Quantum advantage based on photonics

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The recent quantum advantage demonstration by J.-W. Pan's group at University of Science and Technology of China (USTC), based on a quantum optics experiment with 76 photons and a 100-mode interferometer,[1] is a major step in the development of quantum technologies. Prior to this breakthrough, photonics was generally not seen as a leading contender in quantum computing.[2] Several important advantages over superconducting-based implementations have made this work possible: optical photons allow for operation at far higher temperatures, do not suffer from decoherence, can be generated in various entangled states, and allow for long distance communication. The current achievement is based on the calculation of a Torontonian, an intensive mathematical task that would have required an overwehlmingly long time for a supercomputer but took only seconds for Pan's quantum photonics device. Solving problems of scientific and societal relevance, such as the simulation of quantum systems to design new materials or the factorization of large numbers, as well as realizing a reconfigurable device, remains however to be done.

The current approach is based on boson sampling[3] where the propagation of quantum states of light along an optical circuit is computationally hard to simulate on a classical computer but is readily solved by measuring the emerging photons. A system complex enough to demonstrate quantum supremacy can be realized with macroscopic optical elements occupying some square meters of an optical table. Further advances towards a computational device able to solve large and relevant problems would be hard with macroscopic optical elements but will be possible with integrated photonics that offer strong scalability potential. The possiblity to integrate complex photonic circuits[4,5] offers massive potential gains in efficiency, complexity, and reliability, and will allow for the realization of the complex reconfigurable architectures that will process far larger quantum states. A key enabling technology is single photon detection, which is undergoing tremendous evolution; Pan's USTC team used 100 superconducting nanowire single photon detectors with detection efficiencies approaching 85%. The state of the art is now approaching unity detection efficiency, enabling an important additional scale up where vastly more complex quantum states of light can be processed and measured.

Demonstrations of quantum computational advantage in superconducting and photonic systems can be seen as a Sputnik moment where, much like for the space race in the 20th century, a quantum race is taking shape where new technologies will unleash massive advantages. The main applications remain to be invented, much like the GPS had not yet been imagined in the days of Sputnik. Besides allowing for the implementation of new computation protocols, the ability to process information at the single photon level offers the prospect of ultra low energy consumption computation that could well prove crucial in the long run.

References

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