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Half-wavelength-pitch waveguide array for high-density silicon photonic chips

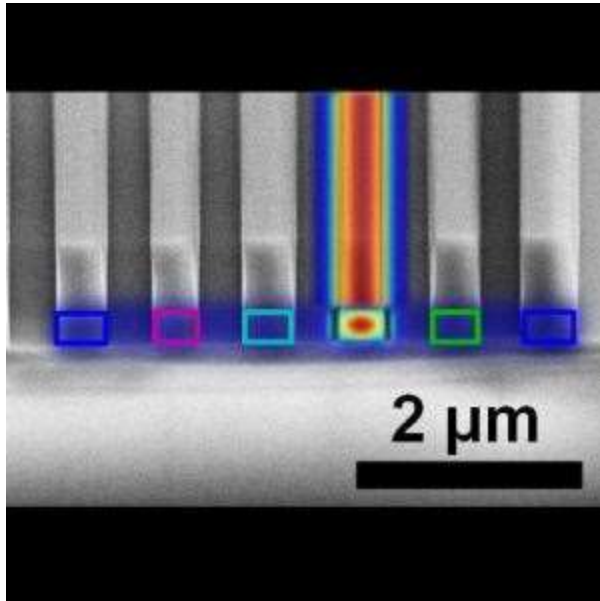


Image of a waveguide superlattice under a high-resolution electron microscope, artificially colored to show the optical field confined in one waveguide.

Electrical engineers at Rutgers University have created a method of integrating denser elements on optical chips. This technology may one day be used to make computer chips and data centers run faster and more cost-effective.

As silicon integrated circuits (ICs) have transformed our life, silicon photonic chips are anticipated to open a new chapter for the information technology, providing novel means for communications and processing data.

Ever increasing integration density, which has proven key to the success of silicon ICs as encapsulated in the Moore's law, will also be crucial to future development of silicon photonic chips.

Towards this goal, a team led by Rutgers electrical engineering associate professor Wei Jiang recently reported a high-density waveguide integration technology for silicon photonic chips that can lead to ultra-dense broadband optical interconnects, drastic cost-reduction for certain silicon photonic chips, and wide-angle, energy-efficient laser beam steering.

The work was recently reported in [Nature Communications](#) on May 11th and was completed in collaboration with Brookhaven National Laboratory, Stanford University, University of Central Florida, and Nanjing University.

Waveguide Integration Density

Higher integration density for integrated circuits means to cram more electronic devices into a given chip area. This method produces more powerful computing chips and lowers cost per device. For photonic integrated circuits on a silicon chip, this has been challenging.

The most ubiquitous components in photonic circuits – silicon waveguides – could not be made very dense mainly due to strong crosstalk or signal interference when waveguides are getting too close. This issue has been known for decades. No practical solution exists to suppress crosstalk and shrink silicon waveguide pitch to sub-wavelength scale.

“There was a very old idea that can suppress crosstalk for two waveguides, but it doesn’t scale to work for a large number of waveguides. It is just like two hydrogen atoms can easily form a molecule, but forming a crystal of hydrogen atoms is a different story,” said Jiang. “For practical applications in integrated photonics/electronics technology, scalability is essential.”

Jiang created a structure called waveguide superlattice to solve the problem. Essentially, the structure comprises a small sub-array of waveguides of different widths periodically replicated in space to form a superlattice of waveguides. The widths of the waveguides in each sub-array are engineered to deter the inter-coupling between nearby waveguides.

As the waveguide pitch is reduced to half-wavelength, even second-, third-, and farther neighbors in a waveguide array can inter-couple. Jiang unraveled the mathematics of such complex coupling and developed a set of superlattice design principles to minimize crosstalk through all possible inter-coupling channels.

In real waveguides, the sidewalls contain roughness, which scatters light and usually causes additional random crosstalk and noise. Yet Jiang’s team found that roughness also plays a subtle role in suppressing coherent crosstalk in some scenarios.

The Journey

Jiang started to note the problem in 2008 when he received a MURI team grant as a co-principal investigator to study optical phased arrays for fast steering of laser beams. High-density waveguide arrays at half-wavelength pitch would be desirable for the project, but this was considered impossible. Later Jiang realized that high-density waveguides were key stumbling blocks for many other photonics applications.

In the quiet summer of 2009, an idea came to Jiang’s mind. In 2010, the group gained access to nanofabrication facilities in the Center for Functional Nanomaterials at Brookhaven National Laboratory. Graduate student Weiwei Song started the experimental effort.

“As we knew that crosstalk can go far beyond the first neighbors as the waveguide pitch shrinks below one micrometer, we had to test an array comprising fairly large number of waveguides,” stated Jiang. The number of crosstalk channels goes up as the number of waveguides squared.

Fabrication of such a dense waveguide array with high-perfection was difficult, especially in academic cleanrooms where industrial-grade process control is unavailable. Indeed, the final

structure had waveguides filling 50% of the space. At such a high density and filling factor, a single tiny imperfection could “short circuit” two waveguides and ruin the entire structure.

“Often we needed to measure more than 100 crosstalk channels. Sometime, an accidental bad crosstalk channel appeared after measuring the first 90 good channels. Weeks of efforts wasted...that was heart-wrenching to the student.” said Jiang. “At times, we questioned whether our goal was realistic.”

The team went back to carefully check theory, conducted further simulations, improved the fabrication quality and reliability, and developed the procedure of faster sifting bad channels in test. Eventually, a high-density waveguide superlattice with half-wavelength-pitch was obtained in early 2013 before Song’s graduation.

Such high-density waveguides can find many useful applications. They can be employed to significantly improve the wavelength resolution of grating spectrometers, increase the bandwidth of optical interconnection on a silicon chip, and enlarge the laser beam steering range for optical phased arrays.

Ming Lu and Aaron Stein of Brookhaven, MURI team member Stanford Professor Fabian Pease’s group, Rutgers Research Associate Professor Warren Lai, and Professor Demetrios N. Christodoulides of the CREOL at University of Central Florida, and Rutgers students Robert Gatdula and Siamak Abbaslou contributed to the research.

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