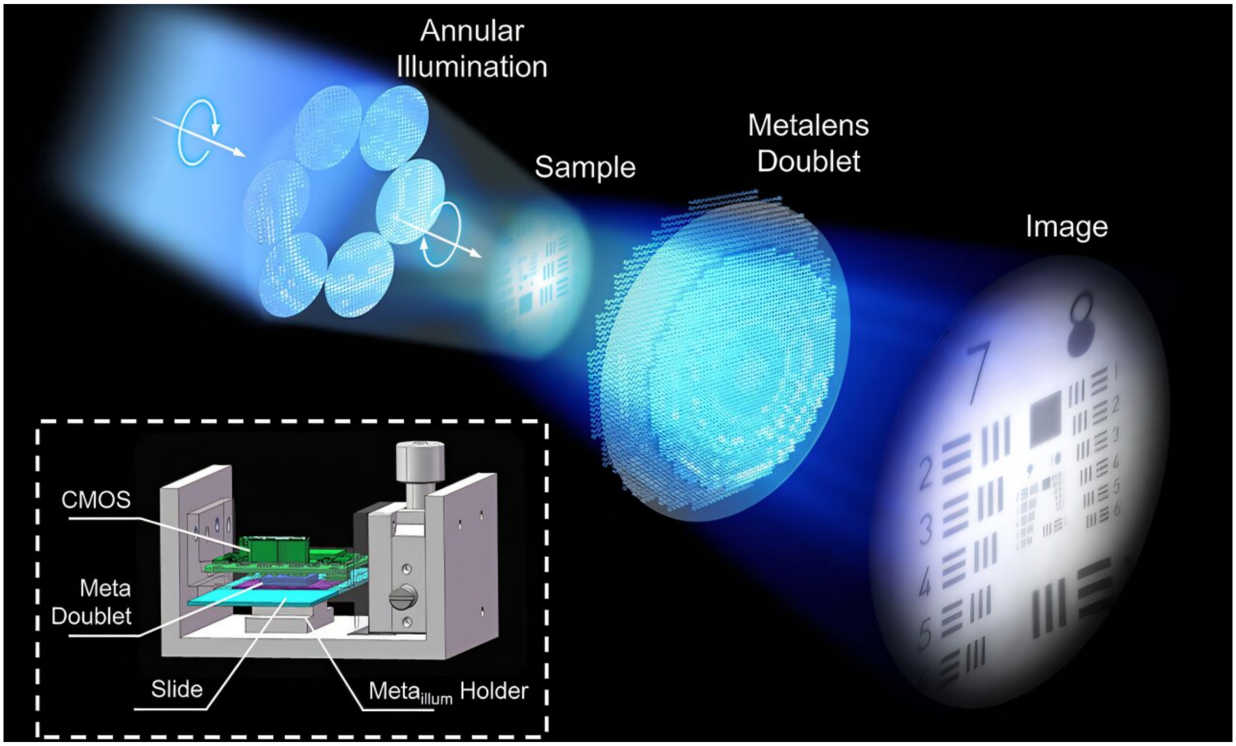
High-resolution metalens doublet microscope enables compact biomedical imaging

May 28 2025



The proposed metalens doublet configuration with annular illumination can overcome off-axis aberrations and achieve unprecedented high-resolution wide-field imaging, even in a compact and highly integrated prototype. Credit: Tao Li and Jiacheng Sun (Nanjing University).

Metalenses represent a revolutionary advancement in optical technology. Unlike conventional microscope objectives that rely on curved glass surfaces, metalenses employ nanoscale structures to manipulate light at the subwavelength level. Thanks to their ultrathin, lightweight, and flat architectures, metalenses can overcome the bulkiness of traditional lenses, making them ideal candidates for integration in electronic devices and compact imaging systems.

Despite their promising attributes for next-generation optical systems, metalenses face significant challenges in practical microscopy applications. Off-axis aberrations, which severely restrict metalens field of view (FOV) and resolution capabilities, are primary limitations.

The inherent trade-off between imaging resolution and FOV has prevented metalenses from achieving performance comparable to conventional microscopes. Although some prior metalens designs have achieved submicron resolution, they operated with an extremely restricted FOV, limiting their practical utility.

Against this backdrop, a research team from Nanjing University, China, has developed an innovative solution that dramatically improves metalens performance in microscopy applications. Their report, published in *Advanced Photonics*, introduces a metalens-based microscope that achieves both wide field of view and high-resolution imaging in a compact design.

The researchers tackled the fundamental limitations of metalenses by employing a doublet configuration—two metalenses on opposite sides of a transparent silica substrate—combined with annular illumination.

The two metalenses consist of silicon nitride nano-fins, crafted as high-aspect-ratio squares with precise dimensions and arranged at carefully calculated intervals. This approach effectively mitigates off-axis aberrations while simultaneously boosting resolution capabilities, thus optimizing imaging performance.

"Our metalens microscope, featuring a FOV of up to 150 μm and a half-pitch-resolution of 310 nm, far exceeds the highest resolution ever reported in meta-microscopy," explains corresponding author Dr. Tao Li. Their achievement represents a significant breakthrough, as the researchers were able to resolve features that no previous metalens system could detect.

To further demonstrate the applicability of their approach, the team developed a highly compact prototype. This integrated device achieved an impressive 1 mm FOV with a respectable half-pitch-resolution of 620 nm. Interestingly, the design leverages metasurfaces not only for imaging but also to generate the annular illumination, further enhancing the system's compactness. It measures only 4 cm × 4 cm × 5 cm—a thousand-fold reduction in size and weight compared to standard microscopes.

The researchers used their meta-microscope to image cervical cancer cells. The system could successfully capture images of various stages of cancer development within the same FOV, revealing important cellular details such as nuclear enlargement, deformation, and division. The ability to observe these features across a wide FOV would provide medical professionals with a comprehensive picture of tissue samples, potentially enhancing diagnostic capabilities.

"Our experimental results demonstrate high-quality microscopic bioimages that are comparable to those obtained from traditional microscopes within a compact prototype, highlighting its potential applications in portable and convenient settings," remarks Li.

This technology holds promise for numerous applications where portability and high-performance imaging are simultaneously required. Potential use cases include biomedical imaging in resource-limited settings, mobile monitoring, and various outdoor research scenarios where traditional microscopes would be impractical.

The potential for integration in microelectronic devices could see the proposed technique being used in emerging technologies, such as state-of-the-art systems for clinical or biomedical automation.

Overall, this advancement represents a significant step toward practical metalens-based imaging systems that can compete with conventional optics while offering substantial advantages in size, weight, and integration capabilities. The proposed approach opens new avenues not only for compact microscopy, but also for the design of other high-performance meta-devices across various optical applications.

More information: Jiacheng Sun et al, High-resolution and wide-field microscopic imaging with a monolithic meta-doublet under annular illumination, *Advanced Photonics* (2025). DOI: 10.1117/1.AP.7.4.046006

Provided by SPIE