Press Release

New MEMS Atomic Cell Platform Accelerates Design Optimization for Chip-Scale Atomic Clocks

- Inkjet-based control of cell gas pressure demonstrated in a wafer-level manufacturing process -

[Highlights]

- Developed an inkjet-based fabrication technology for chip-scale atomic clocks and established a high-precision manufacturing process for MEMS atomic cells
- Demonstrated stable and highly accurate control of atomic-cell gas pressure while maintaining wafer-level manufacturability
- Established a platform that accelerates the design and optimization of atomic cells for chip-scale atomic clocks

The National Institute of Information and Communications Technology (NICT, President: OHNO Hideo, Ph.D.), Kyoto University (President: TACHIKAWA Yasuto), Tokyo Metropolitan University (President: OHASHI Takaya), TOYOBO MC Corporation (President and CEO: FUJII Naoki), and NEOARK Corporation (President: HATANO Satoshi) have jointly established a new MEMS rubidium vapor-cell manufacturing platform that accelerates the design and optimization of atomic cells for chip-scale atomic clocks*1.

In this technology, microparticles of rubidium azide (RbN_3), a precursor material that generates rubidium atoms and nitrogen gas during heat treatment, are deposited onto glass wafers with high precision using an inkjet-based process*2. By precisely controlling the amount of deposited RbN_3, the researchers successfully achieved both wafer-level mass manufacturability and precise control of the nitrogen pressure inside the vapor cells. As a result, they demonstrated highly accurate and reproducible control of the amount of nitrogen gas generated within the cells.

Furthermore, this platform enables the efficient fabrication of MEMS vapor cells with different nitrogen pressures. By evaluating the coherent population trapping (CPT) resonance*3 characteristics used in chip-scale atomic clocks, the researchers identified the nitrogen-pressure conditions that maximize clock performance and demonstrated that these conditions can be systematically optimized within a wafer-level manufacturing process.

[Background]

Chip-scale atomic clocks are expected to find applications in a wide range of fields that support modern social infrastructure, including backup timing sources for Global Navigation Satellite Systems (GNSS), time synchronization in communication networks, satellite-borne equipment, autonomous vehicles, and various sensor systems.



Figure 1. The Fabricated atomic-clock vapor cell is shown with a black soybean for scale.

The high performance required for these applications is known to depend strongly on the pressure and composition of the gases contained within the microfabricated vapor cell that encloses rubidium atoms. Therefore, optimization of the cell environment is essential for achieving higher clock performance.

However, with conventional MEMS vapor-cell fabrication technologies, it has been difficult to precisely control the internal cell conditions while maintaining wafer-level manufacturability, creating a major barrier to

efficiently identifying optimal operating conditions for improved performance.

[Achievements]

The research team focused on rubidium azide (RbN_3), which generates rubidium atoms and nitrogen gas upon heat treatment. In the technology developed in this study, RbN_3 is deposited onto glass wafers using an inkjet-printing process, enabling precise control of the amount of nitrogen gas generated inside each vapor cell. Figure 1 shows an example of a miniature vapor cell fabricated using this technology.

Using this approach, MEMS vapor cells containing different amounts of deposited RbN_3 can be fabricated simultaneously at the wafer level (see Figure 2). Analysis of the nitrogen partial pressure based on measurements of the coherent population trapping (CPT) resonance revealed an excellent linear relationship between the amount of deposited RbN_3 and the nitrogen partial pressure, as shown in Figure 3. These results demonstrate that the cell pressure can be controlled with high accuracy and reproducibility.

This achievement makes it possible to control the nitrogen partial pressure inside MEMS vapor cells at the wafer level as designed, whereas previously it could only be evaluated after fabrication. This represents the establishment of a manufacturing platform that enables efficient optimization of cell pressure while maintaining wafer-level mass manufacturability. Looking ahead, the technology is expected to accelerate the development of high-performance MEMS vapor cells for chip-scale atomic clocks and contribute to the advancement of key technologies supporting next-generation space-time synchronization infrastructure.

[Future Prospects]

In addition to enabling highly precise control of the internal cell pressure, the manufacturing technology developed in this study is distinguished by its compatibility with wafer-level mass production processes.

By further optimizing cell structures and fabrication conditions using this platform, we aim to accelerate the development of high-performance atomic vapor cells for next-generation chip-scale atomic clocks.

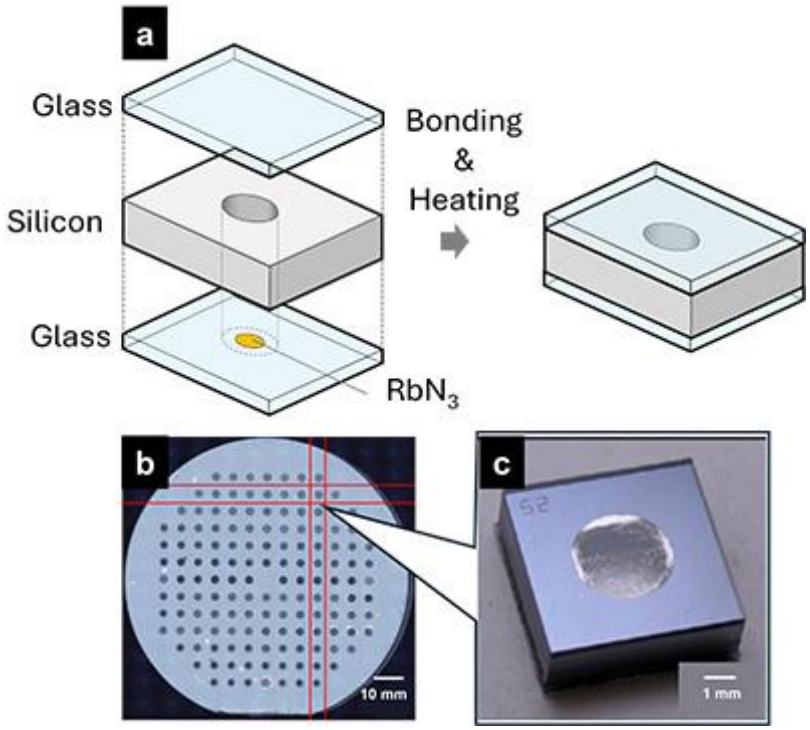


Figure 2. Vapor-cell fabrication technology: (a) The vapor cell is fabricated by bonding a silicon spacer with etched cavities between two glass wafers that allow laser transmission. After bonding, the solid-source material RbN_3 is thermally decomposed to generate rubidium vapor and nitrogen gas inside the cell. (b) This fabrication approach is compatible with wafer-level mass production. (c) The final vapor cells are obtained by dicing the fabricated wafer into individual chips, in the same manner as semiconductor-device manufacturing.

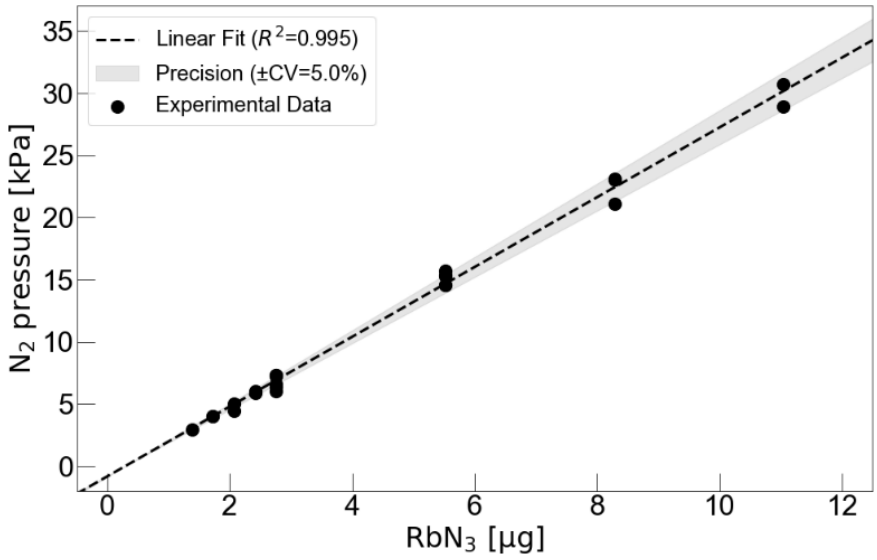


Figure 3. Precise control of the deposited amount of RbN_3 is achieved using the developed fabrication platform, enabling accurate control of the N_2 generated upon thermal decomposition. A strong linear relationship is observed between the amount of deposited RbN_3 and the resulting nitrogen partial pressure within the vapor cell.

[Publication Information]

Authors: Shun Kiyose, Masahiro Fukuoka, Yusuke Odagiri, Satoshi Hatano, Shigeyoshi Goka, Motoaki Hara, and Yoshikazu Hirai

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This result was obtained as part of the Ministry of Internal Affairs and Communications (MIC), Japan, R&D project “Research and Development for Expansion of Radio Wave Resources,” under the project “Research and Development of a High-Precision Time Synchronization Platform for Efficient Utilization of Frequency Resources” (Project Number: JPJ000254; Principal Investigator: Motoaki Hara, National Institute of Information and Communications Technology (NICT)).

< Roles of each organization >

-NICT: Overall leadership and coordination of the development of miniature atomic clocks and the associated MEMS gas cell research and development

-Kyoto University:

Design and fabrication of MEMS gas cells

-Tokyo Metropolitan University:

Analysis and evaluation of atomic resonance characteristics

-TOYOBO MC Corporation:

Synthesis of RbN_3 materials and development of high-precision patterning technology

-NEOARK Corporation:

Development of atomic resonance measurement systems and support for measurement activities

< Related Press Release >

January 23, 2018

National Institute of Information and Communications Technology (NICT)

Tohoku University

Tokyo Institute of Technology

A New Architecture for Miniaturization of Atomic Clocks Exploiting a Piezoelectric-Thin-Film Vibration- From a rack-mount system toward a microchip -

https://www.nict.go.jp/en/press/2018/01/23-1.html

< Glossary >

*1 Atomic clock

A clock that generates time and frequency references based on the intrinsic resonance frequency of atoms. Atomic clocks provide exceptionally high accuracy and long-term stability and are widely used in time synchronization for communication networks, Global Navigation Satellite Systems (GNSS), and space applications. In a miniature atomic clock, as illustrated in Figure 4, an ultra-stable clock signal is generated by locking an external microwave oscillator to the coherent population trapping (CPT) resonance of rubidium atoms.

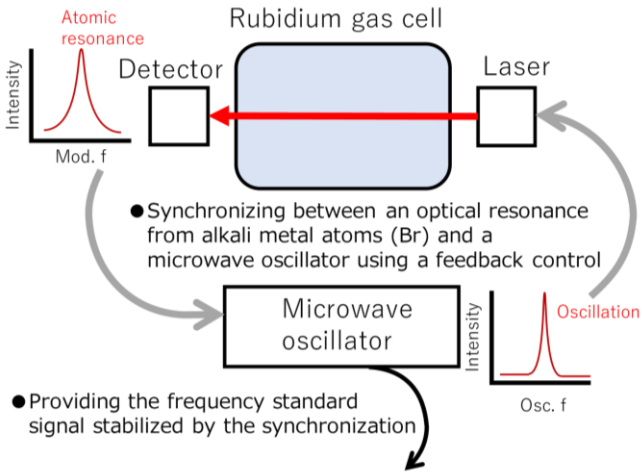


Figure 4. Conceptual diagram of an atomic clock

*2 Inkjet Printing

A technique in which droplets are ejected from microscopic nozzles to deposit materials at desired locations on a substrate. It operates on the same principle as a conventional inkjet printer. In this study, the technique is used to precisely deposit RbN_3 (rubidium azide), which serves as the rubidium source, onto a glass wafer. Figure 5 shows an example of the resulting pattern.

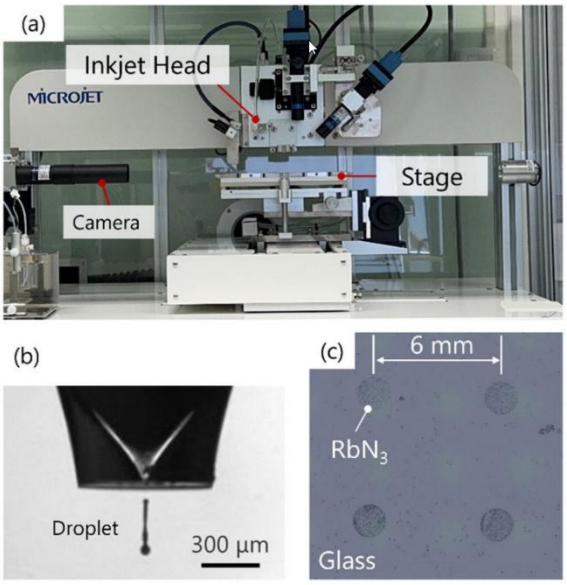


Figure 5. Inkjet printing system and formation of RbN_3 patterns: (a) the custom-developed inkjet printing system, (b) image of droplet ejection during printing, and (c) an example of an RbN_3 pattern formed by inkjet printing

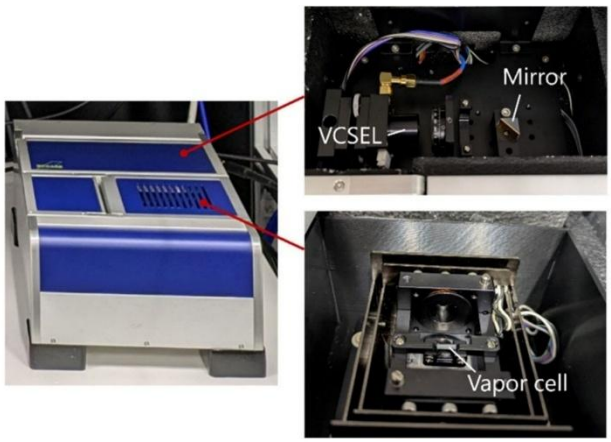


Figure 6. Packaged CPT resonance measurement system: The system enables the evaluation of atomic clock operation through feedback control.

*3 CPT resonance

Coherent population trapping (CPT) resonance is a quantum resonance phenomenon that arises from the interaction between two laser fields and atoms. Under specific conditions, CPT resonance creates a non-absorbing atomic state, known as a dark state, in which the atoms no longer absorb light. As a result, an extremely narrow resonance is observed. Because the resonance frequency corresponds to an intrinsic atomic frequency, CPT resonance serves as a highly accurate frequency reference for miniature atomic clocks. Although the CPT resonance signal obtained from a MEMS gas cell is extremely weak, as part of the development of our technology platform, we have also successfully developed a packaged CPT resonance measurement system, as shown in Figure 6.