Single-Shot Quantitative Phase Imaging via Kramers–Kronig Relations Using a Wavelength-Selective Metalens

Beomha Yang[1]*, Jehyeon Shin*[2] *and Junsuk Rho*[1,3,4,5,6]

[1]Graduate School of Quantum Information Science, Pohang University of Science and Technology (POSTECH) Pohang 37673, Republic of Korea

[2]Graduate School of Artificial Intelligence, Pohang University of Science and Technology (POSTECH), Pohang 37673, Republic of Korea

[3]Department of Chemical Engineering, Pohang University of Science and Technology (POSTECH), Pohang 37673, Republic of Korea

[4]Department of Mechanical Engineering, Pohang University of Science and Technology (POSTECH), Pohang 37673, Republic of Korea

[5]Department of Electrical Engineering, Pohang University of Science and Technology (POSTECH), Pohang 37673, Republic of Korea

[6]POSCO-POSTECH-RIST Convergence Research Center for Flat Optics and Metaphotonics, Pohang 37673, Republic of Korea

Tel.:82-54-279-2834, E-mail: jsrho@postech.ac.kr

Non-interferometric quantitative phase imaging (QPI) based on space-domain Kramers–Kronig relations enables recovery of complex amplitude and phase from intensity-only measurements without a reference beam[1]. However, the conventional approach which isolates positive-frequency components in the Fourier plane inevitably discards negative-frequency content, creating gaps in the spatial-frequency spectrum. Filling these gaps typically requires multi-shot acquisitions under varied illumination angles or wavelengths, increasing system complexity and precluding high-speed imaging of dynamic samples. Recent single-shot implementations using polarization or spectral multiplexing have mitigated this issue, but at the cost of elaborate optical arrangements[2, 3].

In this work, we present a compact 4-f optical configuration featuring a color-dependent local metalens engineered at the nanoscale to filter distinct positive-frequency bands across different visible wavelengths, thereby enabling single-shot Fourier-space completion. By integrating this metalens into a standard 4-f arrangement, we selectively capture the designated positive spatial-frequency components for each illumination wavelength in a single exposure, leveraging complementary Fourier components across wavelengths to fill in one another's missing negative-frequency regions and reconstruct the entire Fourier-domain spectrum. Experimental results indicate that our method achieves reconstruction fidelity and imaging speed comparable to conventional multi-shot schemes, while providing sufficient spatial resolution for real-time phase imaging of dynamic specimens such as living cells.

Acknowledgement

References

1. Baek, Y., et al. Intensity-based holographic imaging via space-domain Kramers–Kronig relations. *Nat. Photonics* **15**, 354–360 (2021)

2. Lee, C. et al. Single-shot wide-field topography measurement using spectrally multiplexed reflection intensity holography via space-domain Kramers–Kronig relations, *Opt. Lett*. 47, 1025-1028 (2022)

3. Chen X. et al., Single-shot resolution-enhancement quantitative phase imaging based on Kramers–Kronig relations, *Opt. Lett*. 48, 3563-3566 (2023)