MOONSHOT
RESEARCH & DEVELOPMENT PROGRAM

Moonshot International Symposium

April 23,2021 @ on line

Development of Quantum Interfaces for Building Quantum Computer Networks

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NIMS

QST

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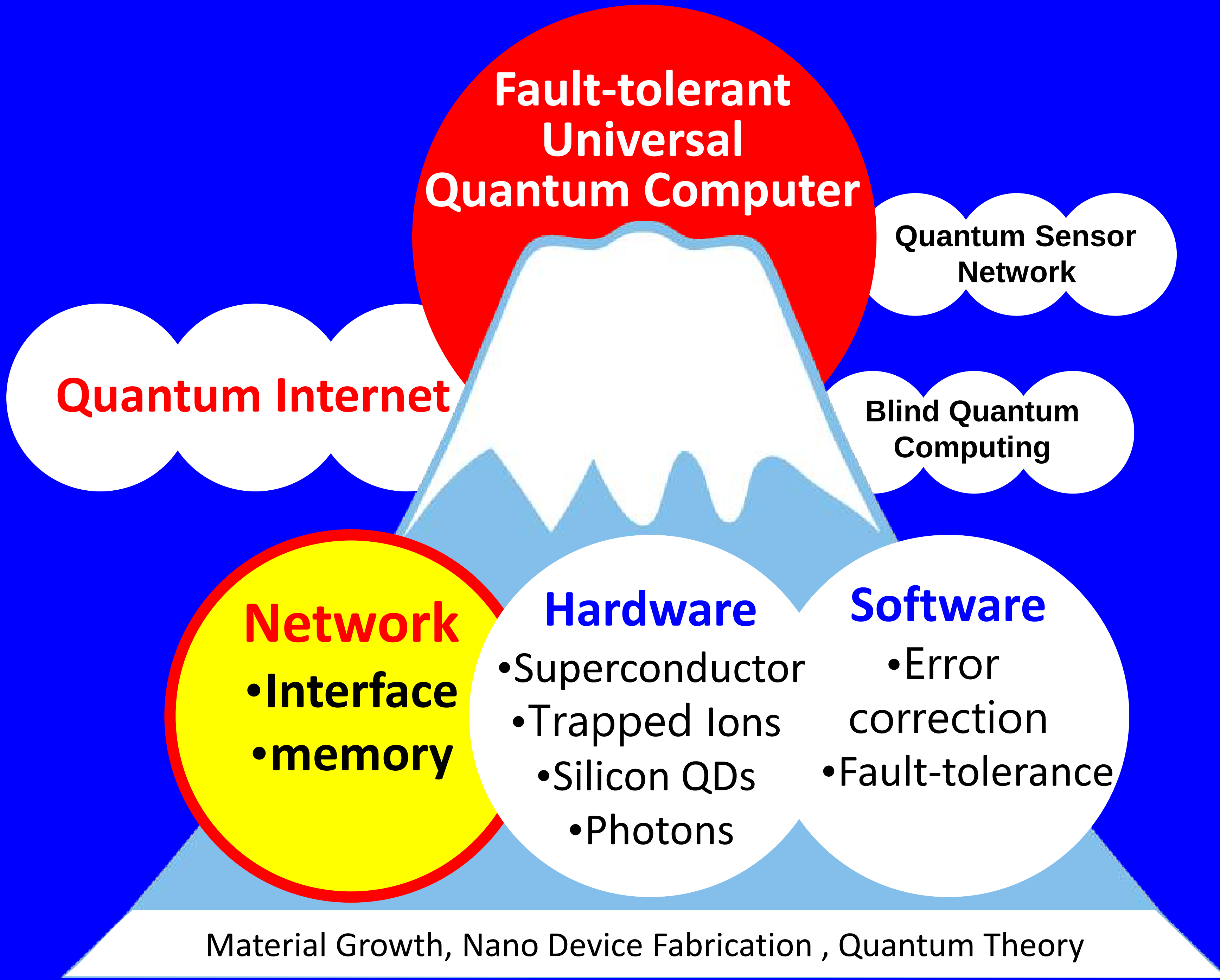
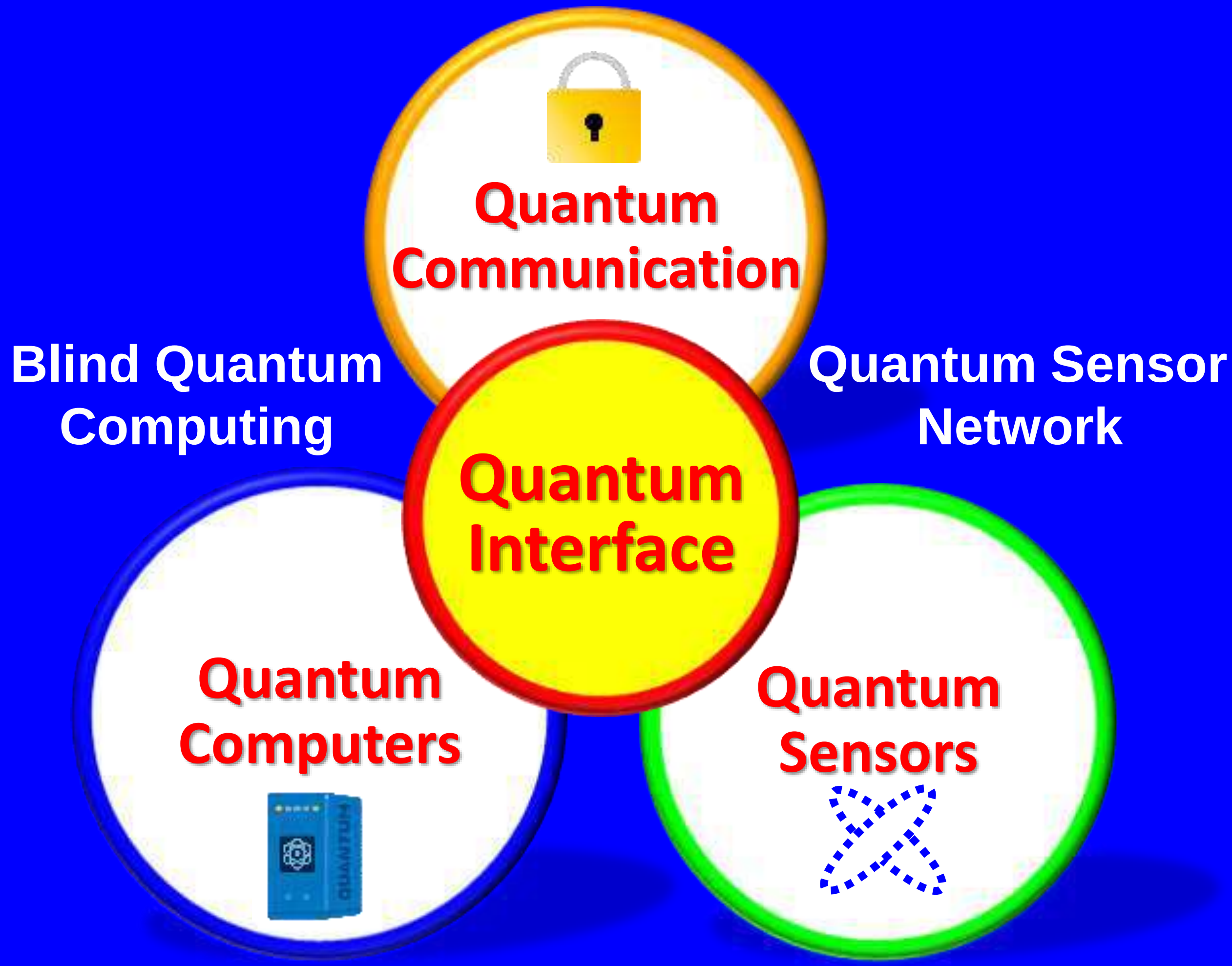

Fault-tolerant
Universal
Quantum Computer
Quantum Sensor
Network
Quantum Internet
Blind Quantum
Computing
Network
•Interface
•memory
Hardware
•Superconductor
•Trapped Ions
•Silicon QDs
•Photons
Software
•Error
correction
•Fault-tolerance
Material Growth, Nano Device Fabrication , Quantum Theory

Quantum Interface



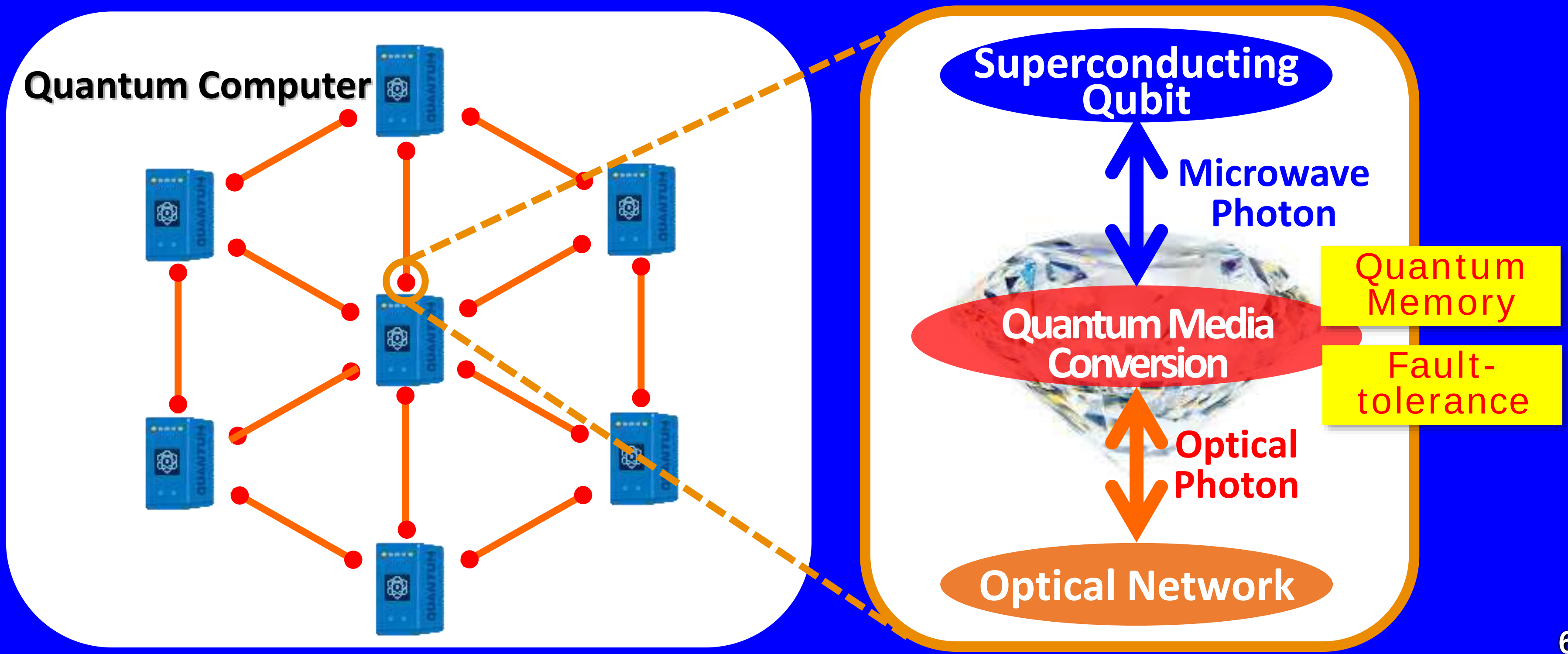
Technology Roadmap in Q. Network

Based on the "Quantum Technology and Innovation Strategy" from Japanese Cabinet Office

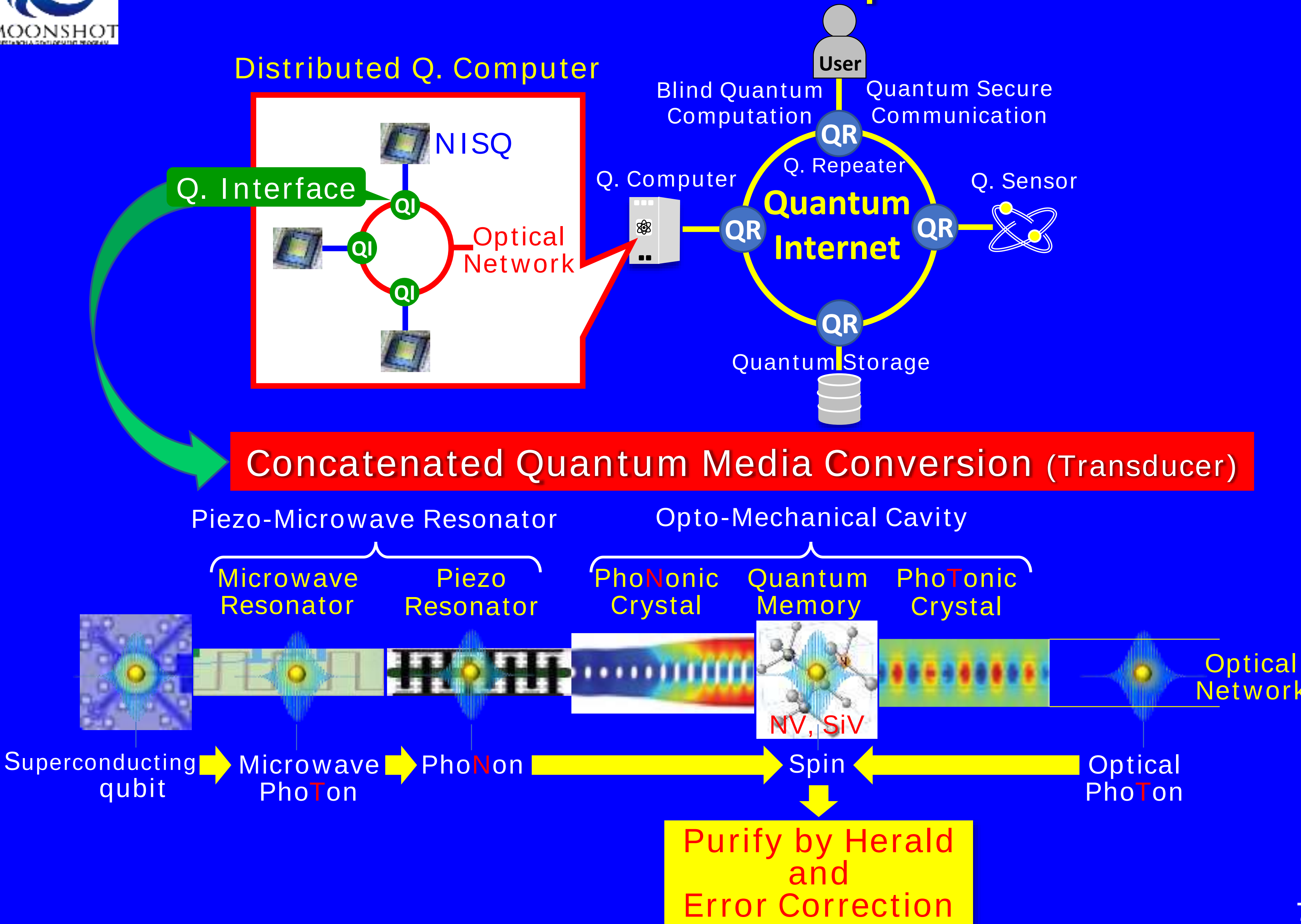
	In 5 years (2025)	In 10 years (2030)	In 20 years (2040)	
Quantum Entanglement Distribution	Field demonstration of quantum repeater (2025–2030)		Entanglement distribution > 500 km via quantum repeater	Key rate > 1 kbps via entanglement distribution
	Entanglement distribution b/w 3 parties via a quantum repeater (2025–2030)			
	Remote entanglement generation b/w memories by emission & absorption	Entanglement with communication-band photon	Multi-party entanglement via quantum memories	
Quantum Memory	· Single-qubit gate · Single-shot measurement · Quantum error correction	Two-qubit gate fidelity > 99.9%	Individual access memories 100~1000 bits	Scalable quantum repeater
	Multiple memories ~10 memory time > 1 min	Complete Bell measure on memories transferred from photons	Fault-tolerant logical memory with quantum coding	
Quantum Interface	Quantum Media Conversion b/w photon & quantum memory	Quantum Media Conversion b/w superconducting qubit & quantum memory (2030–2040)		Distributed quantum computer and quantum sensor
	Quantum wavelength conversion Single photon fiber coupling	Quantum wavelength conversion module	Wavelength division multiplexing quantum communication	
Photon Source	Single photon source Entangled photon source (2025–2030)		All-photonic quantum repeater	

Quantum Computer Network

- **Quantum media converter**
  - **Interface Quantum Computer to Network**
  - **Distributed Quantum Computer** could be built
- **NV center in diamond** under a zero magnetic field
  - Interface **optical & microwave photons** with **memory**
  - **Purification** and **Fault-tolerance** would be expected

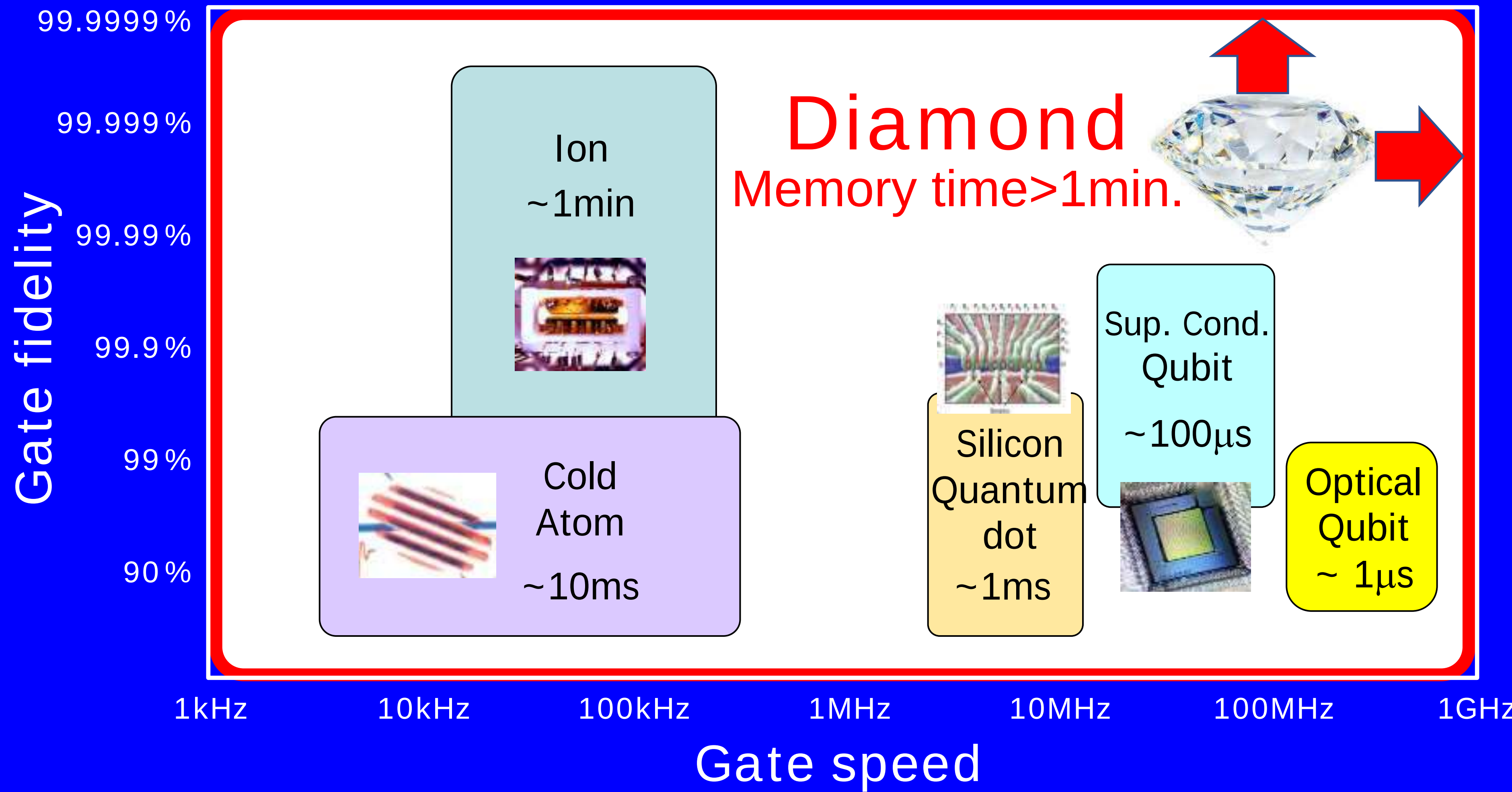


Research Concept



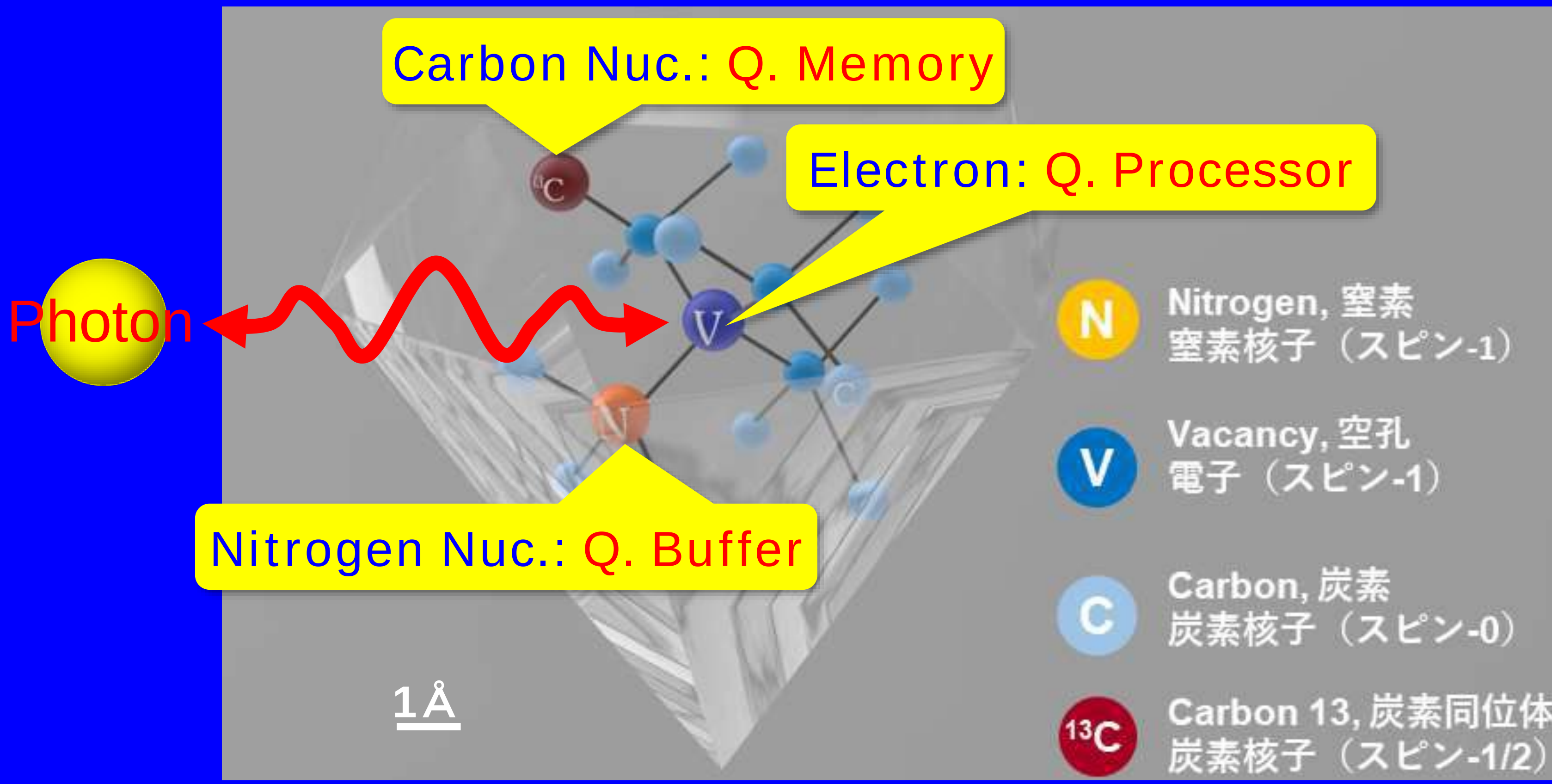
Promising Qubits

Diamond Qubits show high performance
in Speed, Fidelity and Memory no less than other qubits



Diamond NV Center Quantum Interface

Various Spins in an NV center are used as
Q. Memory, Q. Processor, and Q. Buffer



Diamond can be an Ultra-Compact Quantum Computer or Sensor

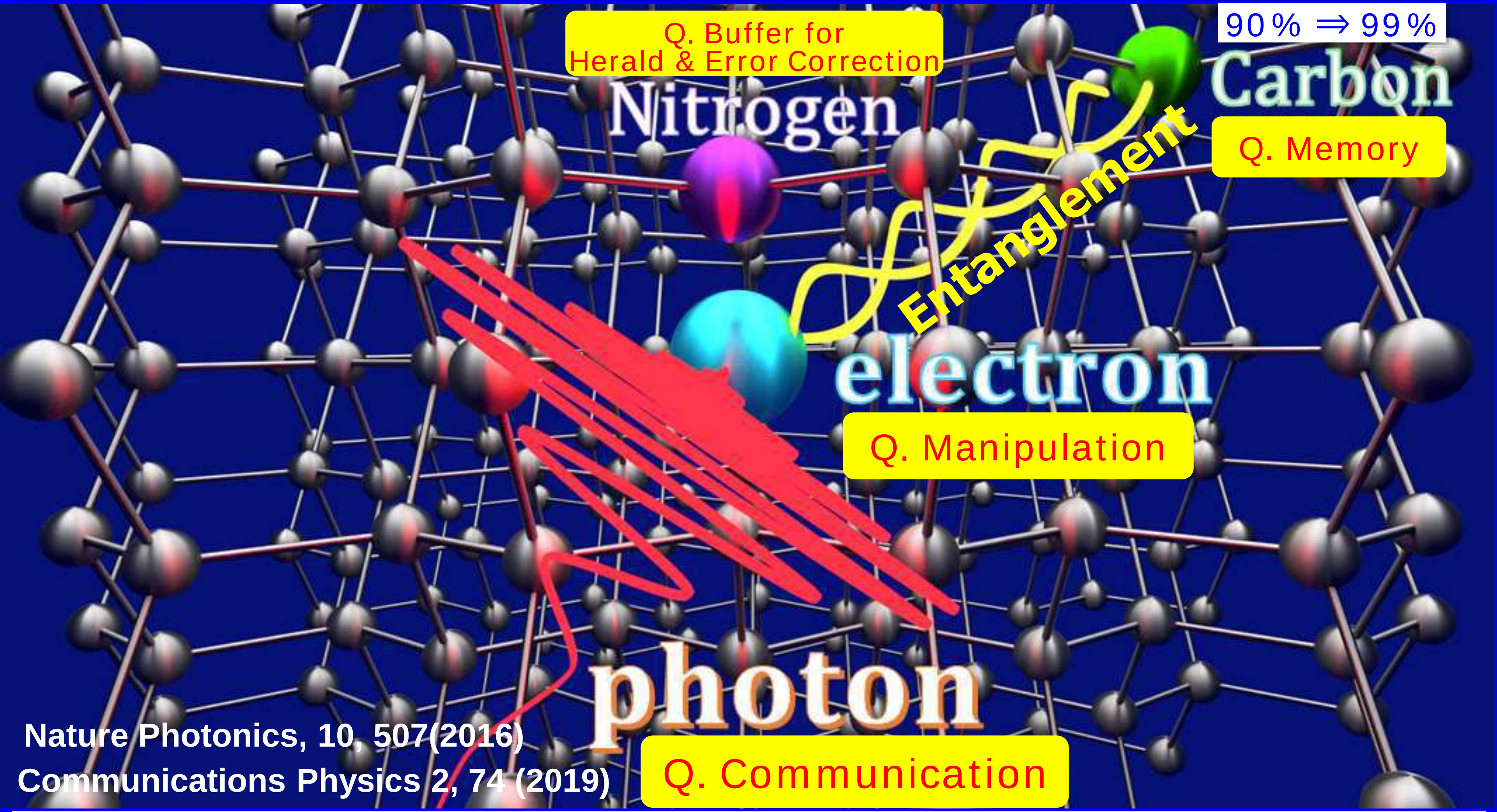
Required Functions

Quantum Manipulation, Memory, Readout and those Combinations in Diamond Spin Qubits under a Zero magnetic field

Functions	Requirements	Status
Quantum Manipulation Fidelity	> 99.9%	99.6%
Quantum Manipulation Time	< 1ns	5 ns
Quantum Memory Time	> 1 min.	1 s
Single-Shot Readout Fidelity	> 99.9%	99.7%
Electron-Photon Entangl. Generation	> 99%	90%
Photon-to-Spin Q. State Transfer	> 99%	90%
Q. Error Correction ⇒ Q. Coding	> 99%	80%
Complete Bell measurement	> 99%	85%
Individually addressable Q. Memory	> 100	10

Quantum Teleportation Transfer

We can Transfer and Store Quantum State from an Optical Photon to a Quantum Memory

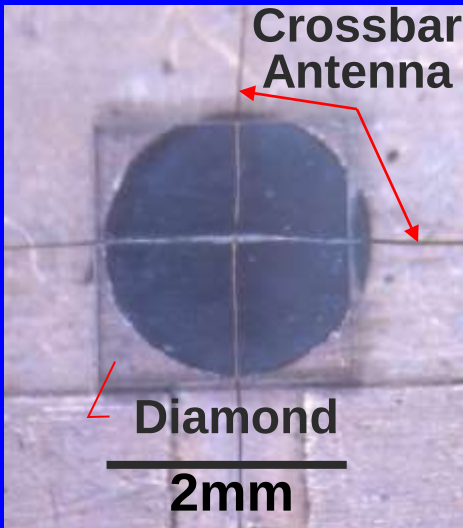


Nature Photonics, 10, 507(2016)
Communications Physics 2, 74 (2019)

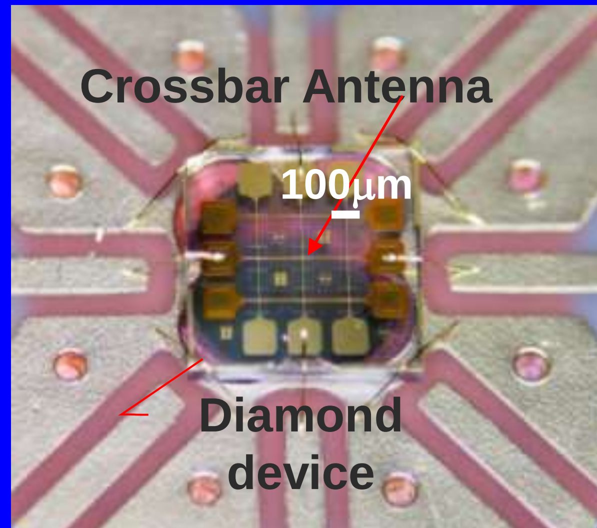
We will be able to Transfer and Store Quantum State from a Microwave Photon to a Quantum Memory.

Diamond Nanotechnology

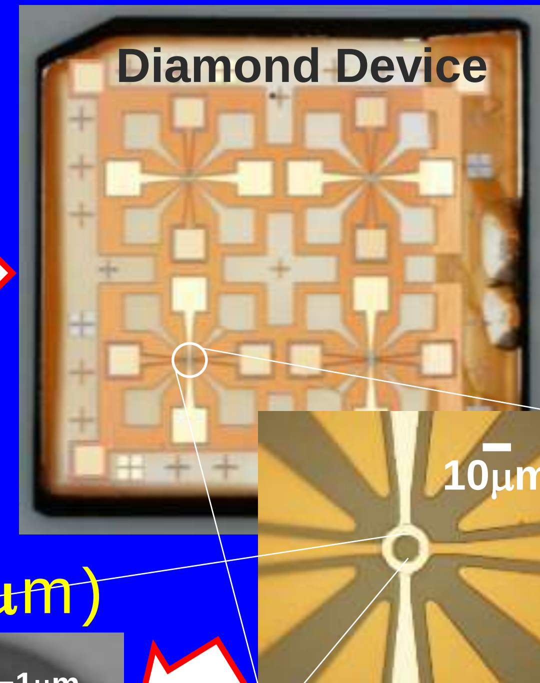
0G (1mm)



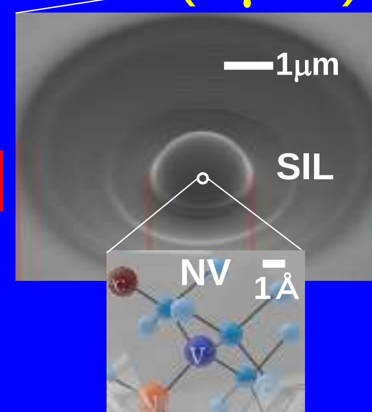
1G (100μm)



2G (10μm)



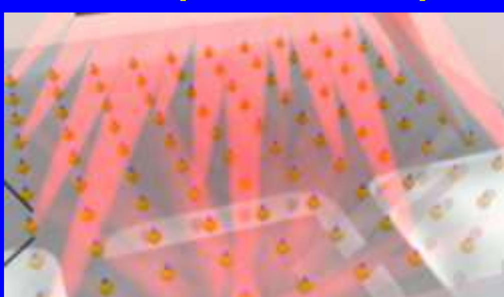
3G (1μm)



4G (100nm)

Diamond Photonic Crystal

5G (Q-RAM)



Large Scale 1K~1M Optical Random Access

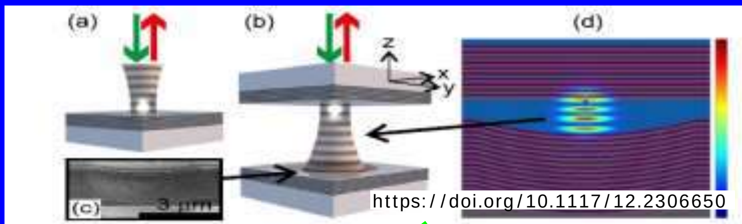
- High Speed
- High Fidelity
- High Density

Diamond Photonic Crystal dramatically improves Efficiency of Quantum Interface

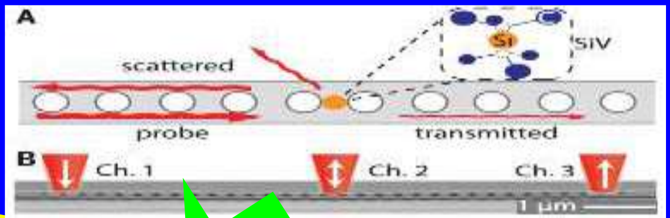
Research Trends in Quantum Interfaces

Combination of Diamond, Superconducting technology with Photonic Integration enables Hybrid Quantum Interface

Diamond + Fabry-Perot Resonator (Delft, Oxford, Basel)



Diamond + Photonic Crystal (Harvard, MIT, Stanford)



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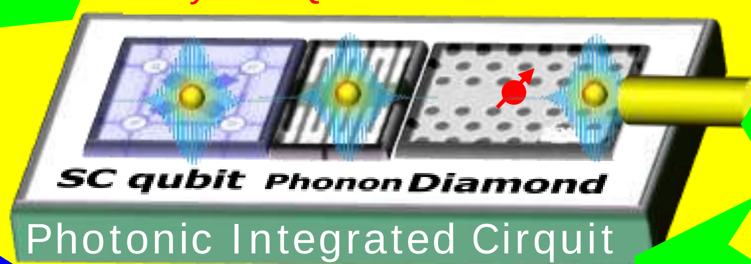
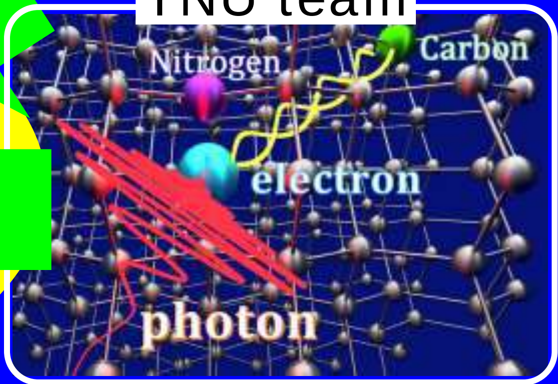
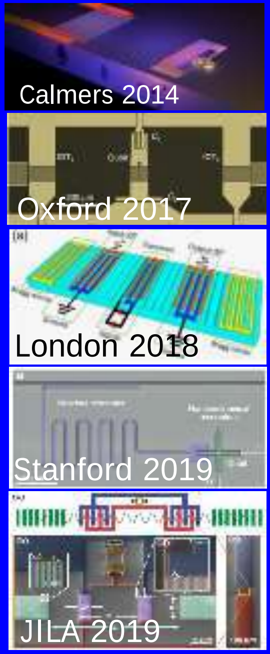
Hybrid Quantum Interface

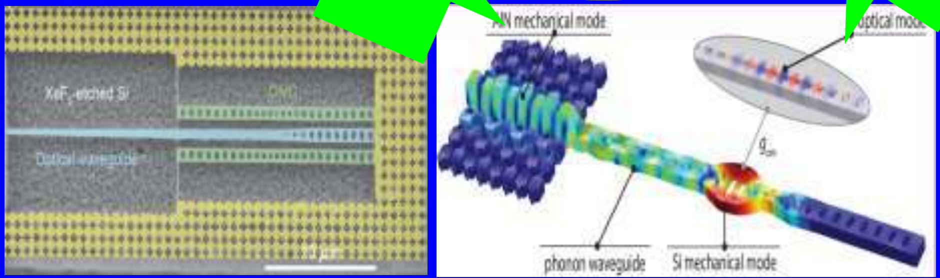


YNU team

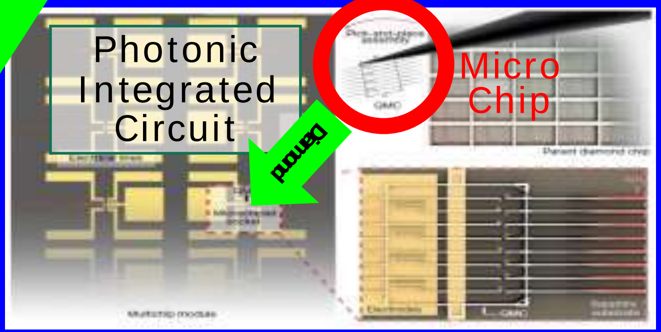


Supercond. + Phonon





Diamond + Opto-Mechanical Crystal (Stanford, UCSB, Caltech)

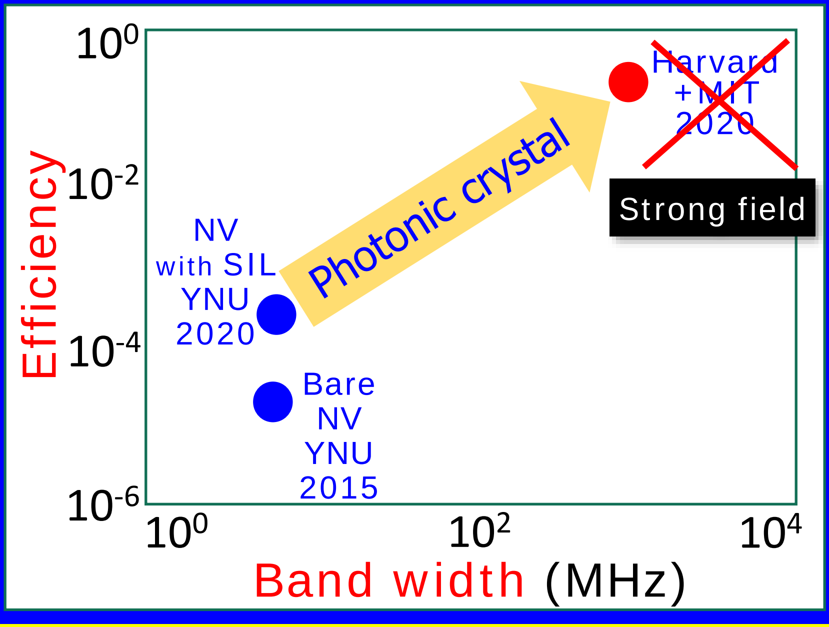


Diamond + PIC (MIT)

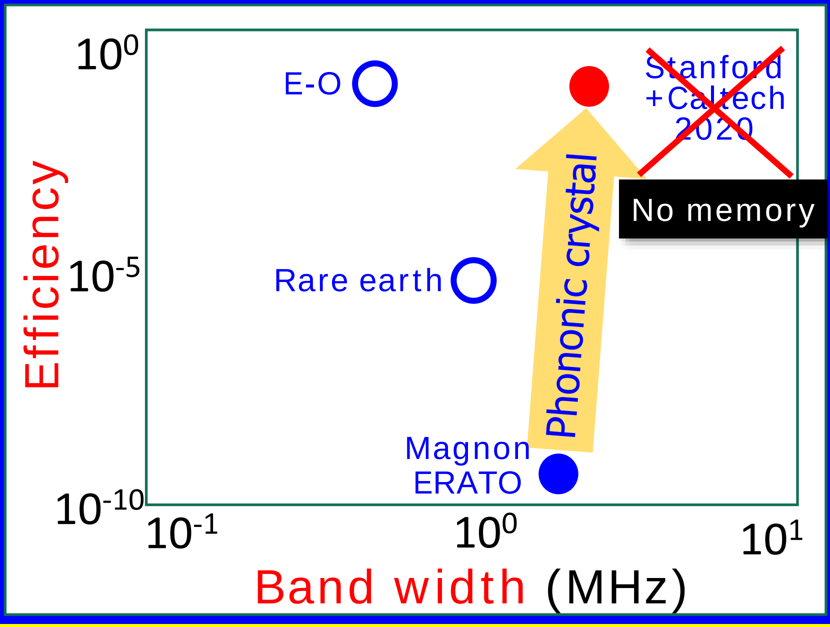
Target Performance

Throughput = Conversion Efficiency × Band width × Fidelity

Photon ⇒ Memory

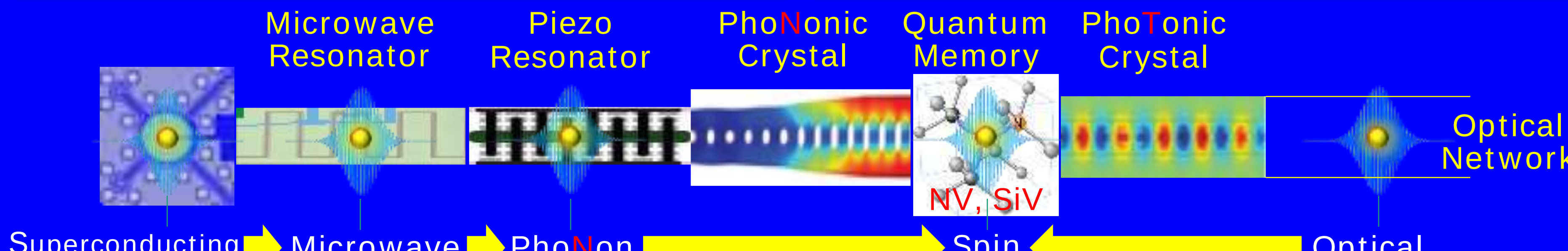


SC qubit ⇒ Photon



Integrity with Superconducting qubit under a Zero magnetic field

Cope with both Efficiency and Fidelity by Quantum Memory



Kosaka Project Members

PM: Hideo Kosaka
Yokohama National Univ. & Quantum Information Research Center

33 Japan's Best Nanotechnology Researchers!

Diamond Q. Memory

- H. Kosaka (YNU)
  Diamond Q. Memory
- H. Kato, T. Makino (AIST)
  Diamond Q. Structure
- T. Teraji (NIMS)
  Diamond Q. Crystal
- S. Onoda (QST)
  Diamond Color Center

Members:

- Y. Sekiguchi(YNU)
- H. Kurokawa(YNU)
- K. Kojima(AIST)
- X. Shen(AIST)
- M. Ogura(AIST)
- Y. Kato(AIST)
- H. Yoshioka(AIST)
- K. Masumoto(AIST)

Opto-Mech. Crystal

- S. Iwamoto (Tokyo)
  Photonic Crystal Cavity
- T. Baba (YNU)
  Photonic Integrated Circuit
- M. Nomura (Tokyo)
  Phononic Crystal Cavity

Members:

- Y. Ota(Tokyo U.)
- M. Nishioka(Tokyo U.)
- S. Ishida(Tokyo U.)
- S. Hachuda(YNU)
- T. Tamanuki(YNU)

Piezo MW Resonator

- H. Kosaka (YNU)
  Piezo-Microwave Cavity
- N. Yoshikawa (YNU)
  Qubit Control Integrated Circuit

Members:

- R. Sasaki(Riken)
- H. Terai(NICT)
- K. Tanabe(Kyoto U.)
- K. Inomata(AIST)
- H. Yamanashi(YNU)
- N. Takeuchi(AIST/YNU)
- A. Christopher(YNU)
- O. Chen (TCU)
- Y. Sekiguchi(YNU)
- H. Kurokawa(YNU)

Collaboration with Yasu Nakamura ERATO and Tsuyoshi Yamamoto MS

Summary

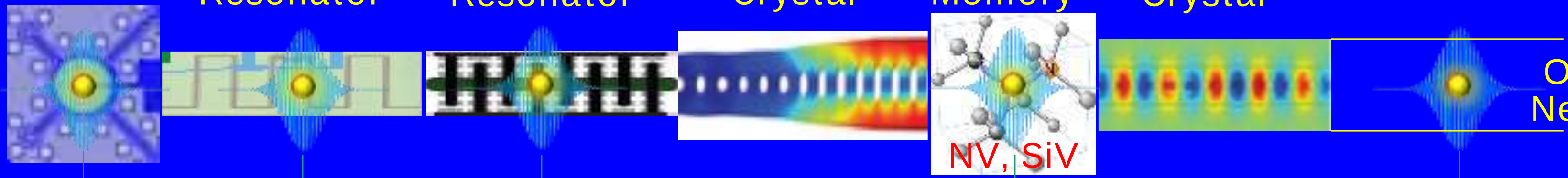
Diamond Qubits show high performance
in Speed, Fidelity and Memory no less than other qubits

Combination of Diamond, Superconducting technology
with Photonic Integration enables Hybrid Quantum Interface

Concatenated Quantum Media Conversion (Transducer)

Piezo-Microwave Resonator — Opto-Mechanical Cavity

Microwave Resonator | Piezo Resonator | PhoNonic Crystal | Quantum Memory | PhoTonic Crystal



Optical Network

Superconducting qubit → Microwave PhoTon → PhoNon → Spin ← Optical PhoTon

Purify by Herald
and
Error Correction

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