T-QUAKE Quantum Mechanical Microchip

3b) How does the product operate?

Delivering quantum-encoded secret keys is known as Quantum Key Distribution, or QKD; in essence it involves transmitting a series of randomly generated, quantum-encoded bits of information between a sender and a receiver, Alice and Bob, over a distance. This string of bits, called qubits, becomes the secret key Alice and Bob use to interpret encoded messages sent over less-secure channels. In the case of T-QUAKE, which relies on quantum photonics, Alice encodes light emitted from a laser diode with specific characteristics. A light particle, for example, can be polarized in either a horizontal or a vertical orientation (corresponding to a 0 or a 1, respectively). When combined with other polarization orientations, Alice can send Bob a series of qubits only they can interpret by comparing notes. Note that Bob's act of measuring each photon alters its quantum characteristics, destroying its quantum-encoded information. Similarly, if a third party attempts to measure the photons en route, Alice and Bob will be alerted that their secret key has been compromised. This detectability is quantum encoding's primary advantage for cryptography.

The above example describes an idealized approach based on a QKD protocol known as discrete variable quantum key distribution (DV-QKD), which involves the encoding and transmission of single photons. In practice, on-chip discrete variable QKD has remained just beyond reach, primarily because transmitting, receiving, and processing single photons reliably with tightly controlled polarization characteristics is highly challenging at the microchip scale; however, the Sandia team has overcome most of the major hurdles related to this approach and anticipates demonstration of on-chip DV-QKD this year.

In 2014, the team realized that another approach known as continuous variable QKD (CV-QKD) would be easier to implement because it doesn't require single photon sources or detectors. Continuous variable QKD involves transmitting pulses of light (wave packets) encoded with information by modifying the light's phase, amplitude, and other characteristics using on-chip lasers, modulators, filters, waveguides, and detectors. This approach has the advantage of relying on well-developed classical coherent optical approaches for encoding and detecting signals.

Previously, CV-QKD had been limited by the challenge of co-transmitting strong laser pulses to establish a common reference frame for coherent detection of the pulse amplitude and phase. This required use of long optical delay lines and other complicated components such as filters and specialized mirrors for time delays and noise rejection. On-chip implementation of these components is extremely challenging and requires filtering the much weaker signal pulses from the reference frame. The breakthrough in developing this method came when our team realized that by inserting intermittent "beacon" pulses into the continuous light transmissions, we could effectively communicate the reference frame information without filtering and with minimal signal delays. This new approach dramatically simplified the chip's architecture and eliminated many previously required components. This realization led to the team shifting R&D resources to the CV-QKD approach and, ultimately, to its successful demonstration in fall 2015. Consequently, T-QUAKE is the first functioning on-chip continuous variable quantum transceiver.

In addition to resolving the numerous and difficult technical challenges of implementing QKD at one-millionth the scale of a bench-top system, the team overcame a number of difficult microfabrication problems. T-QUAKE-integrated QKD transceivers were fabricated in Sandia National Laboratories' Silicon Photonics Platform. This platform includes active amplitude and phase modulation along with dynamic filtering and switching, as well as passive waveguide devices used to dynamically route photons on-chip. Sandia's standard Silicon Photonics Process flow includes selective epitaxial growth of Ge on Si for the formation of high performance detectors to coherently convert optical signals into electrical signals. The platform is based on an electronic complementary metal-oxide-semiconductor (CMOS) process flow, which allows for large-area dense integration of compact photonics devices with advanced CMOS electronic control. This integration makes T-QUAKE's on-chip implementation possible.

Successfully integrating multiple devices–waveguides, modulators, frequency shifters, and detectors–on a single chip also brought a number of inherent, synergistic performance improvements. Functionally, reducing feature sizes to the submicron scale significantly reduces the power required for optical processing, allowing for strong light-matter interaction and increased device speeds. In addition, monolithic microfabrication allows for rock-solid device-wide mechanical stability. At the system level, microintegration of the quantum photonic elements allows for highly compact and scalable circuits.

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