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Metamaterials

Add noise for better multiplexing

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Phase, amplitude and polarization of light can all be engineered using ultra-thin metasurfaces. And, devices based on metasurface can be not only thin compared to conventional optical systems, but may also provide better efficiency or more desirable bandwidth.

Multiplexing based on compact metasurface systems has been previously demonstrated, but there are limits to the number of channels available. For example, for polarization multiplexing with such a two-dimensional platform, which can be represented by a 2 × 2 Jones matrix, we have available just *x*- and *y*-polarization components and thus we seem limited to two independent channels corresponding to the diagonal matrix components; this has actually been extended to three polarization-based channels by exploiting the off-diagonals of the Jones matrix.

Now Bo Xiong, Yu Liu, Yihao Xu, Lin Deng, Chao-Wei Chen, Jia-Nan Wang, Ruwen Peng, Yun Lai, Yongmin Liu and Mu Wang, based in China and the US, experimentally demonstrated 11 independent holographic images — that is 11 channels of polarization-based information — from a single metasurface excited by visible light of different polarization (*Science* **379**, 294–299; 2023).

And, this was enabled by introducing engineered noise. In the pictured 'keyboard pattern' demonstration, nine different polarization channels were used as indicated by the inset arrows. Four unique sets of nine images were generated at different planes away from the metasurface (Z_1 = 330 µm, Z_2 = 430 µm, Z_3 = 570 µm and Z_4 = 830 µm) for a total of 36 holographic images.

Nature Photonics spoke to the authors who explained that they were motivated by breaking this upper limit of three channels in polarization-based multiplexing because it may be crucial for developing high-capacity optical displays and data storage. According to the team, the approach's multiplexing threshold limit depends on factors including the working wavelength, the structure of the metasurface and the imaging distance. And, the upper limit of channels can actually be increased further by relieving the threshold conditions.

"There are two types of noise," the team explained. "One is correlated noise, which is introduced by pursuing an approximate solution instead of a precise solution using the least-square solution of Jones elements. In this way, we slightly sacrifice the precision of the target outputs at each channel and get the approximated solutions that can produce distinct images in more independent channels. Meanwhile, the polarization channels have been increased with a certain level of crosstalk from the adjacent channels. The other type of noise is called non-correlated noise, which helps reduce and even eliminate crosstalk, but at the expense of slightly decreasing the signal-to-noise ratio in the main channels. By synergistically implementing both types of noise, high-capacity and high-purity polarization multiplexing can be achieved."

A genetic algorithm was employed for designing appropriate nanostructures to implement the engineered noise. The structures were fabricated by electron-beam lithography and the team emphasized that inevitable fabrication errors act as an additional non-correlated noise component, which further reduces the crosstalk between the channels.

The team plans to extend this multiplexing strategy to circular polarization and even arbitrary polarization states. According to the authors, they may also be able to combine their method with other multiplexing techniques, such as those based on wavelength and orbital angular momentum, to achieve metasurface multiplexing technology with even higher capacity.

"There are still challenges to be addressed," the team told *Nature Photonics*. "As the number of channels increases, the crosstalk between channels increases, and the signal-to-noise ratio decreases accordingly. We are trying to solve these challenges to enable a hybrid multiplexing system with ultra-high capacity."

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