Optical Metasurfaces for Imaging, Sensing, and Display

Junsuk Rho
Pohang University of Science and Technology (POSTECH), Korea

Abstract— Metamaterials and metasurfaces are novel optical components composed of nanostructure arrays. They offer the advantage of an ultracompact form factor and can image submicron objects with resolution approaching the diffraction limit of light. The scope of this imaging extends from simple microscopes to more advanced light imaging applications such as 3D sensors, LiDAR, bio-imaging, and cameras. The wavelength range of imaging is also diversifying to support various imaging applications. Metalenses operating in the UV region enable high-resolution imaging due to the short wavelength of light. In the visible light spectrum, metalenses can be used for imaging in VR/AR displays. Near-infrared metalenses have potential applications in night vision devices and endoscopes. The wavelength range extends further to include the ultrasound region, where it can be used in photoacoustic microscopy. Additionally, elastic metalenses can be applied for energy harvesting, and acoustic metalenses can be used to focus sound waves. Furthermore, metalenses can perform imaging with various functionalities. They can tune their focal length, demonstrate trichannel imaging based on spin, and even image single photons emitted from a source. While metalenses operate across various wavelengths and offer diverse functionalities for numerous imaging applications, their design is currently not scalable, making large-area designs computationally heavy and expensive. To address this, efficient computational methods like RCWA and AI/DB-based design approaches have been developed. However, even with advances in large-area design capabilities, their commercialization has been hindered by manufacturing limitations such as high cost and low throughput. To reduce the production cost of metalenses, nanoimprint lithography has been employed. To address the low refractive index of conventional imprint resins, high-refractive-index particles are incorporated, creating a one-step printable platform. On the other hand, ArF photolithography has been used to overcome low throughput and produce large-area metasurfaces at wafer scale. However, due to the high manufacturing costs associated with this method, research has been conducted on mass-producing metasurfaces by using wafer-scale nanoimprint technology to replicate metasurfaces initially created through photolithography. These scalable manufacturing approaches are expected to propel metalenses beyond the research level and into practical applications.

Prof. Rho is a Yeon-San Endowed Chair Professor and Mu-Eun-Jae Endowed Chair Professor at Pohang University of Science and Technology (POSTECH), Korea, with a joint appointment in the Department of Chemical Engineering, Mechanical Engineering, and Electrical Engineering. He received his Ph.D. at the University of California, Berkeley (2013), M.S. at the University of Illinois, Urbana-Champaign (2008) and B.S. at Seoul National University, Korea (2007). Prior joining POSTECH, he conducted postdoctoral research in Materials Sciences Division & Molecular Foundry at Lawrence Berkeley National Laboratory, and also worked as a principal investigator (Ugo Fano Fellow) in Nanoscience and Technology Division & the Center for Nanoscale Materials at Argonne National Laboratory. Prof. Rho has authored and co-authored more than 450 high-impact journal papers including Science and Nature. He is also the recipients of several notable honors and awards such as US Department of Energy Argonne Named fellowship (2014), Korean Presidential Early Career Award for Scientists and Engineers (2019), Member of the Young Korean Academy of Science and Technology (Y-KAST) (2020), Associate Member of the National Academy of Engineering of Korea (NAEK) (2022), Fulbright Visiting Scholar Fellowship (2022), Northwestern Simpson Fellowship (2022), Clarivate Highly Cited Researcher (2023, 2024), Elsevier/Stanford World Top 2% Scientist (2021–2025), ACS Nano Lectureship (2024).