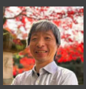
ALKALI METAL VAPOR CELLS FILLED WITH MICROFABRICATED ON-CHIP DISPENSING COMPONENT



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CORE TECHNOLOGY

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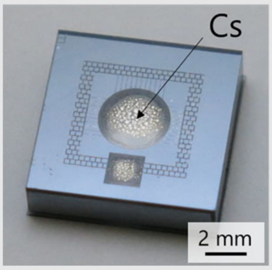
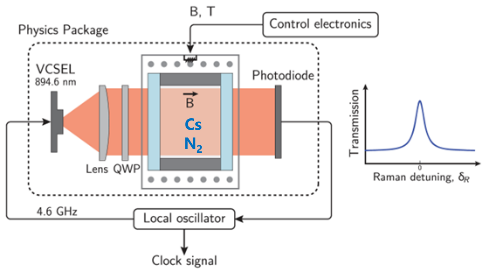
Wafer-level **fabrication of atomic clock's vapor cells** filled with alkali metal

1. Vapor cell structure utilizes a single-mask process with typical **wafer-level Silicon (Si) fabrication**
2. Microfabricated Si grooves with multiple re-entrant structures are used for **efficient (e.g., short time, low temperature) Cs production** from cesium azide (CsN_3)
3. Cs is filled into a cell by thermal heating at 330 °C for 10 min, and **the stability of the Cesium (Cs) atomic density** with the optical measurements has been confirmed over a period of 2 years



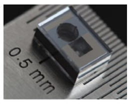
INTRODUCTION

Commercially available atomic clock (https://www.microchip.com/)

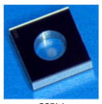


Making progress on miniaturized atomic clocks for future applications

- **New applications and technologies**: 6G (Beyond 5G) networks and GPS alternatives will require precise timekeeping on portable platforms, driving a demand for miniaturized atomic clocks with a low-cost and high performance
- **Key component**: Microfabricated vapor cells contain alkali metal and buffer gas and are typically fabricated by sandwiching the Si wafer between two glasses



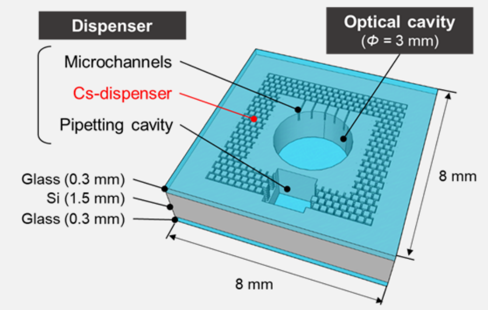
FEMTO-ST (France)



CSEM (Switzerland)

→Don't you need a low-cost, mass production manufacturing technology?

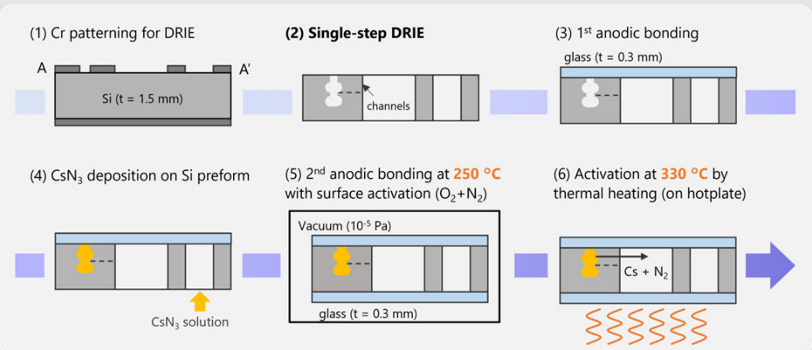
Solution: New vapor cell design

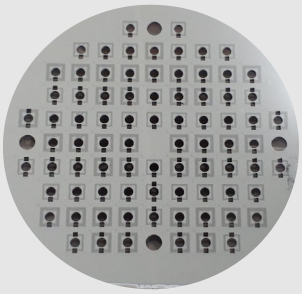


- Cs-dispenser : Microstructure to decompose CsN_3
- Pipetting cavity : Trough hole for pipetting CsN_3 solution
- Microchannels : Filling Cs vapor and N_2 into the optical cavity
- Optical cavity : Optical path for CPT resonance

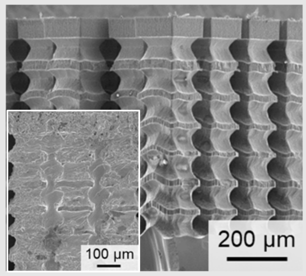
FABRICATION PROCESS

PCT/JP2021/039690





Sample: 4-inch wafer



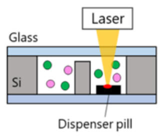
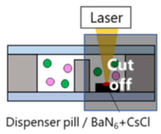
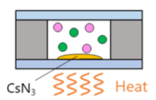
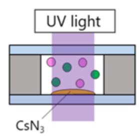
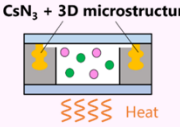
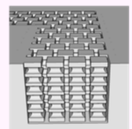
Microstructures to decompose CsN_3 by heating process (Inset: after the CsN_3 deposition process)

A) Wafer-level process: Suitable for the vapor cell manufacturing

- All equipment and process are general Si fabrication for micro-structuring applications
- Si structures in the cell are fabricated by the one-step Si-dry etching process
- Cs production process is only by thermal heating

B) Low temperature and Short time process

- CsN_3 is successfully decomposed when the cells are activated by heating at 330 °C for 10 min
- Micro-size re-entrant structures promote thermal decomposition and enable effective Cs production at low temperatures
- Use of a Si structure for Cs dispensing and a low-temperature bonding process can reduce oxygen (O_2) and water (H_2O) preventing Cs oxidation

Cs source	Cesium dispenser (Cs_2CrO_4/Zr/Al)		Cesium azide (CsN_3)			
Method	Laser activation		Heating on glass	UV irradiation	Heating w/ 3D Si microstructures	
Research group ● Cs ● Buffer gas	FEMTO-ST[1] 	NIST[2], FEMTO-ST[3] 	CSEM[4] 	NIST[5] 	**Kyoto Univ.** CsN_3 + 3D microstructure 	
Typical size	6 mm × 4 mm	3.7 mm × 3.7 mm	4 mm × 4 mm	4 mm × 4 mm	8 mm × 8 mm	[On-going] 4 mm × 4 mm
Cs production efficiency	several sec/cell	several sec/cell	> 650 °C	> 24 hours	330 °C, 10 min. (wafer-level process)	
Yield	+	+			++	
Frequency stability	+	+		++	++ (Expected)	

[1] M. Hasegawa et al., J. Micromech. Microeng. 23, 055022 (2013)
[2] D. G. Bopp et al., J. Phys. Photonics 3, 015002 (2021)
[3] V. Maurice et al., IEEE IFCS-EFTF (Apr. 2022), 5121
[4] T. Overstolz et al., IEEE MEMS (Jan. 2014), pp.552-555
[5] L. Liew et al., Appl. Phys. Lett. 84, 2694 (2004)

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