Lithium Niobate-based Photonic Integrated Circuits for Next Generation Quantum Devices

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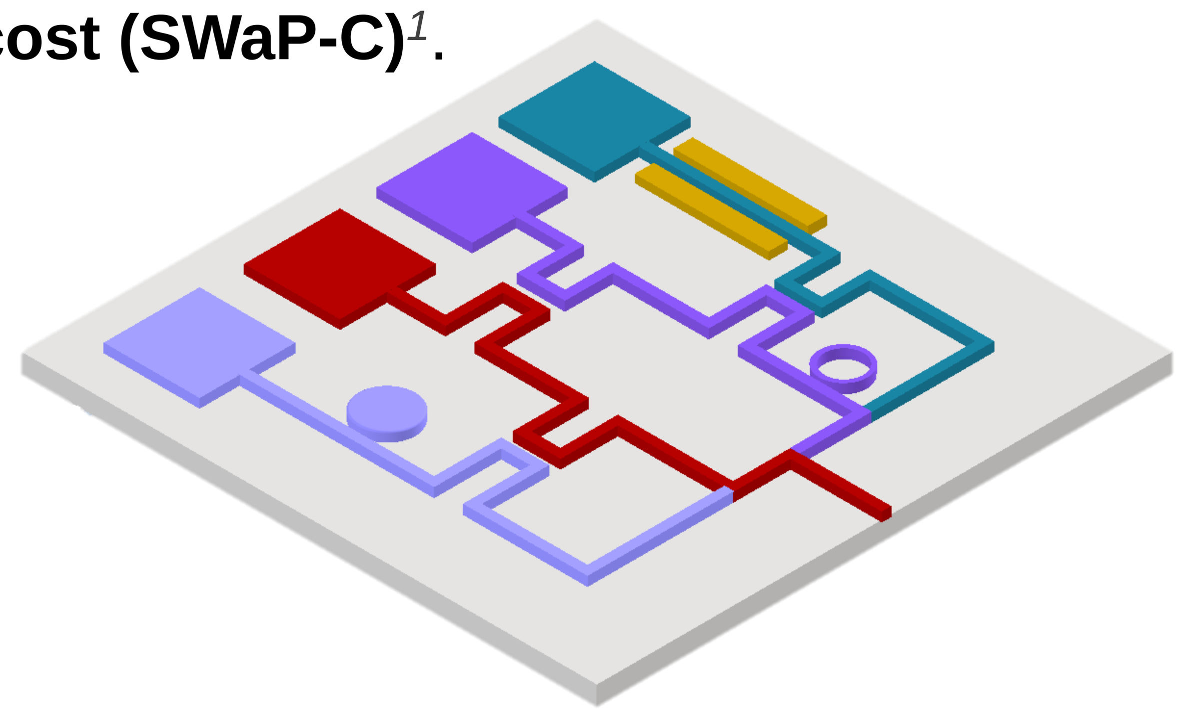
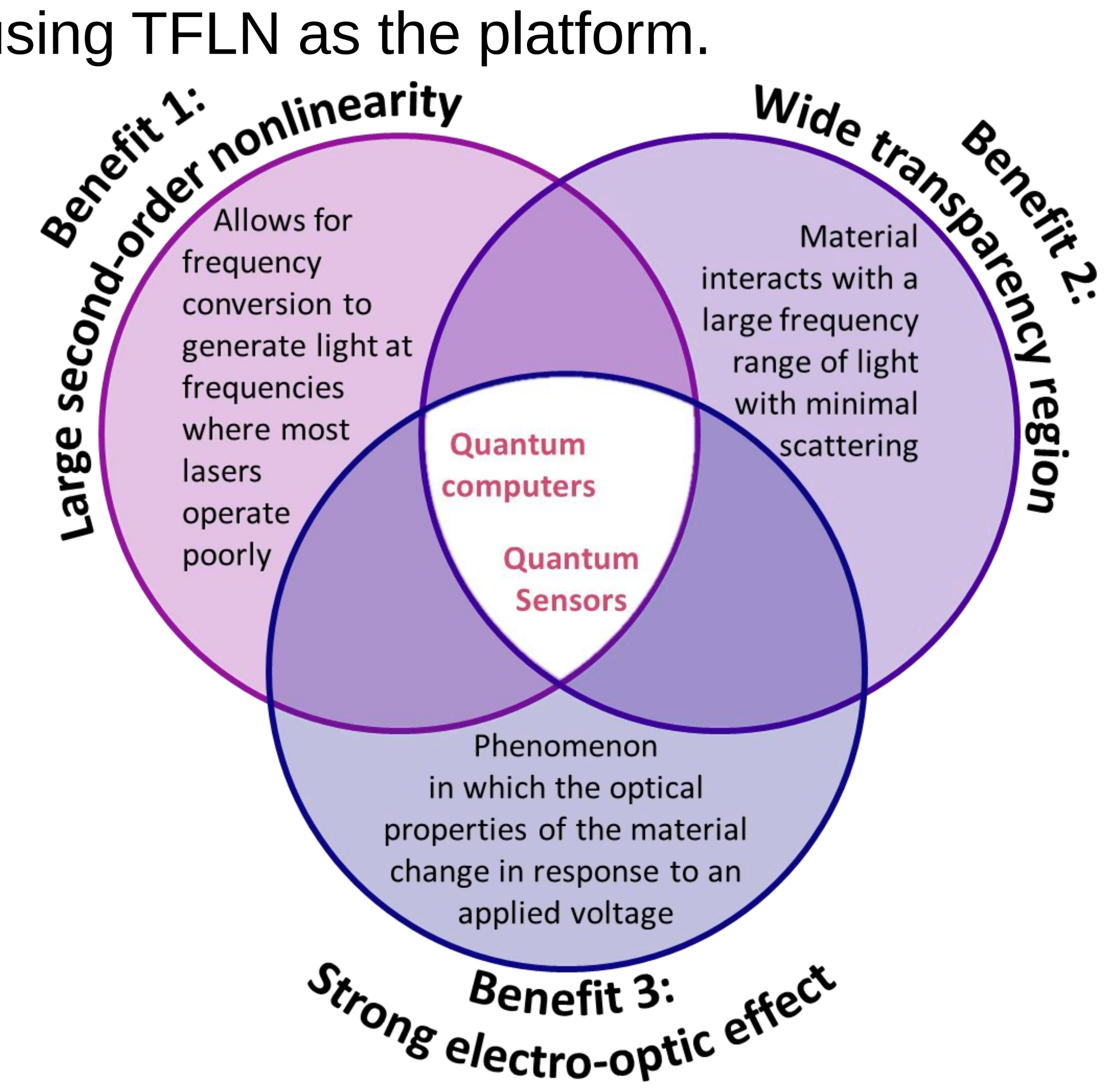
Photonic Integrated Circuits

Photonics is the **science of generating and manipulating photons**, the particle of light. Photonic integrated circuits (PICs) are revolutionizing the way we do optics and photonics. PICs can **accomplish tasks similar to large optical systems** that are crucial for applications in **data transfer and communication, climate and agriculture, and navigation and sensing** but have **advantages in size, weight, power, and cost (SWaP-C)***[1]*.



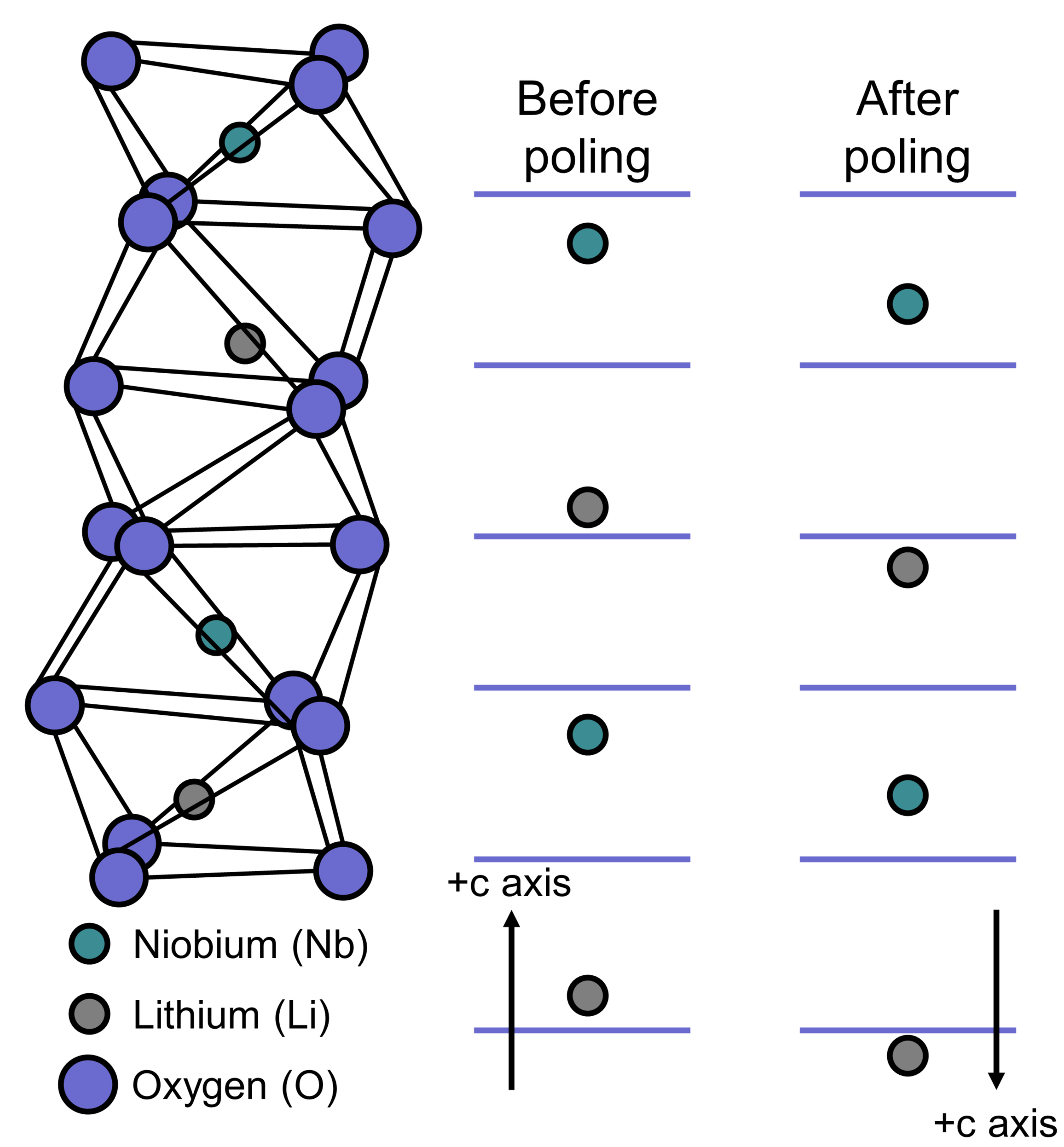
Lithium Niobate Properties

PIC development has **primarily occurred using silicon and silicon nitride** due to **established and mature fabrication methods**; however, these materials **lack certain nonlinearities to make them highly efficient**. A promising **alternative is lithium niobate (LiN)** which hosts a **wide transparency window** for interacting with a large range of wavelengths and **effective nonlinearities** for manipulating light*[2]*. Recent advancements in fabrication methods have allowed for **commercially available thin-film LiN (TFLN) expanding the possible applications for LiN PICs** using TFLN as the platform.

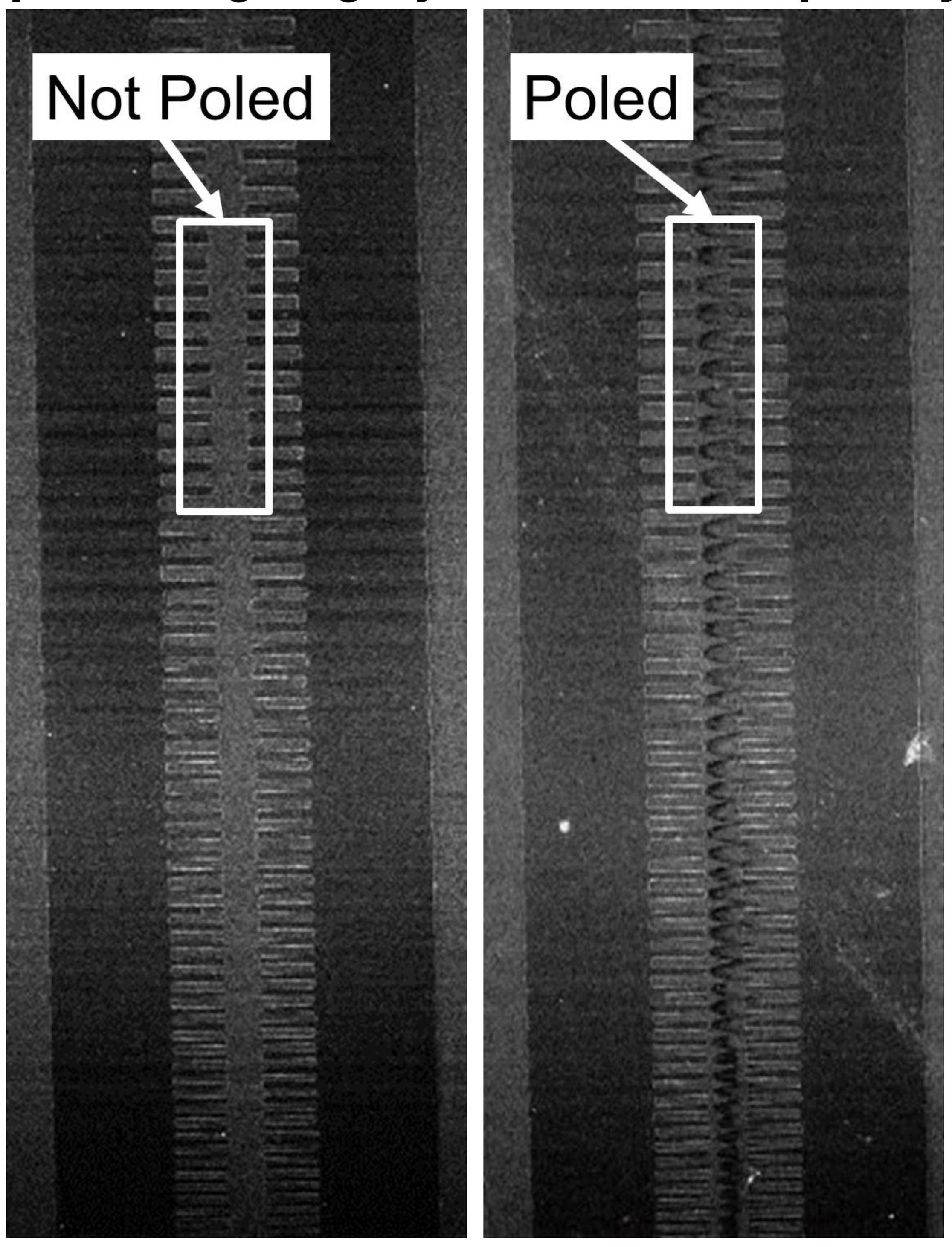


Periodic Poling in Thin-Film Lithium Niobate

Poling works by **applying a high voltage** to a designated section of the TFLN **over a very short time period**. This process allows one to **access the largest second-order nonlinear property** of the material **providing highly efficient frequency conversion.**

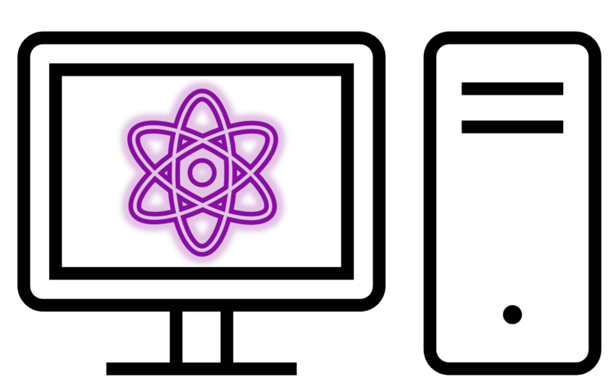


Crystal structure of LiN. Poling moves the positions of the Li and Nb atoms with respect to the oxygen atoms causing an inversion of the optical axis[3].

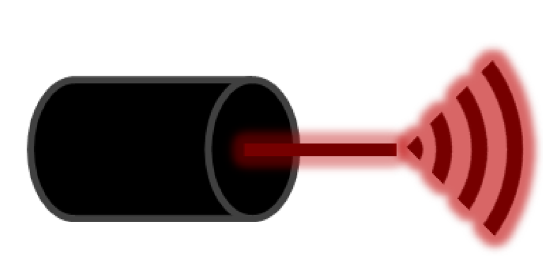


Two-photon microscope images showing poled and non-poled TFLN.

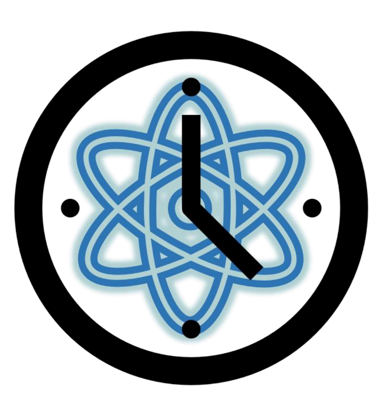
Quantum Devices and Applications



Quantum Computing[1]
- *Cryptography*
- *Communication and data transfer*
- *Simulations*



LiDAR[4]
- *Autonomous vehicles*
- *Greenhouse gas detection*
- *Terrain mapping*



Optical Atomic Clocks[5]
- *Precision timekeeping*
- *Water resource management*
- *Navigation (GPS)*

Quantum Devices with Photonic Integrated Circuits

Rubidium atomic clocks are currently used for GPS but are based around technologies from the 1960s. Most state-of-the-art quantum devices are **confined to the laboratory scale** making them **inaccessible for public applications**. This work aims to **push the boundaries photonics research by developing robust PIC technologies for the advanced quantum devices described above.**

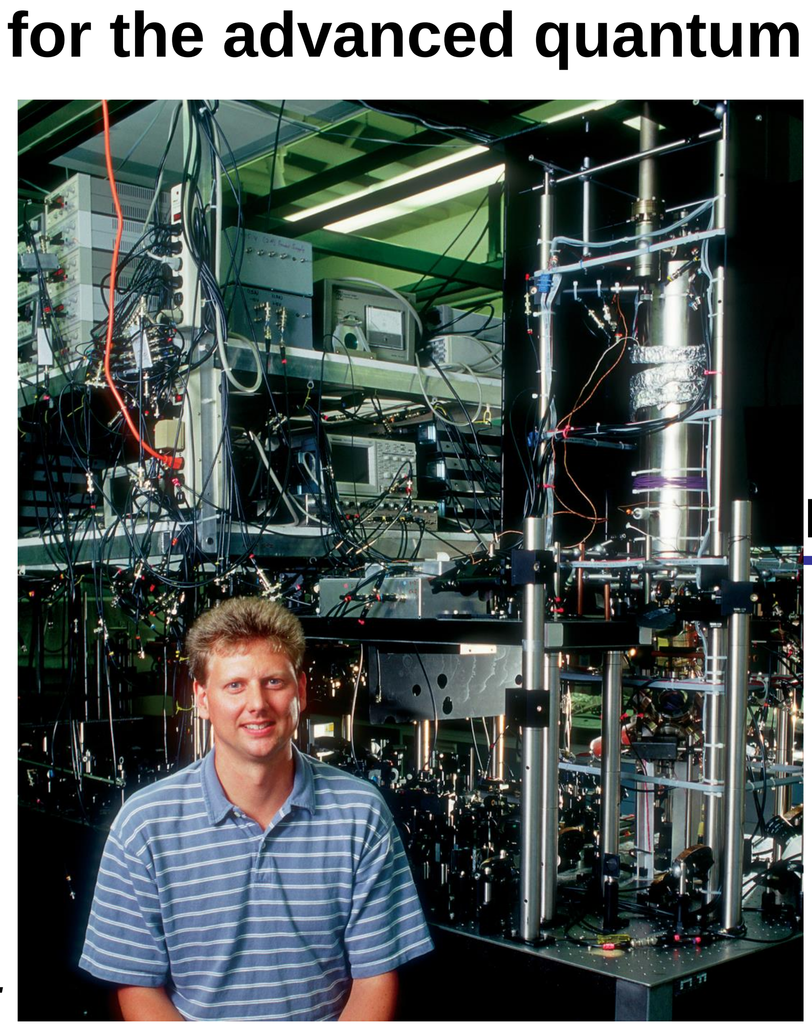
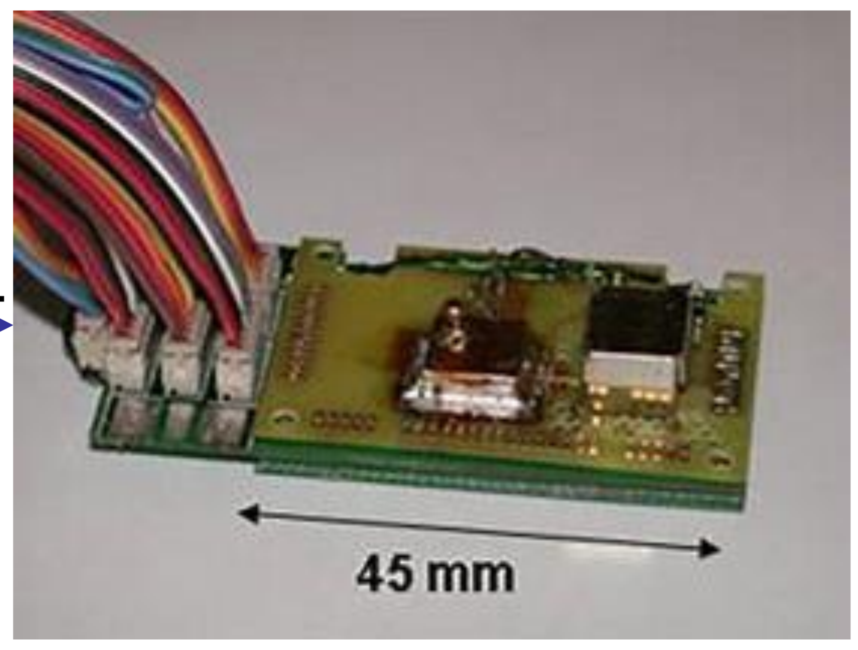


Table-top rubidium atomic clock from Penn State University[6].

From big…
…to small!



Integrated rubidium atomic clock from NIST in Boulder, Colorado[7].

References

1. G. Moody, et al. JPhys Photonics, 4, 1 2022. **2.** A. Honardoost, et al. Laser and Photonics Reviews, 14, 9 2020. **3.** D. Zhu, et al. Advances in Optics and Photonics, 13:242, 6 2021. 4. National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center. "Lidar 101: An Introduction to Lidar Technology, Data, and Applications." 2012. **5.** A. D. Ludlow, et al. Reviews of Modern Physics, 87, 6 2015. **6.** James Collins. Penn State University. "Rubidium atomic clock at Pennsylvania State University that Gibble designed and built". **7.** J. Kitching. Applied Physics Reviews 5, 031302 2018