saes

Enabling ultra-clean Alkali vapor cells for compact quantum sensors

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Business Development EMEA

EPIC Technology Meeting on Photonics for Defense at Exosens

Brive, France

SAES: an Advanced Material Company

More than 80	~670	8	~128 Mio €	R&D-based Group:
Years of innovation	Employees	production sites worldwide	total revenues of the Group	our first values are Research & Innovation

Our key competences

- Surface Science
- Gas-Solid Interaction
- Advanced Metallurgy
- Macro-molecular Chemistry

Our Advanced Functional Materials

Functional Metals

> Getter Alloys
> Alkali Metal Dispensers
> Sintered Heat Sink submounts
> Shape Memory Alloys

Functional Chemicals

> Inorganic & Organic Getters
> Advanced Polymers
> Advanced Composites

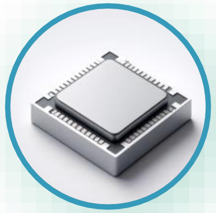
SAES Industrial division: Markets, Applications & Products

(Opto)Electronics

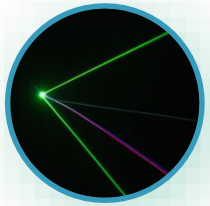
Space and Defense

Healthcare

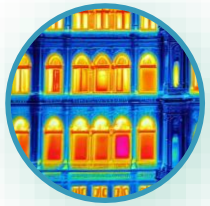
Scientific



Inertial sensors



Photonic devices



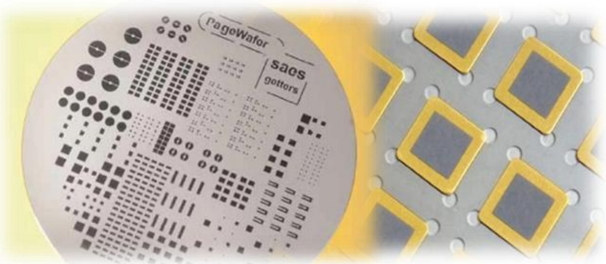
IR Imaging & sensing

RF amplifiers/TWT

X-Ray diagnostic

Organic Electronics

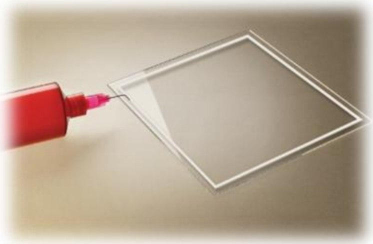
Sintered getters



Thin film getters

Alkali metal dispensers

Polymeric adsorbers



Dispensable dryers and active barrier sealents

Quantum sensing

NATO Report 2023-2043

Quantum sensing has distinct advantages over alternative technologies in eight applications.

Applications for quantum sensing

Bioimaging
Neural sensing and heart imaging

Spectroscopy
Imaging of molecular structures such as proteins

Communication
Signal receiving and amplification for radar communication; calibrating electrical standards to support 5G/6G

Navigation
Providing high-accuracy GPS; assisting with navigation inside buildings and underground

Environmental monitoring
Predicting volcanic disruption and measuring CO_2 emissions

Infrastructure monitoring
Monitoring mechanical stability and detecting leaks

Geographical surveying
Assisting with the location of oil and gas

Fundamental science
Accessing high-energy physics beyond the standard model

- Theoretical precision beyond classical sensors
- Absolute references based on atomic properties, identical by definition

Why it matters in defence systems

- Advanced PNT for GPS-denied operations
- Secure communications & synchronization
- Radar, EW, autonomous systems, ISR
- Critical infrastructure monitoring

Quantum sensing platforms

IDTechEx Research	Quantum Computing	Quantum Sensing	Quantum Communications
Superconducting Chips	• Superconducting qubits (universal & annealing) • Topological qubits • Single photon detectors for photonic qubits	• Superconducting nanowire single photon detectors (SNSPDs) • SQUID magnetometers	• SNSPDs for QKD reception and networking
Photonic Systems	• Photonic qubits • Quantum interconnects • Control of trapped ion, neutral atom, diamond qubits	• Single photon detectors & quantum imaging • Control of atomic quantum sensors	• Satellite and fiber-based QKD networks • Optical QRNG • Quantum networking
Atomic Interferometry (Photonics)	• Trapped ion qubits • Neutral atom qubits	• Atomic clocks • OPMs • Atomic gyroscopes & accelerometers • Atomic gravimeters • Atomic RF sensors	
Nanomaterials & Diamond	• Diamond defect qubits • Quantum dot single photon sources for photonic qubits	• NV diamond magnetometers and gyroscopes	• Diamond defect quantum memory/repeaters • Quantum dot single photon sources for networking

1) Photonics is a key platform for quantum sensors

2) Atoms are key sensing media in photonic quantum systems

Identical by nature : No aging, no calibration drift, no device-to-device variability

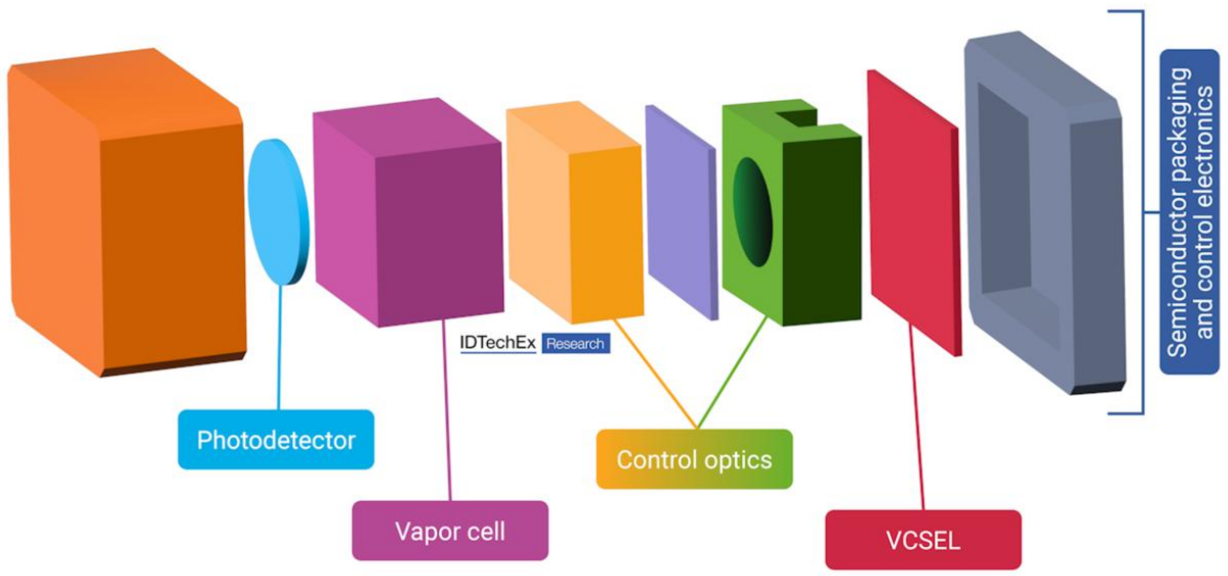
Discrete quantum states: External perturbations shift energy levels predictably

Universal reference: Sensor performance tied to fundamental constants

POSSIBLE READOUTS

- Time / frequency
- Magnetic fields
- Electric / RF fields
- Acceleration / rotation / gravity

Photonic quantum sensor architecture



- Laser sources for state preparation & readout
- Optical pumping and probing
- Photodetectors and optical filtering
- Integrated micro-optics

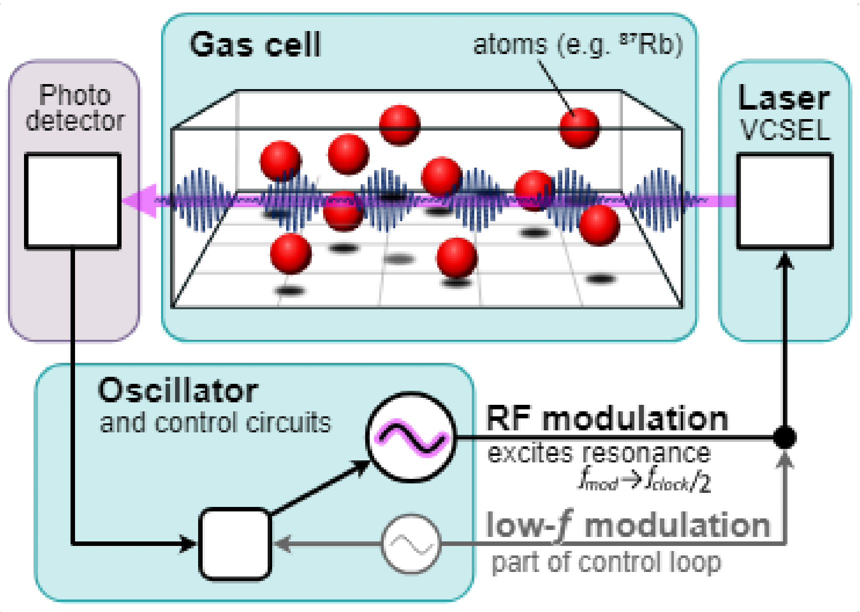
VAPOR CELL AT THE CORE

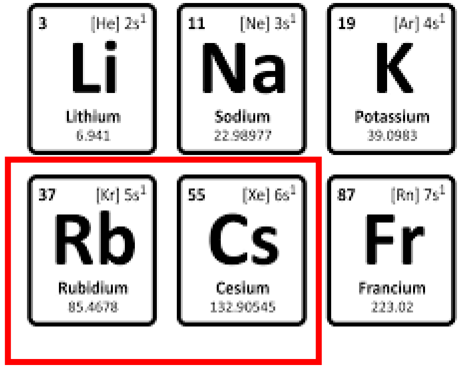
Structure
hollow sealed cavity made from glass or silicon-glass, allowing optical access for lasers to interact with the atomic vapor.

Filling
reference atomic vapor in a buffer gas

Size
Micro-Electro-Mechanical Systems (MEMS) fabrication technology allows for micro-fabricated vapor cells at wafer level

Vapor cell atomic clocks





Atomic clocks use CPT (Coherent Population Trapping) and hyperfine transitions in alkali atoms as frequency reference.

Cs-133 at 9.192 GHz ; Rb-87 at 6.834 GHz

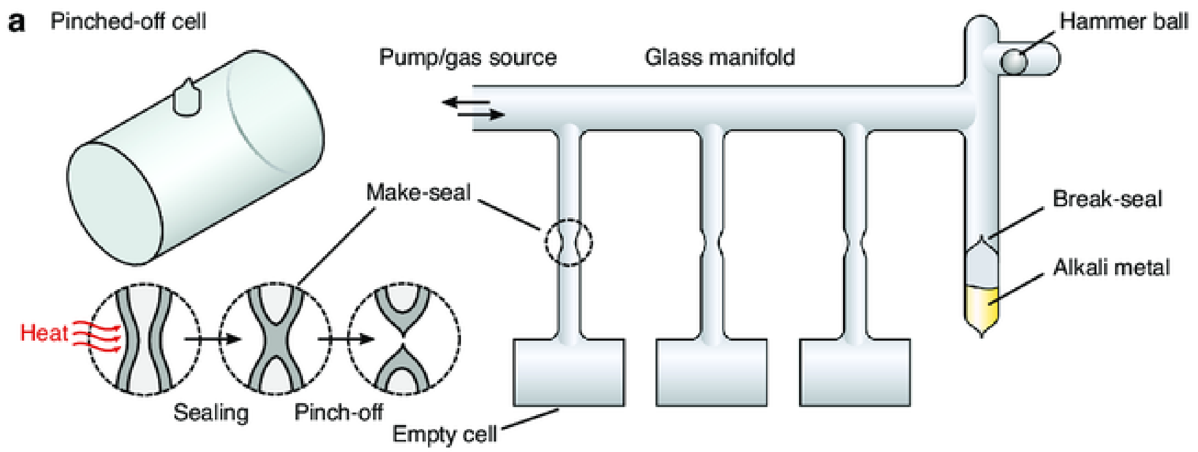
Operation loop:

1. RF oscillator modulates laser light
2. when the frequency matches the one between two energy levels in the atomic cloud, optical absorption reduces the photons detected
3. feedback loop from photodetector is used to tune oscillator

WHY ALKALI METALS

- Single valence electron → simple, strong optical transitions
- Convenient laser wavelengths (near-IR)
- Large hyperfine splitting → high readout signal-to-noise ratio (SNR)
- High vapor pressure at modest temperatures, enabling room-temperature operation

Vapor cells fabrication

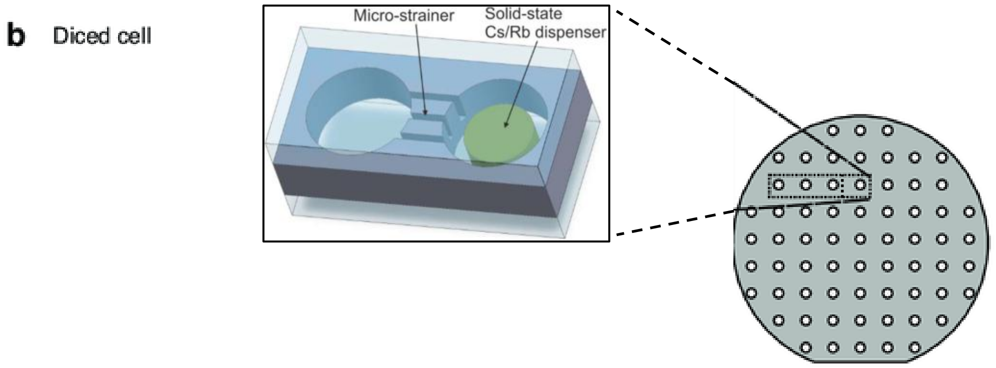


Pinched-off alkali vapor cells

•Traditional glass cells filled by diffusion of an alkali metal source from a reservoir appendix, and sealed by pinching a glass stem.

•Fabricated individually using glassblowing or semi-automated sealing equipment.

•Common in laboratory atomic clocks, magnetometers, and early commercial devices.



MEMS alkali vapor cells

•Microfabricated cells built with silicon or glass wafers and batch processing.

•Alkali introduced via micro-dispensed sources, solid dispensers, or vapor deposition.

•Sealed at wafer scale and diced into many tiny cells.

•High throughput, high reproducibility, high integration potential

→ challenge: dosing the right amount of alkali while ensuring cleanliness and impurity control

Images source: "Wafer-level vapor cells filled with laser-actuated hermetic seals for integrated atomic devices", Microsystems & Nanoengineering volume 8, Article number: 129 (2022)
"Technological Assessment of MEMS Alkali Vapor Cells for Atomic References" Micromachines 10, 25 (2019). doi:10.3390/mi10010025

Contaminant mitigation in MEMS vapor cell fabrication

Possible contamination sources:

FROM SOME TYPES OF ALKALI PRECURSORS

- Contaminants added by alkali procursor dosing process, some of them are also dangerous/toxic (e.g. azides, chlorides)
- Oxide byproducts (e.g. from metallic alkali sources)

→ **Process stability and purity of the alkali metal source is key**

FROM OTHER SOURCES

- Residual gases trapped during wafer anodic bonding
- Long-term outgassing effect after hermetic sealing sealing
- Buffer gas impurities

→ **Mitigation of residual gas contaminants is key**

Effects of contaminants:

- ➢ buffer gas pressure variation and presence of impurities may influence the CPT signals and optical trasparency;
- ➢ reactive impurities can also induce chemical degradation and instability in the vapor cell.

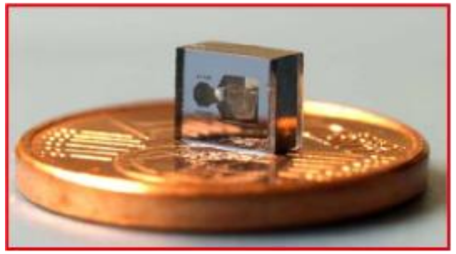
Alkali Metal dosing methods

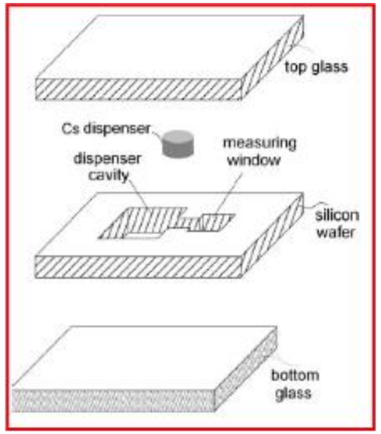
Method description	MEMS compatibility	Alkali Vapor Source	Activation mechanism	Internal Atmosphere Quality	Process Repeatibility
Pipetting of Pure Alkali Metal	Possible	Pure Alkali Metal	-	Good	Excellent (but not easy microdosing)
Hybrid Glassblowing and cell fabrication	None	Pure Alkali Metal	-	Good	Good (but not easy microdosing)
Alkali-wax mcropackets	Possible	Evaporation of Alkali Metal	Laser Ablation λ = 355nm	Poor	Good (but not easy microdosing)
Alkali compound in cell	Possible	Reaction between Ba azide and alkali chloride	Thermal, T = 200-300°C	Poor	Fairly Good
Alkali Metal by external compounds reaction	Possible	Reaction between Ba azide and alkali chloride	Thermal, T = 200-300°C	Fairly Good	Poor
Alkali azide in cell	Possible	Photolysis of alkali azide	Long UV activation (>8 hours)	Bad	Bad
Electrolytic A.M. release	Difficult	Electrolytic release from alkali metal enriched glass	Electrolytic 540°C, 700V	Poor	Fairly Good
Dispenser in Cell	**Possible**	**Solid-state dispenser (SAES AMD)**	**Heating of dispenser by NIR laser**	**Excellent**	**Excellent**

Sources: “Technological Assessment of MEMS Alkali Vapor Cells for Atomic References”, Micromachines 10, 25 (2019). doi:10.3390/mi10010025
“MEMS caesium vapour cell for european micro-atomic-clock”, Proc. Eurosensors XXIV, Linz, Austria, Volume 5, 721-724 (2010).
“Key Technologies in Developing Chip-Scale Hot Atomic Devices for Precision Quantum Metrology» Micromachines 15, 1095, (2024). https://doi.org/10.3390/mi15091095

Pure alkali sources in miniaturized devices

EU PROJECT: MAC-TFC (2008-2012)





Ref. New approach of fabrication and dispensing of micromachined cesium vapor cell, J. Micro/Nanolith. MEMS MOEMS 7 (3), 033013, (Jul–Sep 2008)

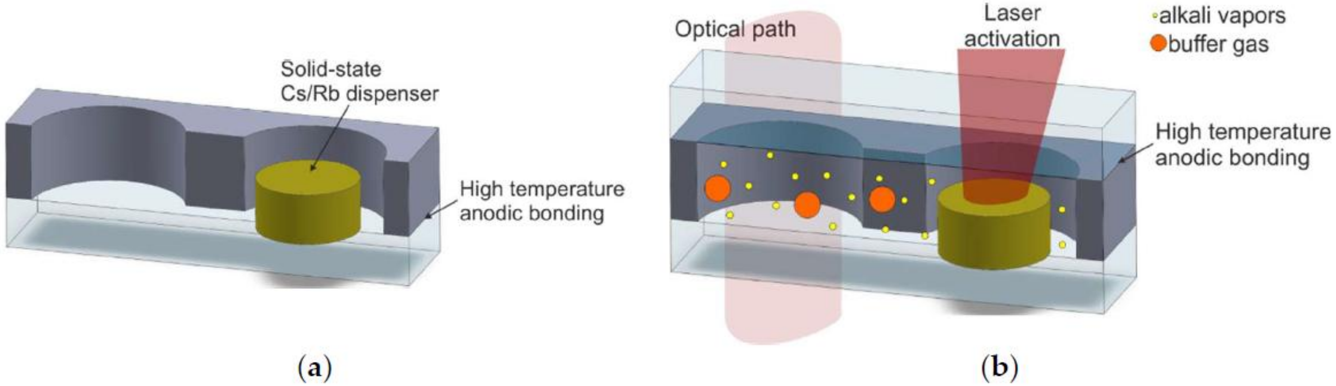


Figure 12. Cell fabrication utilizing solid-state dispenser: (**a**) silicon–glass preform with the dispenser, (**b**) laser-induced on-chip dispensing of alkali vapor.

Technological Assessment of MEMS Alkali Vapor Cells for Atomic References, Micromachines 2019, 10(1), 25

Thermally induced reaction

Me^{+} salt (solid) + getter ZrAl alloy (solid) $\rightarrow$ **$Me^{\uparrow}$** (gas) + mixed oxides (solid)

Me **:** Cs, Rb, K, Na, Li

The ZrAl alloy is in excess to assure an extra-getter action

Evaporation promoted by laser irradiation at T>400°C after bonding

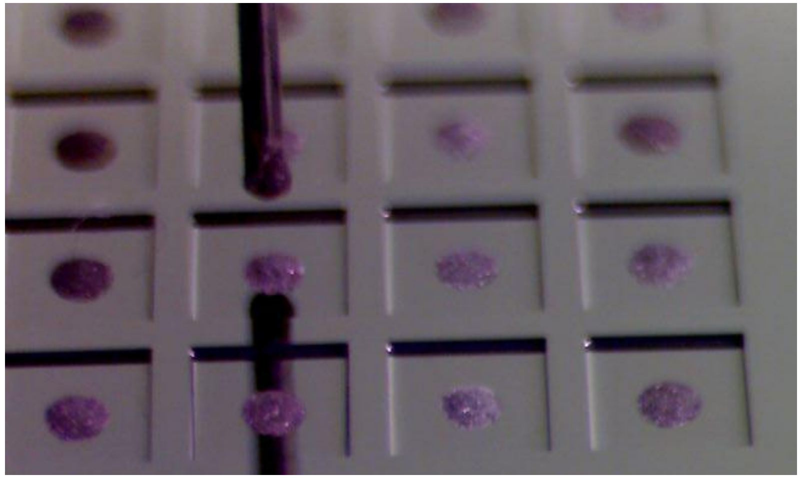
Pure alkali sources in miniaturized devices

CURRENTLY AVAILABLE

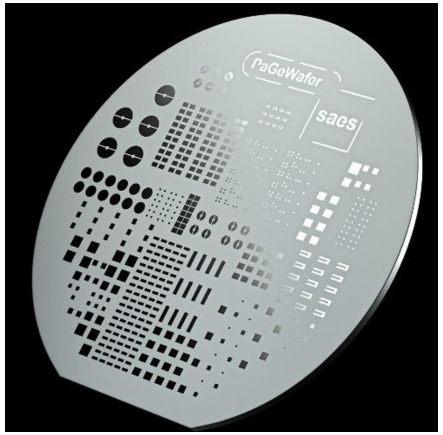
- Type of alkali: Rb, Cs, K
- Isotope purity: natural abundance
- Format: solid pill made of pressed powder
- Minimum size: diameter 1 mm; height 0.6 mm
- Wafer filling mode: pick & place

RESEARCH & DEVELOPMENT

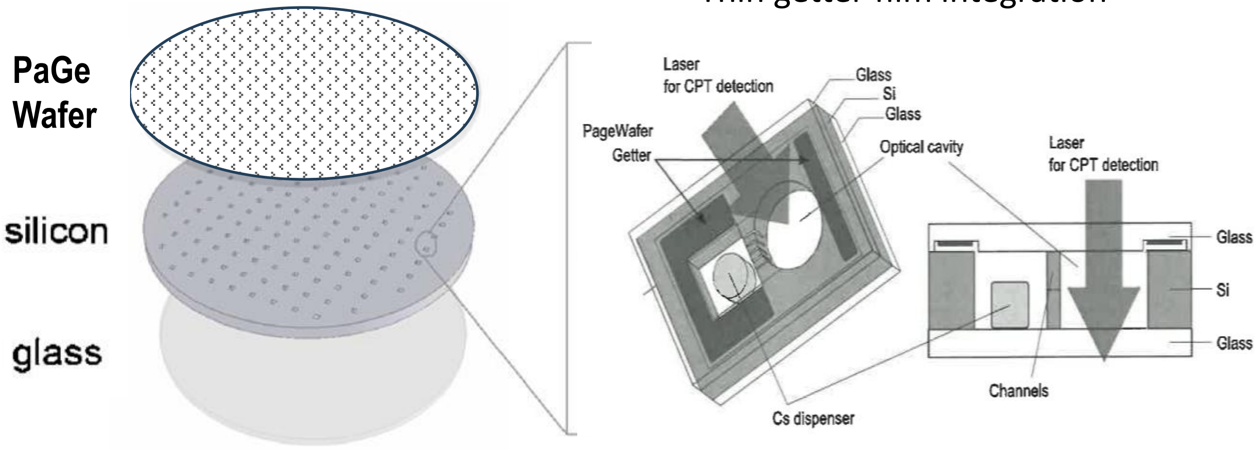
- Micro-dosing techniques to decrease AMD footprint (smaller vapor cells)
- Pure isotopes (e.g. 87-Rb)
- Sr dispenser



Getter film in wafer-packaged vapor cells



Thin getter film integration



Effects of getters on hermetically sealed micromachined cesium–neon cells for atomic clocks

April 2013 - Journal of Micromechanics and Microengineering· 23(5):055022

- The Wafer-level integration of PageWafer® has been studied in hermetically sealed miniature glass-Si-glass cells filled with Cs and Ne
- Quadruple Mass Spectroscopy showed that the residual gases (H_2, O_2, N_2 and CO_2) attributed to anodic bonding process can be drastically reduced by the getter films while Ne remains unaffected.
- CPT (Coherent Population Trapping) signals measured on getter-integrated cells were stable and similar to each other within a cell batch, suggesting a good potential of application of this getter film in wafer-level sealed MEMS devices

Results of RGAs on cells without /with Getter Film

	Residual gas pressure (mbar)	
	Cell A (Getter-free)	Cell B (Getter-integrated)
H_2	2.76×10^{-2}	0.00
He	3.71×10^{-3}	1.63×10^{-3}
CO	0.00	0.00
N_2	8.12×10^{-2}	0.00
CH_4	4.45×10^{-3}	2.79×10^{-2}
H_2O	0.00	0.00
Ne	1.40×10^{2}	1.42×10^{2}
O_2	8.09×10^{-1}	0.00
C_2H_6	0.00	5.28×10^{-3}
C_3H_8	7.62×10^{-3}	2.12×10^{-2}
Ar	7.28×10^{-3}	0.00
CO_2	1.33	0.00

[a] Cells were filled with Ne (set pressure: 133 mbar).

Conclusions

- Alkali vapors are a cornerstone of quantum sensing
- Photonics provides control, readout, and integration
- Miniaturization amplifies the importance of materials purity and mitigation of contaminants
- SAES pure alkali metal sources and thin film getters are a cross-cutting enabling technology

THANK YOU! LET'S CONNECT TO DISCUSS:

> Collaborations on next-generation quantum sensors

> Fabrication and integration challenges

> EU or national funded projects fostering material innovation for quantum sensors

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Thank you

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