Light confinement in a 3-D space

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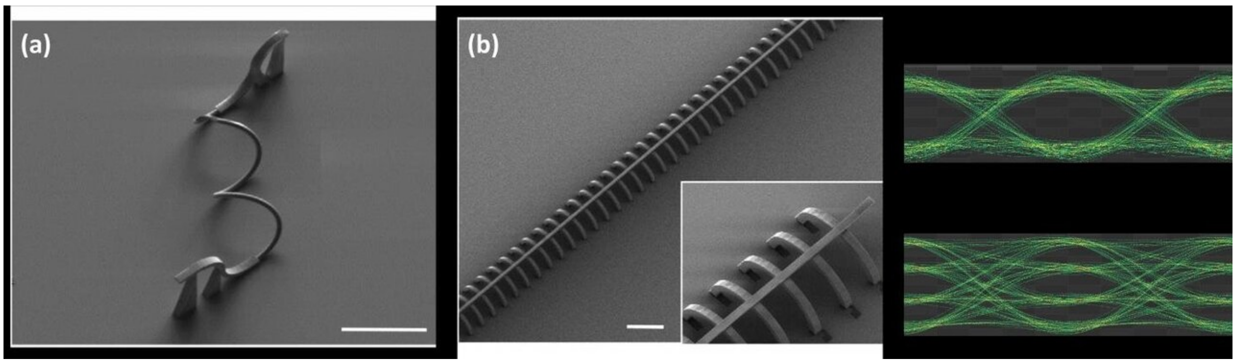

a) 3D spiral waveguide. (b) Suspended air-bridge waveguide; inset shows the input and output coupling sections. (c) 30Gb/s NRZ and (d) 56Gb/s PAM4 eye diagram of the 3D Printed Waveguide output. Credit: SUTD

The emerging services such as data center cloud interconnection services, ultra-bandwidth video services, and 5G mobile services stimulate the fast development of photonic integrated circuits (PIC), which can meet the increasing demand of communication systems for internet.

However, PICs today are largely perceived as planar structures, able to guide light in a single plane. This planarity arises because of the traditional top-down fabrication processes.

Multiphoton lithography is a new and promising 3-D printing technology that allows for 3-D objects to be fabricated more easily, compared to the fabrication of 3-D objects in conventional cleanroom type fabrication methods used in electronics and optoelectronics.

With this technique, there is no longer a restriction of the top-down exposure for the realization of PICs as it unlocks the functions availed by the third dimension. Leveraging concepts of additive manufacturing, 3-D multi-photon lithography involves the use of a femtosecond light source to initiate two-photon polymerization when focused onto a specific location in material. This technique was used to realize the high-resolution 3-D photonic structures.

Researchers at the Singapore University of Technology and Design (SUTD) have demonstrated high-resolution 3-D waveguides which transcend the restrictions of light confinement in a single plane. In the paper published in *Advanced Optical Materials,* Dr. Gao Hongwei, Associate Professor Dawn Tan and their colleagues at the Photonics Devices and Systems Group demonstrated high-resolution 3-D waveguides which guide light in a spiral and air-bridge configuration (refer to SEM images below).

Alongside these novel devices, they also demonstrated very low loss 3-D waveguide couplers with 1.6dB fiber-waveguide coupling losses and 3dB bandwidth exceeding 60nm. This is in contrast with the current industry standards which require very labor intensive packaging for losses of around 1dB. The research team demonstrated their losses to be low without requiring any post processing or post-fabrication packaging. The high-resolution fabrication also resulted in ring resonators with sub-micron feature sizes.

"The fabricated photonic devices are an innovative advancement in the domain of photonic integrated circuits. Importantly, we were also able to demonstrate error-free 30Gb/s NRZ and 56Gb/s PAM4 data transmission through these waveguides. This is important because these high-speed testing formats and rates are in alignment with those used in commercial direct-detection transceiver products today," explained principal investigator Associate Professor Tan who heads the photonics devices and systems group at SUTD.

Indeed, the team managed to derive only small power penalties of 0.7 dB for NRZ (bit error rate [BER] = 10^{-12}) and 1.5 dB for PAM4 (BER = 10^{-6}) from the photonic devices. These results successfully demonstrate high speed, error-free optical transmission through the 3-D fabricated waveguides. This also showcases the devices' suitability as low-loss waveguides and optical interconnects.

"Importantly, the 3-D quality of these waveguides allows us to exceed the limitations of traditional planar structures. In this way, it is possible to achieve far higher density PICs. The high resolution, sub-micron feature sizes are also promising, especially to achieve advanced functions such as spectral filtering, resonator structures and metasurfaces," said Dr. Gao, the first author of the paper and postdoctoral researcher from SUTD.

"This work demonstrates the potential of additive manufacturing in making advanced photonic devices with superior 3-D designs in high resolution," added co-author Associate Professor Low Hong Yee from SUTD.

In the future, the capability to realize high resolution 3-D photonic structures may create even more advancements in both form and function in photonics, including advanced optical signal processing, imaging techniques and spectroscopic systems.

More information: Hongwei Gao et al, 3D Photonic Waveguides: High-Resolution 3D Printed Photonic Waveguide Devices, *Advanced Optical Materials* (2020). DOI: 10.1002/adom.202070071

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