Metalens array to enable next-generation true-3D near-eye displays

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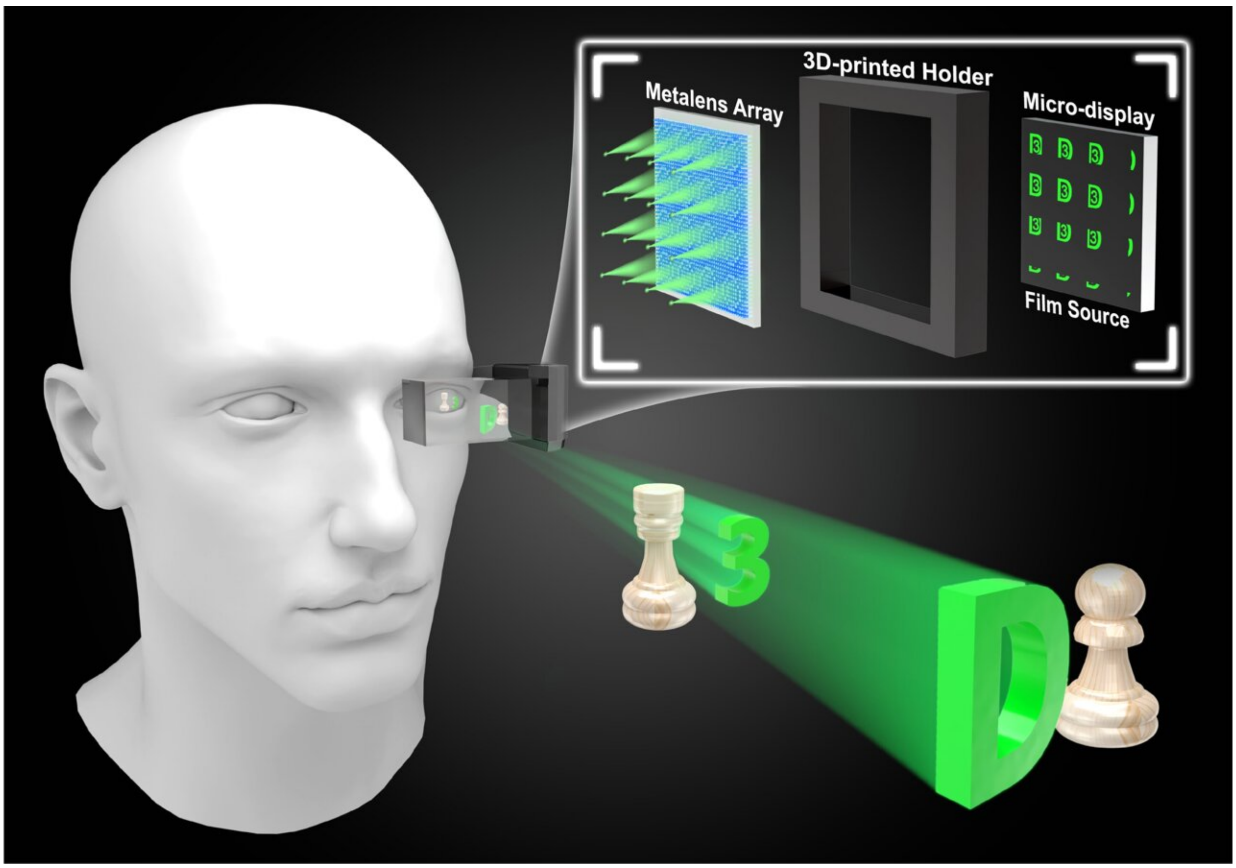


The 3D AR effect of the meta-II NED with the major components of the metalens array and the micro-display. The virtual 3D images are reconstructed to coincide with the chess pieces. Credit: Zhi-Bin Fan, Yun-Fan Cheng, Ze-Ming Chen, Xia Liu, Wen-Long Lu, Shi-Hao Li, Shao-Ji Jiang, Zong Qin, Jian-Wen Dong

Integral imaging (II) display is one of the most promising near-eye displays (NEDs) due to its compact volume, full parallax, convenient full-color display, and, more importantly, true-3D and more realistic depth perception from eliminating the vergence-accommodation conflict (VAC). However, II displays based on the conventional optical architecture, such as microlens arrays, are limited in resolution, field of view, depth of field, etc.

As micro-displays have increasingly higher pixel densities, conventional optical architecture is inadequate in pixel-level light manipulation. Meta-optics has the potential to break through these bottlenecks with its unprecedented flexibility in pixel-level light manipulation by a monolithic device. Meta-II display is expected to be a big step towards next-generation virtual reality (VR) and augmented reality (AR) by creating more immersive experiences.

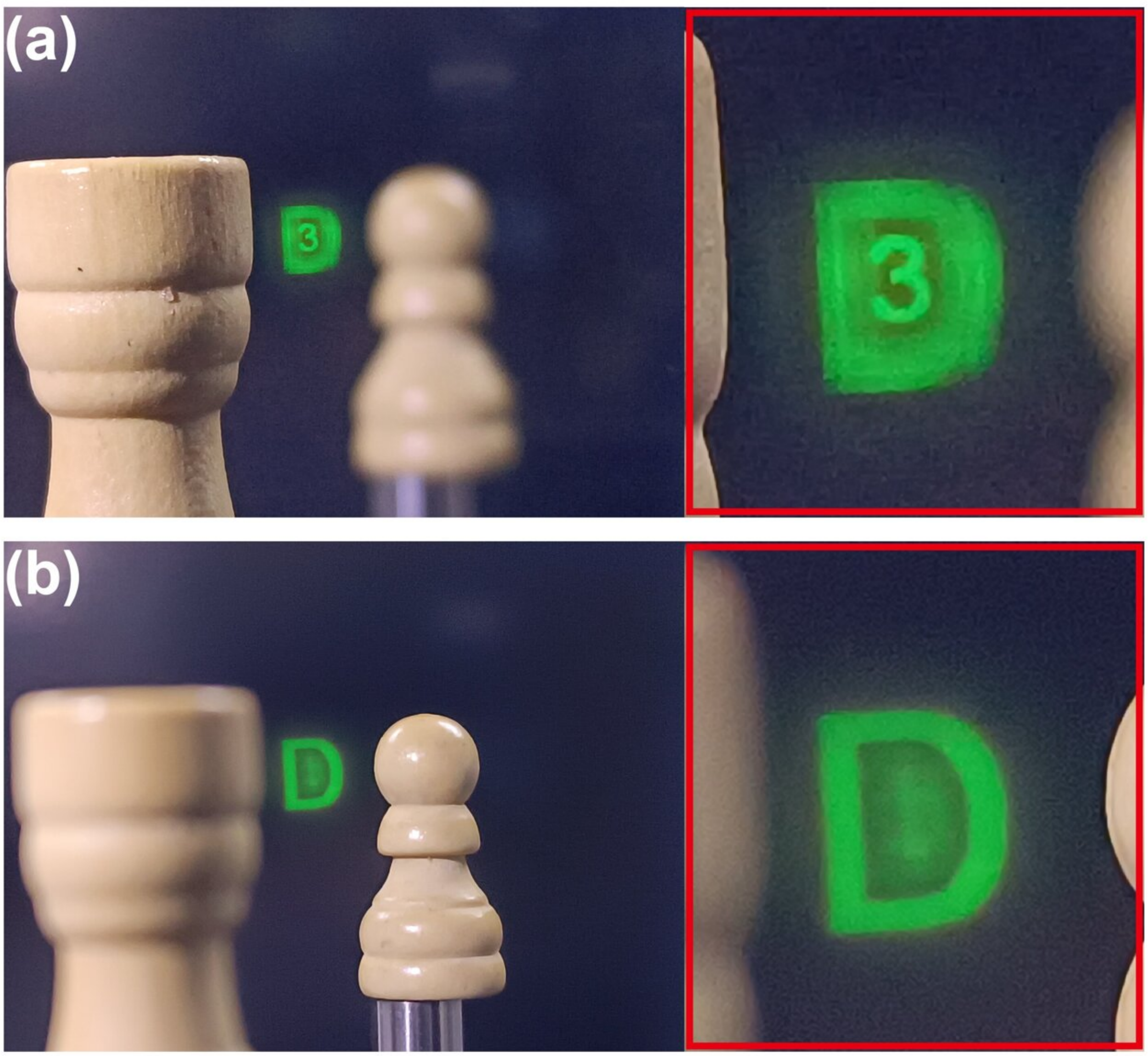
However, some challenges must be overcome before the meta-II display can become mainstream in the field of NED.

One challenge is that the metalens array, the critical component of a meta-II display, is too small to match commercial high-resolution micro-displays and their etendue due to the underdevelopment of large-area higher-precision nanofabrication technology.

Another challenge is that the rendering is computationally expensive for high-resolution wearable NEDs because the elemental image array (EIA), the signal input into the meta-II display, must be calculated for every viewpoint and thus need GPUs to accelerate.

Fortunately, recent advances in nanofabrication and II algorithms open the possibility of practical meta-II displays. The meta-II displays are expected to advance VR/AR displays as these challenges are overcome. They can revolutionize how people interact with these technologies and eventually become the standard for VR and AR displays.

In a new paper published in *eLight*, a team of scientists led by Professor Jian-Wen Dong and Zong Qin from Sun Yat-sen University created a novel true-3D technical architecture called meta-II NED, first achieving the combination of meta-optics and II displays to the practical application of NED.



(a) Captured image by focusing on the number "3" and the chess piece "Rook" with details enlarged in the right red frame. (b) Captured image by focusing on the letter "D" and the chess piece "Pawn". Credit: Zhi-Bin Fan, Yun-Fan Cheng, Ze-Ming Chen, Xia Liu, Wen-Long Lu, Shi-Hao Li, Shao-Ji Jiang, Zong Qin, Jian-Wen Dong

The meta-II NED combines a commercial high-pixel-density micro-display and a large-area metalens array. The metalens array, with a minimum feature size of around 100 nm and a maximum nanostructure height of about 500 nm, is made of high-refractive-index nanoimprint glue and fabricated using high-precision large-area nanoimprint technology.

Compared to electron beam lithography, nanoimprint technology can quickly replicate many metalens array samples, especially large-area samples.

The low-cost, large-area nanoimprint fabrication process makes metalens arrays feasible for mass production. To match this convenient meta-II NED architecture, a new real-time rendering method was developed to quickly generate the EIA with an average frame rate of 67 FPS by exploiting the invariant voxel-pixel mapping.

True-3D display was verified experimentally through monocular focus cues and motion parallaxes. A see-through effect of the meta-II NED module was realized by merging 3D images with surrounding objects, showing the broader potential of the meta-II display for AR.

The research team has pioneered the development of true-3D NED with a combination of meta-optics and II displays. Note that the design flexibility of metalens arrays is promising for next-generation NEDs regarding several long-standing issues in conventional II architectures.

For example, extended depth of field is vital for true-3D NEDs to present images from the person space to the vista space, whereas the microlens array induces a very limited depth of field.

In contrast, a metalens array can be easily designed as a polarization multiplexing element with varying focal lengths to allow depth of field extension. In addition, the meta-II architecture provides a promising solution to increase the FOV for further study: freeform phase profiles that precisely compensate for the field-dependent aberration of conventional microlens arrays can be recorded in a slim metalens array.

More importantly, both extended-depth-of-field and FOV-expanded meta-II architectures suffer from no cost in computational complexity and system volume compared with the meta-II proposed above. In general, metalens arrays are enabling next-generation true-3D near-eye displays.

More information: Zhi-Bin Fan et al, Integral imaging near-eye 3D display using a nanoimprint metalens array, *eLight* (2024). DOI: 10.1186/s43593-023-00055-1

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