OSA Industry Development Associates

# OIDA QUANTUM PHOTONICS ROADMAP

## Every Photon Counts

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Created in collaboration with

CORNING

# EXECUTIVE SUMMARY

Quantum technology is a growing field in physics and engineering focused on harnessing principles of quantum mechanics to enable functions and applications not currently achievable with classical-physics-based technologies. While quantum mechanics has been studied in the research community for a century – and has produced technologies such as lasers, MRI imagers, transistors, etc. – recent progress in controlling individual photons, atoms, electrons, etc. has enabled new advancements.

OIDA developed this roadmap to clarify the market applications and timing for quantum technologies and to specify improvements in optics and photonics components needed to enable advancement.
The ability to create, manipulate, and read out states of individual quantum units is expected to have utility across multiple applications in three primary categories:

- *Sensing and Timing:* The extreme sensitivity of quantum systems to environmental influences can be exploited to measure physical properties with more precision.

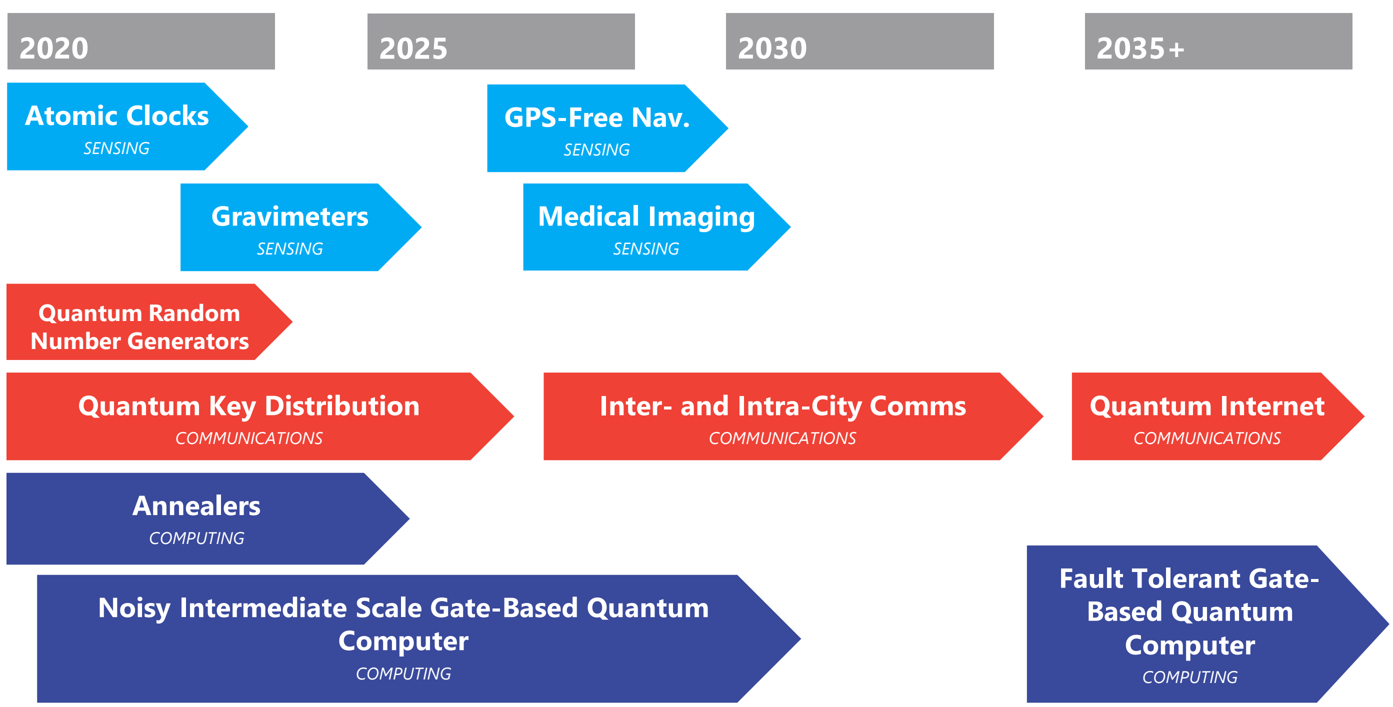
- *Communications:* Attempts to observe a quantum communication channel will irreversibly alter the state of the system in a way that is detectable by the parties exchanging information. A quantum network can distribute entanglement between distant users.

- *Computing:* Using the principles of superposition and entanglement, significant speedup over classical computers is theoretically possible for some problem types.

Early products are being commercialized today, but quantum technology is still a very new frontier. Atomic clocks, quantum key distribution systems, and noisy intermediate-scale quantum computers are available in the near-term, but many other proposed use cases require more advanced hardware and software, and, in some cases, further physics advances.

**QUANTUM TECHNOLOGIES TIMELINE**

*-- Illustrative, Not Exhaustive --*




*Chevron placement represents anticipated start date of commercialization
Source: Expert interviews, Newry analysis

**EXAMPLE APPLICATIONS FOR QUANTUM TECHNOLOGY**

*-- Not Exhaustive --*

| END MARKETS | SENSING & TIMING | COMMUNICATIONS | COMPUTING |
|---|---|---|---|
| **Telecom** | Clocks for synchronization | Cryptography | Network optimization |
| **Medicine** | Improved brain imaging | Protecting patient data long-term | Drug discovery |
| **Oil & Gas** | Through-ground imaging | Protecting critical infrastructure | Drilling location analysis; oil distribution logistics |
| **Finance** | Clocks for trade timestamping | Secure transactions | Portfolio management |
| **Transportation** | GPS-aided navigation; quantum LiDAR | Cryptography for connected vehicles | Battery material simulation; traffic optimization |

Quantum computing in particular is attracting significant attention and funding because of its possible security implications. A universal, fault tolerant quantum computer would theoretically be able to factor very large numbers much faster than a classical computer, which could undermine public key cryptography methods such as RSA encryption. While the industry expects it will take more than a decade to develop a quantum computer capable of this kind of computation, there is widespread concern about the potential future vulnerability of highly sensitive information.

This concern is motivating investment in another realm of quantum technology: quantum key distribution (QKD). QKD hardware can create a more secure network in which eavesdroppers trying to steal encryption keys would be detected and could be circumvented.

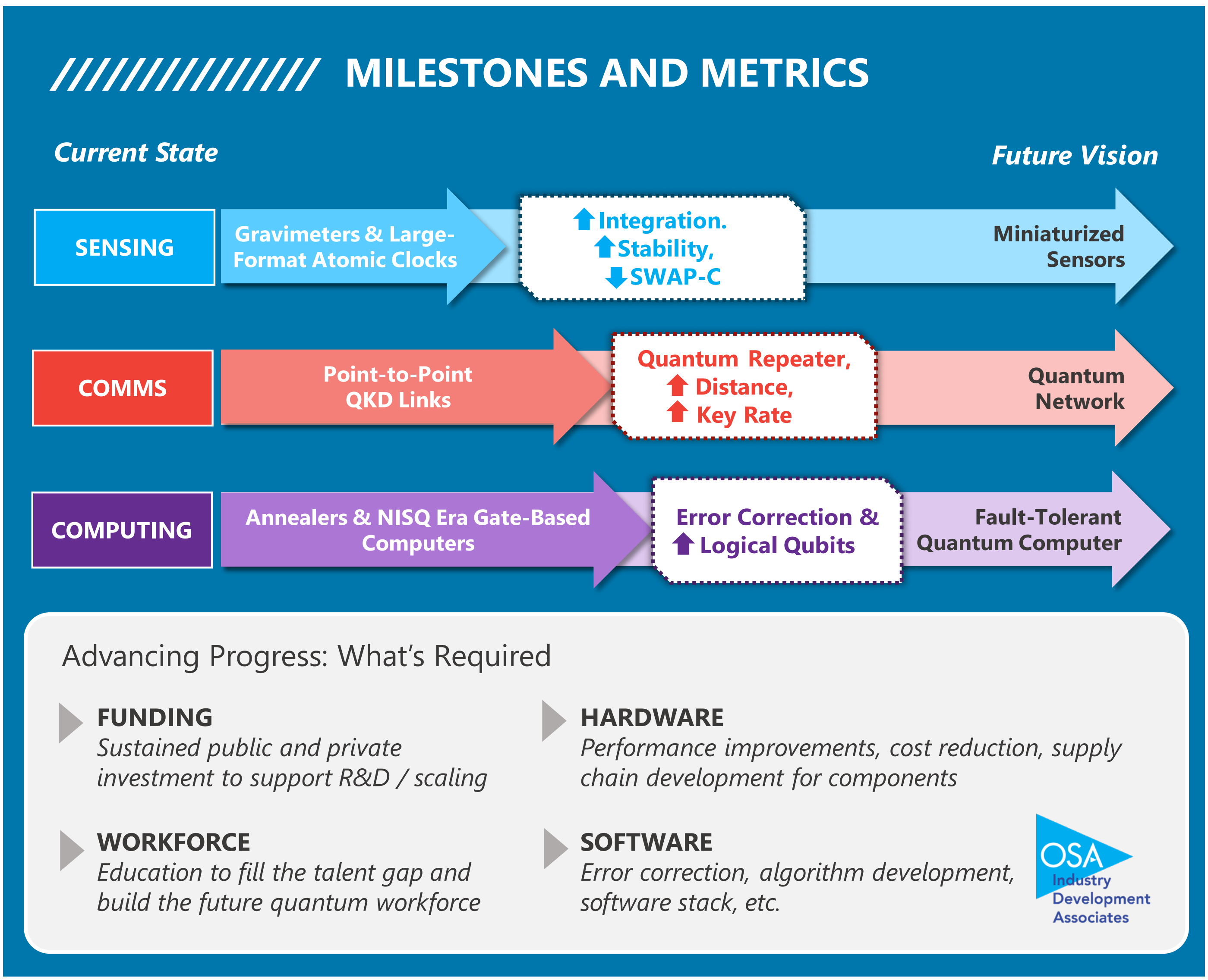
Beyond the cybersecurity implications of quantum technologies, there are many other opportunities for value creation across industries and applications. Quantum sensors are expected to enable higher-performance sensors for GPS-free navigation, through-ground imaging, biomedical imaging, etc. Quantum computers are expected to improve simulation and optimization for drug discovery, material science, financial portfolios, distribution and logistics, etc. Quantum communications infrastructure could network individual quantum computers or sensors together to further enhance performance.

In light of the opportunities and threats created by quantum technologies, significant investments are being made across the public and private sectors. Many governments have large multi-year programs with funding levels that exceed US$1 billion. Thirty-two venture capital deals were executed in 2018, amounting to US$173 million in investment in 2018 alone (Gibney, 2019). In addition to venture-backed startups, many large, established, multi-national corporations that already supply legacy sensing, telecommunications, and computing markets recognize the potential of and are investing in the development and commercialization of quantum technologies.

In addition to proponents, quantum technologies also have their share of skeptics whose opinions are valid. While some applications such as atomic clocks and point-to-point QKD links are commercially available today, current use is modest relative to their addressable market size due to limitations and tradeoffs between technical performance and cost.

Quantum computing has tremendous theoretical potential to disrupt and transform a range of industries; however, we are still many years away from a fault-tolerant quantum computer capable of delivering the performance necessary to enable many applications such as decryption and drug discovery.

For the skeptics who are looking for more evidence of progress, as well as the proponents who wish to make measured investments that balance risk and uncertainty, we recommend monitoring a few metrics and "beacon" milestones that will be indicative of substantial progress. In quantum sensing, progress will be application-specific, as performance and cost advantages need to be demonstrated relative to incumbent sensing approaches. Further integration of these systems (e.g., on-chip) would be a notable advancement to facilitate lower size, weight, power, and cost (SWAP-C) devices. In quantum communications, the development of a quantum repeater and consistent improvements in distance and key rates will indicate advancement. Lastly, implementation of error correction and subsequent scaling in the number of logical qubits will be important improvements on the path to developing a fault-tolerant quantum computer.



Optics and photonics are a core enabling element of quantum technologies, as many of the systems require very precise control of light. To enable many of the applications highlighted above, additional innovation and supply chain development is required. Subsequent chapters further specify necessary components to illustrate the many opportunities available to optics and photonics suppliers, including photon sources, photon detectors, optical fiber, integrated photonics, couplers, modulators, frequency converters, and optical-to-microwave transducers.

In addition to developing the optics and photonics components for individual subsystems (e.g., sensors, computing nodes), interconnects to link subsystems to create a large-scale quantum network or computer are also needed. Quantum interconnects must transfer the quantum states between various physical media (e.g., atoms, photons, microwave fields, semiconductor electronics) with high fidelity, fast rates, and low loss. The community is beginning to recognize the importance of systems thinking and engineering for enabling the full ecosystem of quantum technologies.

## SUMMARY: OPTICS AND PHOTONICS COMPONENT REQUIREMENTS

Required | May Use

| Category | Technology | Lasers | Single or Entangled Photon Sources | Single Photon Detectors | Heterodyne and Homodyne Photon Detectors | Fiber or Integrated Photonic Waveguides | Modulators | Transducers and Converters | Memories or Repeaters |
|---|---|---|---|---|---|---|---|---|---|
| Sensing | Atomic Clocks | | | | | | | If networked | |
| | Atom Interferometers | | | | | | | If networked | |
| | NV Center Sensors | | | | | | | If networked | |
| | Quantum LiDAR | | | | | | | | |
| Comms. | Continuous Variable QKD | | | | | | | | |
| | Discrete Variable QKD | | | | | | | | |
| | Entanglement-Based QKD | | | | | | | | |
| Computing | Superconducting | | | | | | | If networked | |
| | Ion Trap | | | | | | | If networked | |
| | Neutral Atom | | | | | | | If networked | |
| | Photonic - Discrete Variable | | | | | | | Memory-dependent | |
| | Photonic - Cont. Variable | | | | | | | Memory-dependent | |
| | NV Center | | | | | | | If networked | |
| | Silicon Spin | | | | | | | If networked | |
| | Topological | | | | | | | TBD | TBD |

Source: Expert interviews, Newry analysis