devices) will require solid-state solutions⁸. The use of organic solvents is beneficial as it mediates the diffusion-controlled energy transfer events, but other properties such as solvent volatility and toxicity would be detrimental to long-term operation. Solid-state solutions have generally demonstrated lower efficiencies than their liquid media counterparts, which is primarily due to impaired energy transfer processes. For practical utilization of UC in a solar cell context, solid-state TTA-UC systems will be necessary. In a solid-state system, molecular diffusion needs to be replaced by exciton diffusion and the challenge is to engineer those systems towards optimal intramolecular energy

transfer and annihilation processes. A variety of solid-state systems have been proposed with varying UC efficiencies, and continued research will be crucial to successfully merge some of these solutions with solar cell devices. With this contribution from Gholizadeh and colleagues, a new exciting path towards this end has opened up, and the future for this emerging technology looks brighter than ever before.

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Competing interests

The authors declare no competing interests.

QUANTUM OPTICS

Scalable sources

As quantum technologies continue to develop there is a growing desire to explore high-dimensional entanglement and multiphoton states for information processing. However, these tasks demand new forms of large-scale, controllable and stable quantum light sources.

Now, Lin Li and co-workers from China, Hong Kong and Taiwan have demonstrated a 100-path spontaneous parametric down-conversion (SPDC) photon source by combining a 10×10 metalens array with a thin (0.5 mm thick) nonlinear crystal of β -barium borate (BBO) (*Science* **368**, 1487–1490; 2020).

The metalens array is composed of a dense pattern of GaN nanopillars fabricated by electron-beam lithography, dry etching and resist removal. Each metalens in the 10×10 array has an area of $100 \mu\text{m}$ by $100 \mu\text{m}$ and is designed to have a focal length of 1.1 mm at a working wavelength of 404 nm. The nanopillars are 800 nm high and spaced by 200 nm (pictured; scale bar, $1 \mu\text{m}$).

In order to control quantum states by phase of light, the metalenses in the array are designed to have different initial phases. There are four phase differences

Credit: AAAS

of $\Delta\phi = 0, \pi/2, \pi$ and $3\pi/2$ between the adjacent metalenses.

When a diode laser (404 nm, 100 mW) was incident on the metalens array, a 10×10 array of focal spots was formed inside the BBO crystal. Each of the spots triggered a SPDC process and generated pairs of entangled photons in a probabilistic manner. Two-dimensional (2D), 3D and 4D entanglement states were thus generated by

two, three and four metalenses, respectively, as verified by reconstructions and quantum state tomography measurements.

The fidelities of the pure 2D, 3D and 4D entangled states were estimated to be 0.984, 0.966 and 0.955, respectively, close to the perfect value of 1.

Furthermore, the multiphoton source based on the metalens array system was characterized with a 415-nm femtosecond pulsed laser. The quadratic and cubic pump-power dependencies confirmed the four- and six-photon generation from two and three adjacent metalenses, respectively. The purity and indistinguishability of four-photon generation was experimentally confirmed by the Hong–Ou–Mandel interference.

“Metasurface structures can provide a route for the generation and control of complex quantum states, not only increasing the quantum system dimensionality but also allowing for the coherent control of multiple photons”, Li said.

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