Quantum Sensing

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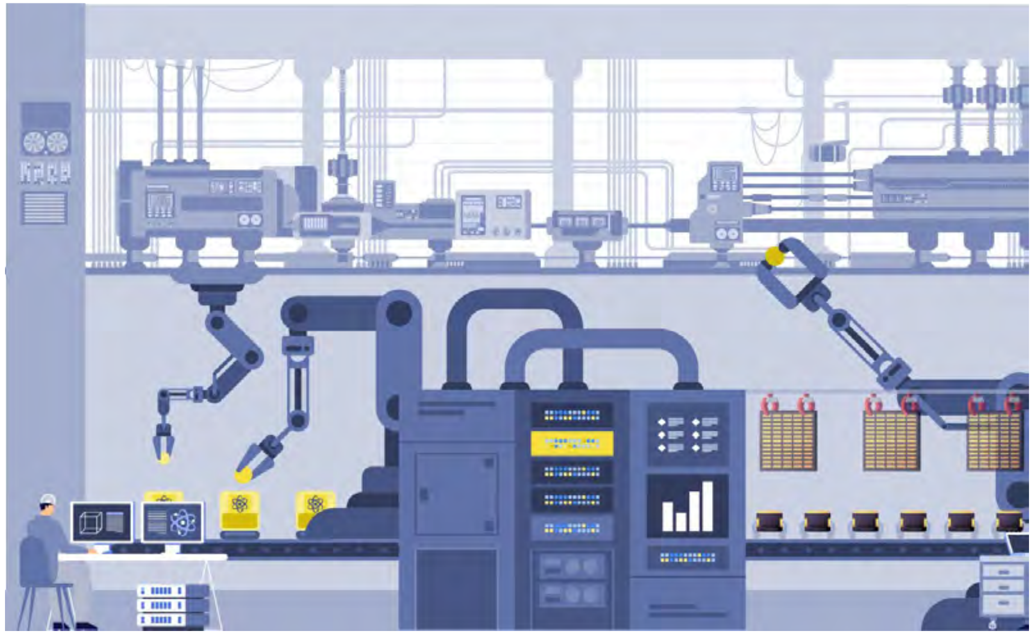
Realize domestic manufacturing for emerging technologies such as quantum sensing, integrated photonics, and non-von Neumann computing

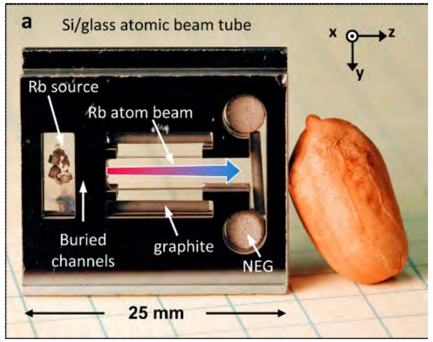


Artist Concept of a future manufacturable sensor assembly. Source: DARPA

- Metrics or figure of merit (FOM) to realize domestic manufacturing of emerging technologies
- FOM hypothesis: reduced touch points and labor hours and increase parallelization
- Determine the economic structures and frameworks needed to enable domestic, scalable, and sustainable manufacturing of emerging technologies
- Establish and develop the tools, equipment, and processes needed to enable scalable manufacturability

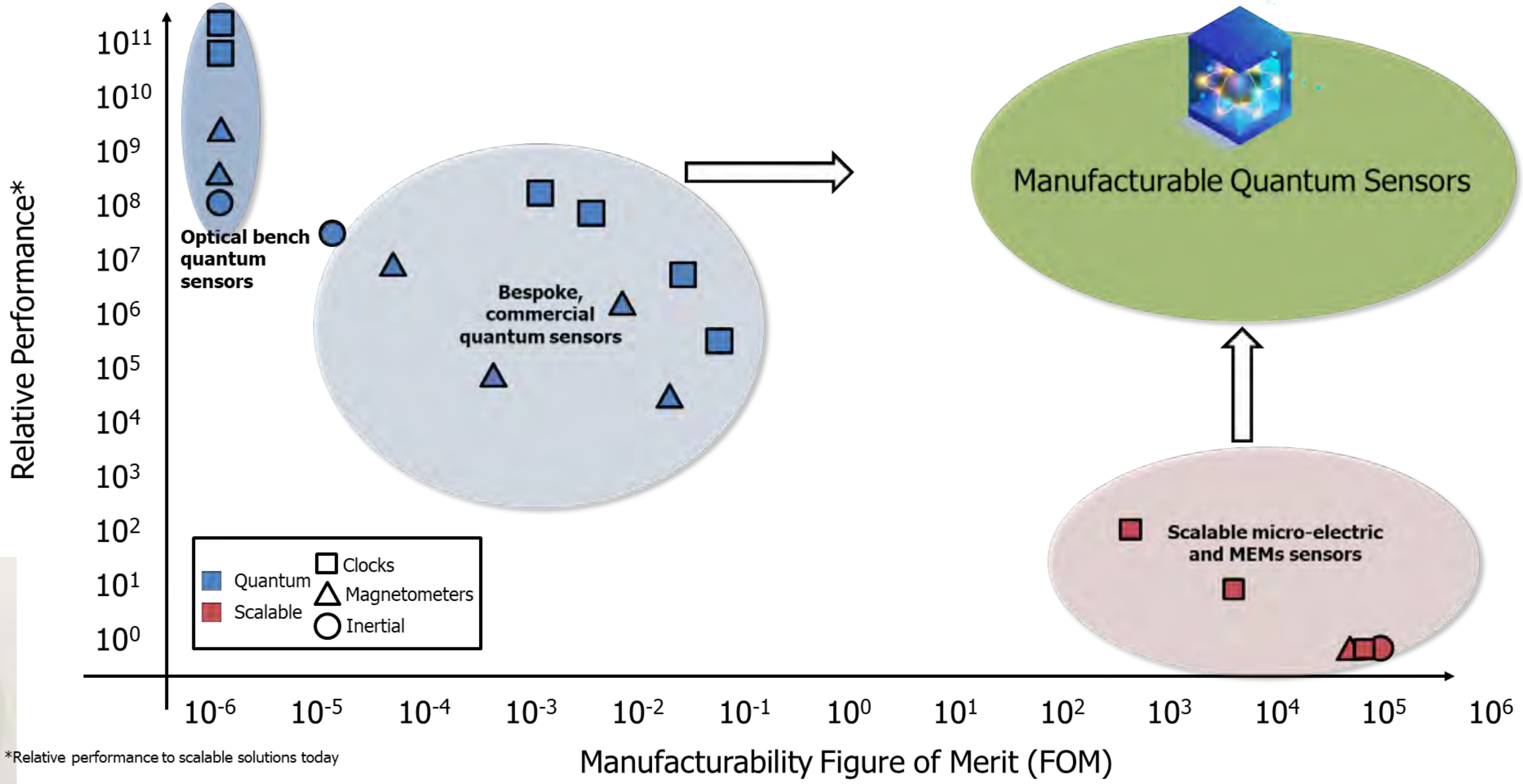
How do we enable domestic quantum manufacturing at scale?
What are the right figures of merit?
What are the right tools?

Manufacturable and Proliferated Quantum Sensing

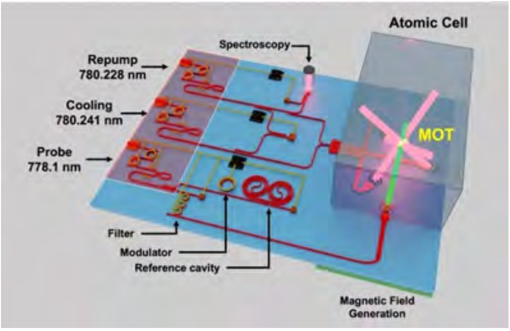


"A chip-scale atomic beam clock"

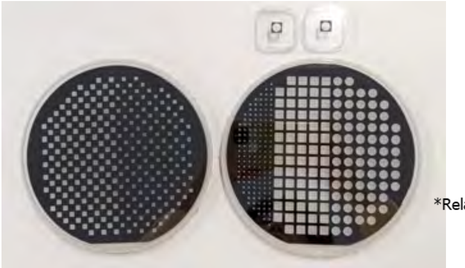
https://www.nature.com/articles/s41467-023-39166-1



*Relative performance to scalable solutions today

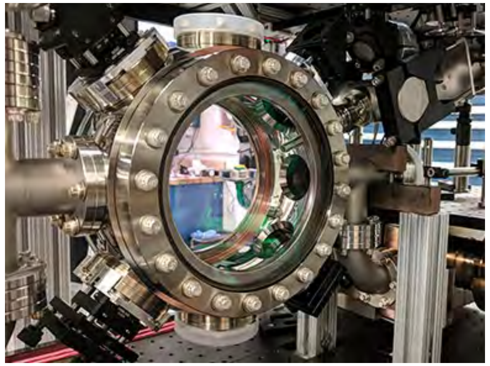


UCSB



"Hamamatsu's new quantum sensor technology"

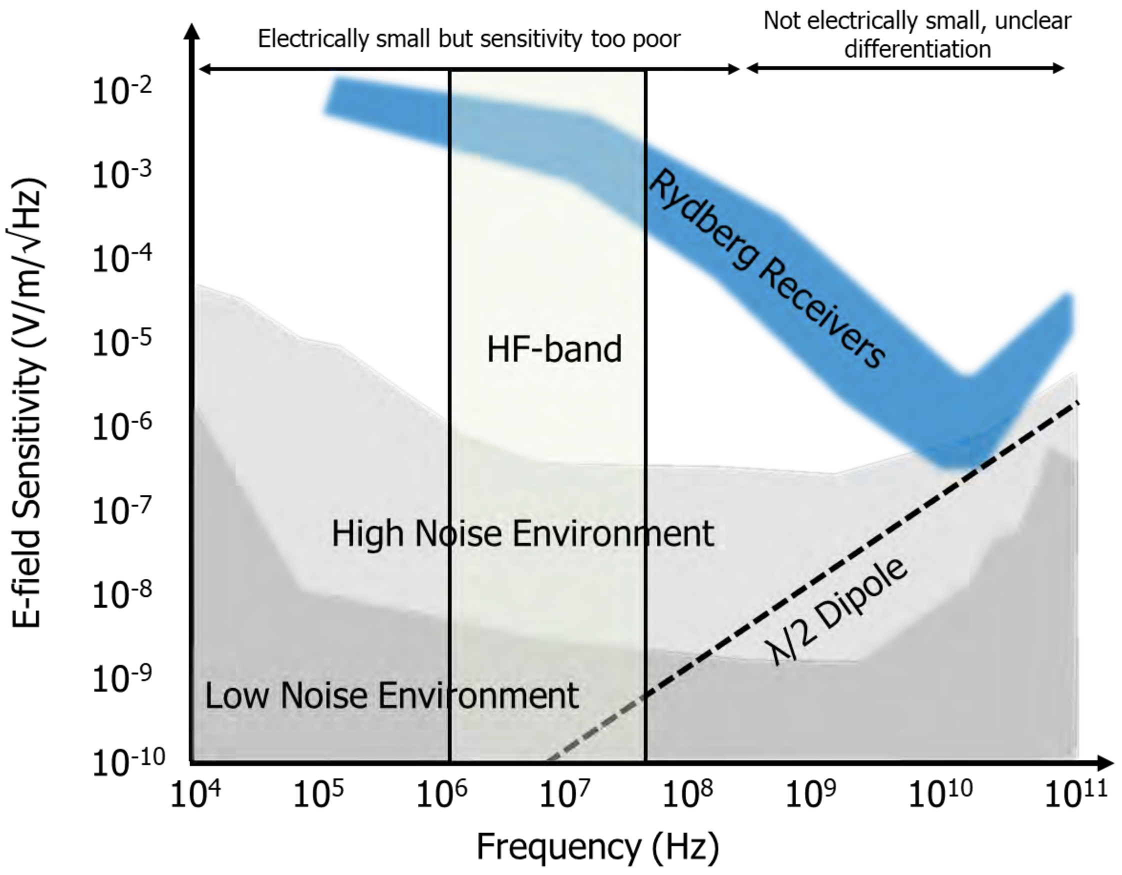
https://www.hamamatsu.com/us/en/news/featured-products_and_technologies/2025/hamamatsu-s-new-quantum-sensor-technology.html



Fermilab

Tackling challenges of integration and parallelization of heterogenous and homogenous quantum sensor systems: qubit sources, qubit housing, electronic and photonic routing, and qubit integration

Revolution in Radio Frequency (RF) High Frequency (HF) Sensing



Quantum sensing enables capture of HF signals using sensors of cm-scale dimensions, regardless of wavelength of the detected signal

Today

- The High Frequency (HF) band, generally 3 to 30 MHz, is driving renewed interest in Over-the-Horizon Radar (OTHR) and communications
- Antennas for HF applications are matched to signal wavelength
  - This leads to antenna monopoles and related structures to 100 meters in length
  - Size challenges are compounded when antennas are placed in space-consuming OTHR receive arrays

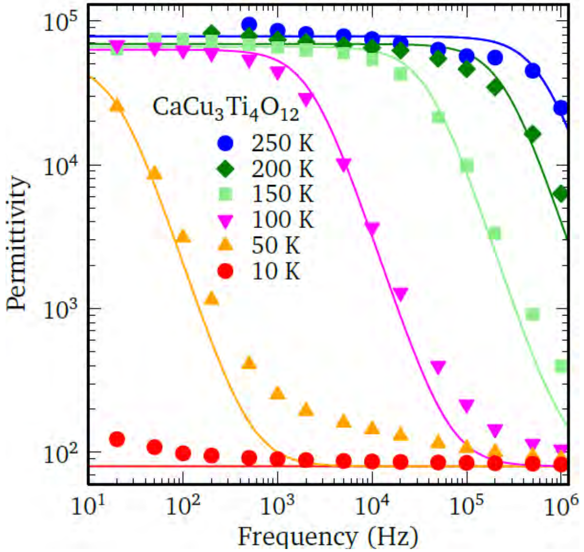
Opportunities

- Advancements in quantum sensing have shown feasibility of applying Rydberg atoms in alkali vapors at microwave frequencies
  - But sensitivity diminishes at HF frequencies
  - Need new fundamental detection schemes to drive up quantum sensitivity and bandwidth
- Other promising HF detection schemes
  - Ferrite coil structures with high permeability materials

Materials for Low Loss, High Permeability and Permittivity

Rolatube Technology (UK)

Motorola SRX 2200 two-way portable radio



Dielectric permittivity of $CaCu_3Ti_4O_{12}$ over frequency and temperature (from C.C. Homes, "Progress in High Dielectric Constant Materials," *16th IEEE Nanotechnology Materials and Devices Conference*, 2021)

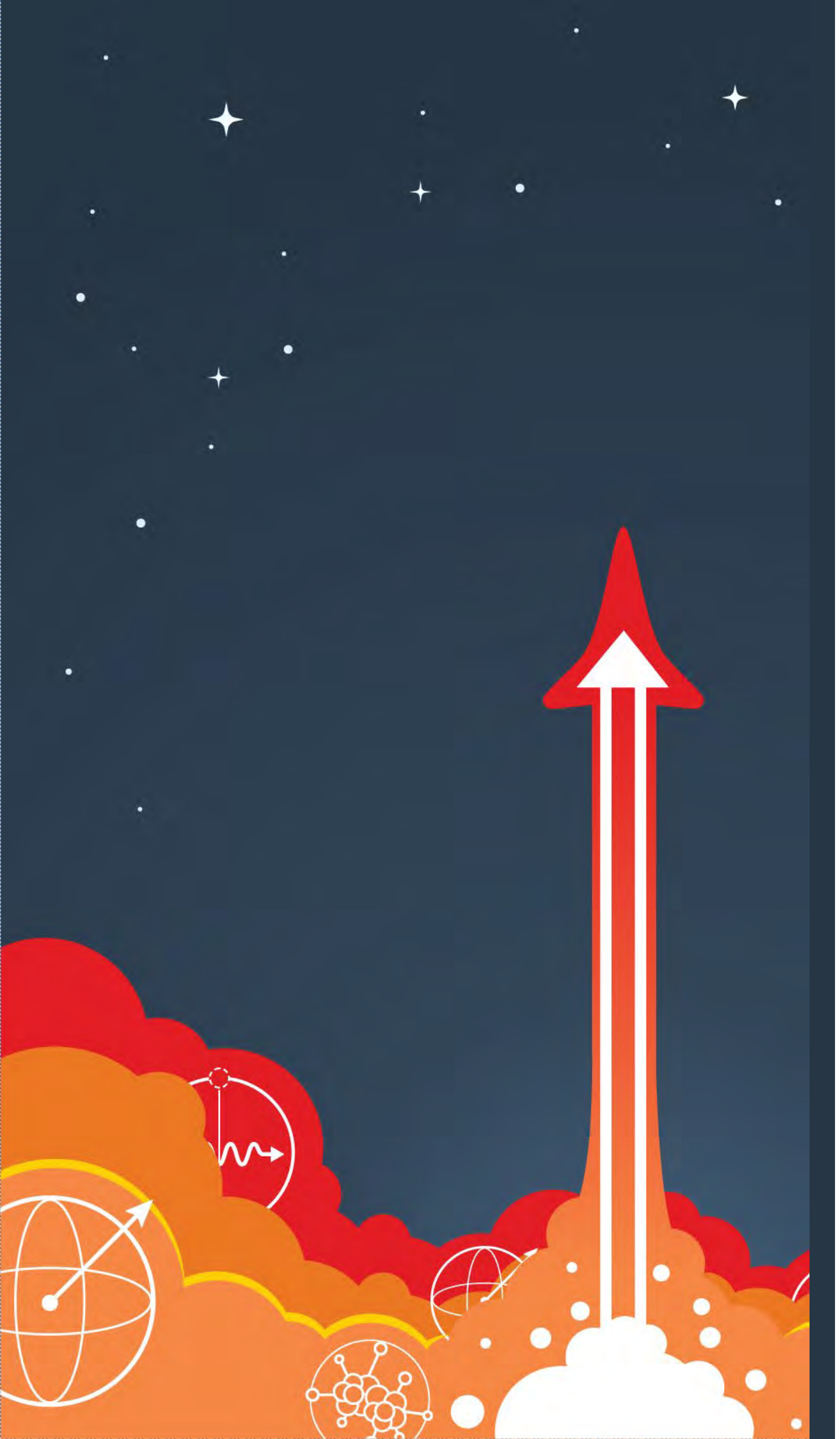
Today

- Antenna size is dictated by frequency and effective refractive index ($\sqrt{\mu\varepsilon}$) of surrounding material
- Therefore, material properties constrain antenna size, especially for frequencies <1 GHz
- Materials-based approaches to higher permeability (ferrites) and permittivity (ceramics) have not advanced to practical use

Opportunities

- Advances in magnetic metamaterials have demonstrated control over effective permeability
  - E.g., silicon-ferrite composites can achieve μ_r >300,000 but losses remain a challenge
- Recent research in "colossal permittivity" materials achieve $\varepsilon_r > 10^4$
  - Observed in $CaCu_3Ti_4O_{12}$ and presence of "defect dipoles" but losses and frequency range remain challenges
  - New 3D printing and macromolecular materials technologies open opportunities for high-permittivity materials through structural charge

Materials with both high permeability and high permittivity, with low loss will revolutionize capacitors, transformers, and electrically small antennas



We need your help

- **How do we enable domestic manufacturing of emerging technologies?**
- **What are the figures of merit, economic frameworks, and tools needed to keep emerging technology in the US?**
- **How can we proliferate quantum sensors?**
- **How do we fundamentally change communications?**
- **What are new methodologies that break the traditional trades in communications, PNT and sensing?**

MTO SPARK TANK

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