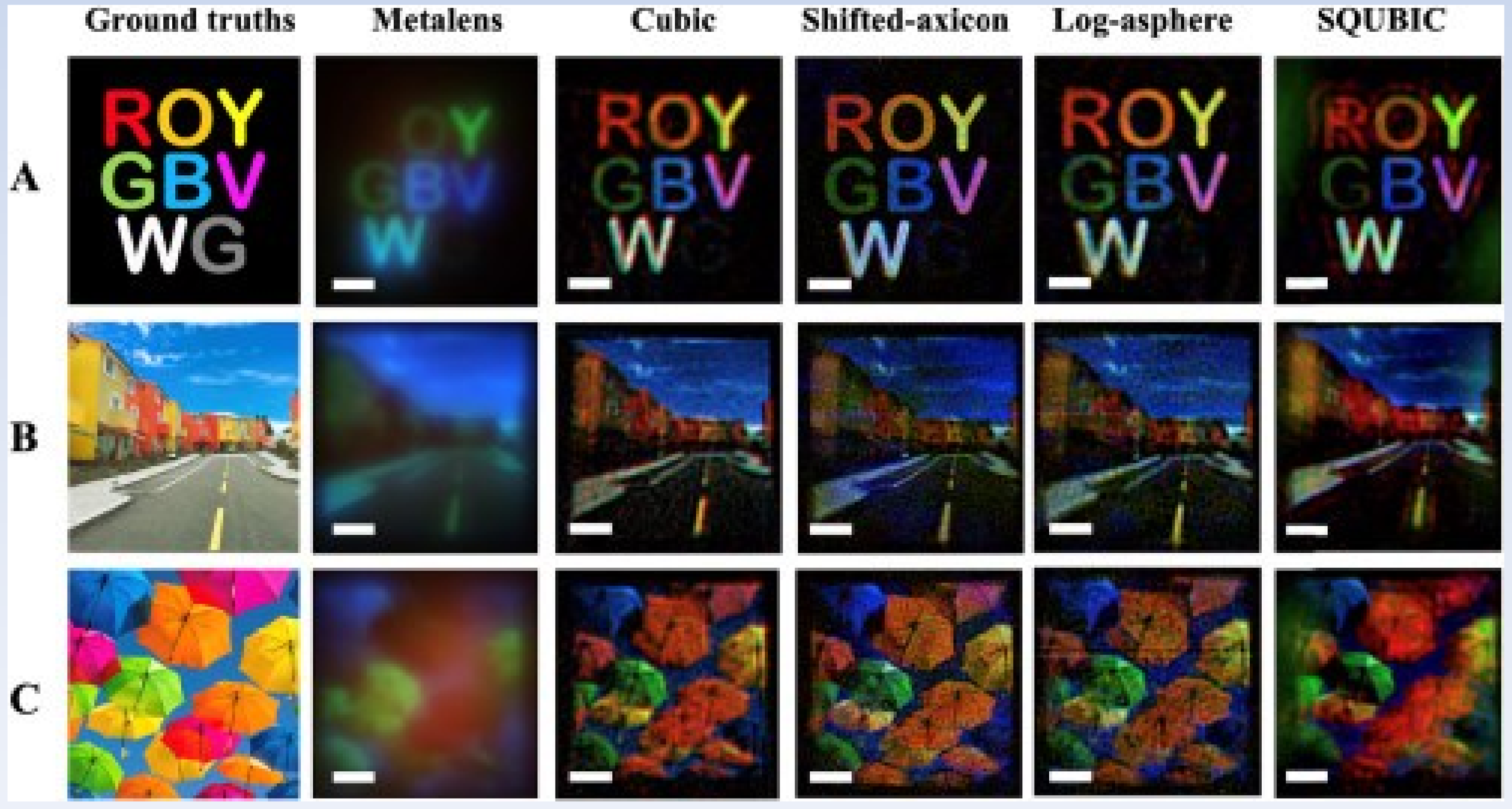
Visible Full-color Imaging

- Here, we present an alternative technique to mitigate chromatic aberration and demonstrate high-quality, full-color imaging using extended depth of focus (EDOF) metalenses and computational reconstruction. [3]
- We designed and fabricated 3 novel EDOF meta-topics to compared to the state-of-the-art meta-optics (see right).



Full-Color Imaging

- the EDOF metasurfaces demonstrate an impressive ability to maintain a highly invariant PSF across a large spectral range. The imaging results as well as the SSIM calculations indicate that EDOF metasurfaces significantly outperform the standard metalens in full-color imaging. The log-asphere and shifted axicon designs both demonstrate the highest optical bandwidth for imaging.



Future Work and References

Future work

- Optical neural network
- Inverse designed meta-optical doublets for broadband applications.
- Inverse designed LWIR meta-optics

[1] E. Tseng, S. Colburn, J. Whitehead, L. Huang, S.-H. Baek, A. Majumdar, and F. Heide, "Neural nano-optics for high-quality thin lens imaging," Nature Communications, vol. 12, no. 1, 2021.
[2] L. Huang, Z. Coppens, K. Hallman, Z. Han, K. F. Böhringer, N. Akozbek, A. Raman, and A. Majumdar, "Long wavelength infrared imaging under ambient thermal radiation via an all-Silicon metalens," Optical Materials Express, vol. 11, no. 9, p. 2907, 2021.
[3] L. Huang, J. Whitehead, S. Colburn, and A. Majumdar, "Design and analysis of extended depth of Focus Metalenses for achromatic computational imaging," Photonics Research, vol. 8, no. 10, p. 1613, 2020.

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