Progress in Linear Optical Operation Gates and Circuits in Si Photonics Towards Photoelectronic Converged Accelerators

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For a long time, the performance of electronic processors has been continuously improved by its scalability and many advances in fabrication technologies. However, the electronics finally has reached the limit of physical dimensions causing large wiring resistance, leak current, and characteristic fluctuation of transistors. These facts would never allow us to scale up electronic circuits any more [1]. Moreover, the increase of wiring resistance slows down the computational latency. This latency issue could be crucial for real time applications in communication, control, finance, and security systems.

As an alternative approach after Moore's law, "computing with light" is getting more realistic and practical. The first concept has been suggested more than 30 years ago. At that time, people tried to exploit the massive spatial parallelism of light (wavelength, polarization, mode etc.). However, it was defeated once by the rapid rising of the integration density of Si CMOS electronics. But actually, the related fabrication technology has brought us the drastic evolution in Si CMOS photonics. The uniformity and the reliability of on-chip integrated photonic components are now pretty sufficient to achieve matrix switch consisting of more than thousands of components [3].

But still there is a large gap of size between photonics and electronics. To fill this gap, our group has been consistently developing nanophotonic components to realize more dense photoelectronic converged accelerators. And around 5 years ago, our group has also suggested "photonic pass gate logic" to achieve ultralow latency operations. The minimization of the photonic pass length is required to realize ultralow latency, so it is suitable to utilize nanophotonics.

At the same time, nonlinear conversions are essential for universal operations. However, there are still many drawbacks in nonlinear photonic gates in terms of length (latency) and loss. So our group has focused on linear optical components because they can perform almost energy less analog linear conversions. In this talk, we summarize the topics for optical Boolean logic operation using Si "Ψ" gates [4] and digital/analog conversion based on circuit topology [5], which could be one of key elements to justify the photonic analog processing (multiply-accumulate operations) in artificial neural networks [6].

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References

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