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(54) METHOD FOR FILLING, ON WAFER, CHIP-LEVEL ATOMIC CLOCK ABSORPTION BUBBLES WITH HIGH-PURITY ALKALI METAL

(57) A method for filling, on a wafer, chip-level atomic clock absorption bubbles with a high-purity alkali metal. The method comprises: 1) forming a micro groove (102), an absorption bubble cavity groove and an accommodation cavity groove in a silicon wafer (101); 2) sealing an alkali metal compound (106) in an accommodation cavity (103) in the center of the wafer, and forming a vacuum environment in the wafer comprising a temporary flowing micro channel, an absorption bubble cavity and the alkali metal accommodation cavity (103); 3) implementing decomposition of the alkali metal compound to generate a rubidium or cesium metal in a needed amount, and vaporizing and volatilizing the metal; 4) solidifying and coagulating the gaseous alkali metal in the absorption bubble cavity (104); and 5) bending a glass sheet under the action of electrostatic force, eliminating the precast temporary flowing micro channel (108), and simultaneously sealing all absorption bubbles. By means of the method, the problems of high filling difficulty, complex process and the like caused by extremely high probability of oxidization of an alkali metal are solved, reaction impurities probably left in the absorption bubbles are eliminated, and all the absorption bubbles on the alkali metal wafer are filled at a time, and the method can be used for mass production of chip-level atomic clock bubbles.

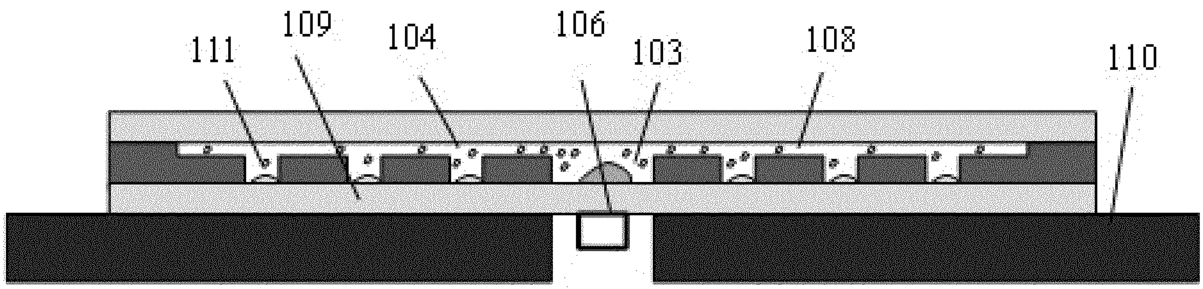

FIG. 1c

Description

FIELD OF THE INVENTION

[0001] The present invention relates to a method for filling wafer-based chip-scale atomic clock absorption cells with a high-purity alkali metal.

BACKGROUND OF THE INVENTION

[0002] All our daily life, scientific research, navigation, surveying and mapping and other work can't be separated from time. Time measurement relates to two quantities-epochs and time intervals. Any natural phenomena with periodical changes can be used to measure time. As timing instruments have also constantly developed with humans' progress over 3,500 years, people's demand for timing accuracy is becoming higher and higher. As for timing instruments, people developed sundials which take advantage of the periodic change law of earth rotation to identify time changes, then sand clocks, astronomical clock towers, mechanical pendulum clocks, quartz clocks, atomic clocks and optical clocks. It is clear that all of them use the natural phenomena with periodic changes to measure time.

[0003] As one of the most accurate timing instruments at present, the theory of the atomic clocks was first put forward in the 1930s and then the atomic clocks were produced. Gradually, more and more atomic clocks have been used in national defense and scientific research. In recent years, miniature chip-scale atomic clocks produced by using MEMS (Micro-Electro-Mechanical Systems) technology have begun to develop. The development of clocks will make breakthroughs in receivers' clock performance, be more widely applied to timing frequency standards of all kinds and have a revolutionary social impact.

[0004] An atomic clock is an instrument which realizes accurate time measurement by using atomic transition radiation frequency between hyperfine energy levels in the atomic ground state. The miniature atomic clock based on the CPT (Coherent Population Trapping) phenomenon is an inexorable development trend of atomic clock miniaturization. And the miniaturization of its core chip alkalis metal vapor cavity plays a critical role in the miniaturization of the atomic clock.

[0005] At present, the technical methods for filling micro absorption cells with an alkali metal can mainly be divided into two categories. One category is to directly inject a pure alkali metal (such as rubidium and cesium) into the absorption cell. This category needs an sophisticated large vacuum equipment and a strict vacuum environment. A trace of residual oxygen in the cavity may lead to the oxidization of the alkali metal and then reduce the service life of the atomic clocks. The second category is to directly inject alkali metal compounds into the absorption cell cavity to produce the corresponding alkali metal through chemical reactions. This category needs to strictly control the amount of the compounds which are injected into the absorption cell while the residual impurities of the reactions may remain in the absorption cell and then affect the atomic clock performance. In addition, the two categories share the same disadvantage: absorption cells need to be filled one by one so it is difficult to realize production on a large scale.

SUMMARY OF THE INVENTION

[0006] The present invention puts forward a method for filling wafer-based chip-scale atomic clock absorption cells with a high-purity alkali metal. The present invention aims at overcoming the problem of the prior art that alkali metals are extremely prone to oxidization during the production of atomic clock absorption cells. Through the method of wafer level filling and partial reactions, the present invention realizes the filling of all absorption cells on the wafer at the same time to meet the demand for large-scale production of atomic clocks. The present invention is characterized by low cost and high efficiency.

[0007] The technical solution to the present invention: a method for filling wafer-based chip-scale atomic clock absorption cells with a high-purity alkali metal. The present invention is characterized in that the method comprises the following process steps:

(1) using the MEMS ICP etching technique to form micro grooves, absorption cell cavity grooves and placement cavity grooves on the silicon wafer;

(2) using the three-layer wafer level anodic bonding technique to form prefabricated temporary micro flow channels, absorption cell cavities and placement cavities, and sealing the placement cavities at the center of the wafer after putting the alkali metal compound into the placement cavities;

(3) controlling the chemical reaction intensity of the alkali metal compounds by separately adjusting the temperature of the placement cavities to realize the decomposition of the alkali metal compounds to produce a needed amount of rubidium or cesium and make rubidium or cesium vaporize;

(4) passing the prefabricated temporary micro flow channel and cooling part of the absorption cell cavity to make alkali metal gas congeal in the absorption cell cavities; and

(5) reusing the three-layer wafer level anodic bonding technique to make the sheet glass bend under the influence of electrostatic force to eliminate the prefabricated temporary micro flow channels and seal all the absorption cells at the same time.

[0008] The invention has the advantages of easy processes and rapid, low-cost, large-scale production of atomic clock alkali metal absorption cells.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]

FIG. 1 a is a schematic representation of using the MEMS ICP etching technique to form micro grooves 102, alkali metal placement cavity grooves 103 and absorption cell cavity grooves 104 on the double-side polished silicon wafer 101.

FIG. 1b is a schematic representation of using the three-layer wafer level anodic bonding technique to form prefabricated temporary micro flow channels 108, absorption cell cavities 104 and alkali metal placement cavities 103.

FIG. 1c is a schematic representation of making the alkali metal compound decompose by adjusting the temperature of the alkalis metal placement cavities 103 to produce alkali metal gas which passes through the prefabricated temporary micro flow channel and cooling part of the absorption cell cavity to make the alkali metal gas congeal in the absorption cell cavities.

FIG. 1d is a schematic representation of sealing all the alkali metal absorption cell cavities.

FIG. 2 is a schematic representation of a single alkali metal absorption cell of an atomic clock.

[0010] In the drawings, the following reference numbers are used: 101. double-side polished silicon wafers; 102. shallow micro grooves; 103. alkali metal compound placement cavities; 104. alkali metal absorption cell cavities; 105. sheet glass A; 106. alkali metal compounds; 107. sheet glass B; 108. temporary micro flow channels; 109. alkali metal vapor; 110. equipment for partial cooling; 111. high-purity solid alkali metal; 201. high-purity alkali metal; 202. silicon alkali metal absorption cell cavities; 203. upper-layer glass; and 204. lower-layer glass.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0011] A method for filling wafer-based chip-scale atomic clock absorption cells with a high-purity alkali metal is characterized in that the method comprises the following process steps:

(1) using the MEMS ICP etching technique to form micro grooves, absorption cell cavity grooves and placement cavity grooves on the silicon wafer;

(2) using the three-layer wafer level anodic bonding technique to form prefabricated temporary micro flow channels, absorption cell cavities and placement cavities, and sealing the placement cavities at the center of the wafer after putting the alkali metal compound into the placement cavities;

(3) controlling the chemical reaction intensity of the alkali metal compound by separately adjusting the temperature of the placement cavities to realize the decomposition of the alkali metal compound to produce a needed amount of rubidium or cesium and make rubidium or cesium vaporize;

(4) passing the prefabricated temporary micro flow channel and cooling part of the absorption cell cavity to make alkali metal gas congeal in the absorption cell cavities; and

(5) reusing the three-layer wafer level anodic bonding technique to make the sheet glass bend under the influence of electrostatic force to eliminate the prefabricated temporary micro flow channels and seal all the absorption cells at the same time.

[0012] The glass-silicon-glass three-layer wafer level anodic bonding technique is carried out in two steps: the first step is to form temporary micro flow channels for alkali metal vapor; and the second step is to reuse the anodic bonding technique to realize the sealing of the alkali metal compound.

[0013] Make the alkali metal compound in the placement cavities react chemically by separately adjusting the temperature of the placement cavities to produce high-purity alkali metal through decomposition. The intensity of decomposition reactions can be controlled by adjusting the temperature of the alkali metal placement cavities.

[0014] The flow channel of the alkali metal vapor is that the alkali metal vapor diffuses into the absorption cell through silicon-glass temporary micro flow channel and congeals in the absorption cell through partial cooling.

[0015] Make the silicon wafer with the temporary micro flow channels re-bond with the sheet glass. During the re-bonding process, increase pressure or voltage to make the sheet glass bend under the influence of electrostatic force to eliminate prefabricated temporary micro channels and realize the sealing of all alkali metal absorption cell cavities.

EMBODIMENTS

[0016] Carve a shallow micro groove 102 which is 1-2 μm in depth and 80-90 mm in diameter on one side of a 4-cun double-side polished silicon wafer 101, and an alkali metal compound placement cavity 103 which is 20 mm in diameter at the center of the double-side polished silicon wafer 101. Carve an array of alkali metal absorption cell cavities 104 in square which is 2 mm in length within the scope of the shallow micro groove 102 on the double-side polished silicon wafer 101. The alkali metal compound placement cavity 103 and the alkali metal absorption cell cavity 104 both have a through-hole structure, running through the double-side polished silicon wafer 101, as shown in FIG. 1a.

[0017] Bond the side of the double-side polished silicon wafer 101 without the shallow micro groove 102 with a sheet glass A 105 through the silicon-glass wafer level anodic bonding. Put a well-computed amount of alkali metal compound 106 in the alkali metal compound cavity 103, and bond the side of the double-side polished silicon wafer 101 with the shallow micro groove 102 with a sheet glass B 107 through the silicon-glass wafer level anodic bonding. The shallow micro groove 102 and the sheet glass B 107 constitute the micro flow channel of the alkali metal vapor together to form a small vacuum environment, as shown in FIG. 1 b.

[0018] Separately adjust the temperature of the alkali metal compound placement cavity 103 by a reaction device to make the alkali metal compound 106 decompose to separate out alkali metal vapor 109. The alkali metal vapor 109 diffuses in the whole cavity including the alkali metal absorption cell cavity 104 through the temporary micro flow channel 108. An equipment for partial cooling 110 can adjust the temperature of the double-side polished silicon wafer 101 excluding the alkali metal compound placement cavity 103. The alkali metal vapor 109 congeals at the bottom of the alkali metal absorption cell cavity 104 to become a high-purity solid alkali metal 111 used to fill the alkali metal absorption cell cavity 104, as shown in FIG. 1c.

[0019] Re-bond the double-side polished silicon wafer 101 with the sheet glass B 107 through the silicon-glass wafer level anodic bonding. During the bonding process, increase pressure (1800 mbar-2000 mbar) or voltage (-800 V- -1000 V) to make the sheet glass B 107 bend under the influence of electrostatic force to eliminate the prefabricated temporary micro flow channel 108 and realize the sealing of all the alkali metal absorption cell cavities 104, as shown in FIG. 1d.

[0020] As shown in FIGS. 1a to 1d, the atomic clock alkali metal absorption cells made by the wafer level technique can be cut into individual atomic clock alkali metal absorption cells by slicing the wafer. As shown in FIG. 2, a high-purity alkali metal 201 is placed in a silicon alkali metal absorption cell cavity 202 which is sealed by an upper-layer glass 203 and a lower glass 204.

Claims

1. A method for filling wafer-based chip-scale atomic clock absorption cells with a high-purity alkali metal, **characterized in that** the method comprises the following process steps:

   (1) using a MEMS ICP etching technique to form micro grooves, absorption cell cavity grooves and placement cavity grooves on a silicon wafer;

   (2) using a three-layer wafer level anodic bonding technique to form prefabricated temporary micro flow channels, absorption cell cavities and placement cavities, and sealing the placement cavities at the center of the wafer after putting alkali metal compound into the placement cavities;

   (3) controlling the chemical reaction intensity of the alkali metal compound by separately adjusting the temperature of the placement cavities to realize the decomposition of the alkali metal compound to produce a needed amount of rubidium or cesium and make rubidium or cesium vaporize;

   (4) passing the prefabricated temporary micro flow channel and cooling part of the absorption cell cavity to make alkali metal gas congeal in the absorption cell cavities; and

   (5) reusing the three-layer wafer level anodic bonding technique to make a sheet glass bend under the influence of electrostatic force to eliminate the prefabricated temporary micro flow channel and seal all absorption cells at the same time.

2. The method of claim 1, **characterized in that** a glass-silicon-glass three-layer wafer level anodic bonding technique is carried out in two steps: the first step is to form temporary micro flow channels for alkali metal vapor; and the second step is to reuse the anodic bonding technique to realize the sealing of the alkali metal compound.

3. The method of claim 1, **characterized in that** the alkali metal compound in the placement cavities react chemically by separately adjusting the temperature of the placement cavities to produce high-purity alkali metal through decomposition and the intensity of decomposition reactions can be controlled by adjusting the temperature of alkali metal placement cavities.

4. The method of claim 1, **characterized in that** flow channel of the alkali metal vapor is that the alkali metal vapor diffuses into the absorption cell through silicon-glass temporary micro flow channel and congeals in the absorption cell through partial cooling.

5. The method of claim 1, **characterized in that**: the silicon wafer with the temporary micro flow channels is re-bonded with the sheet glass by reusing the wafer level anodic bonding technique; during the bonding process, pressure or voltage is increased to make the sheet glass bend under the influence of electrostatic force to eliminate the prefabricated temporary micro flow channel and realize the sealing of all alkali metal absorption cell cavities.

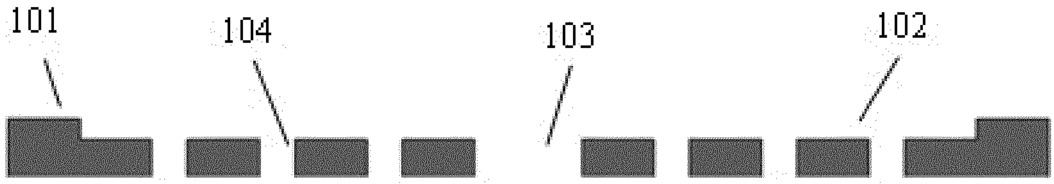

FIG. 1a

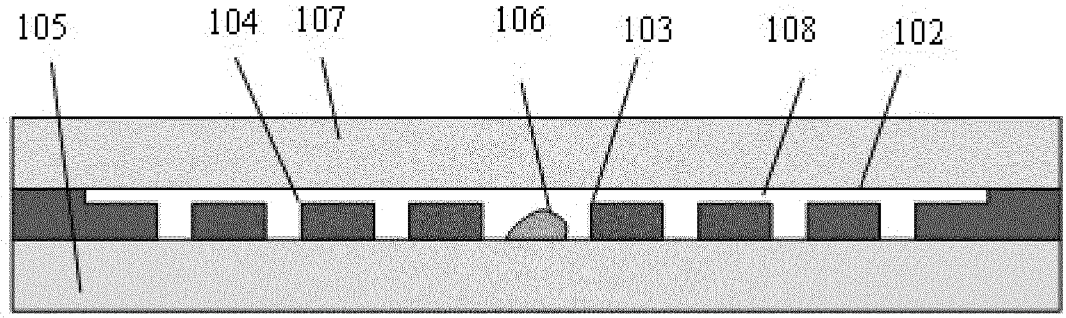

FIG. 1b

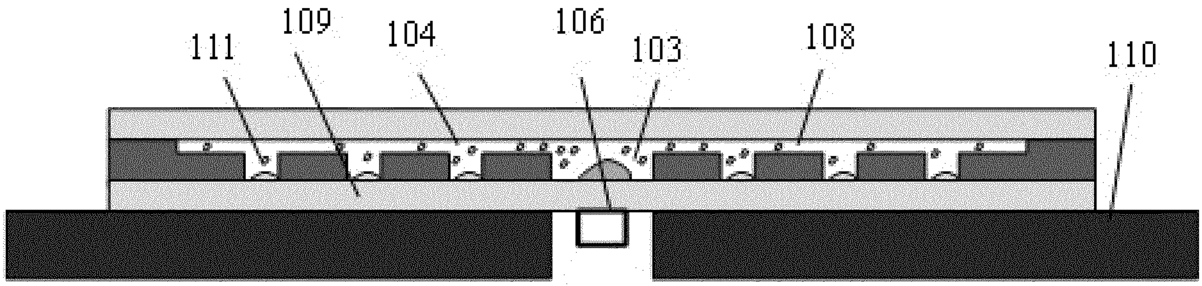

FIG. 1c

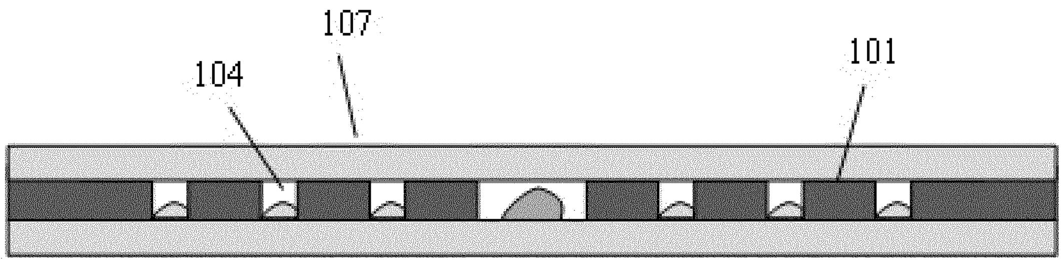

FIG. 1d

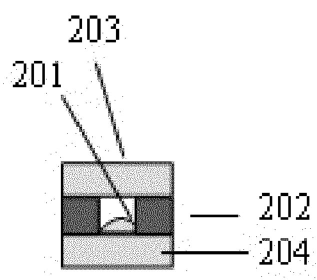

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2014/000816

A. CLASSIFICATION OF SUBJECT MATTER

B81C 1/00 (2006.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B81C; B81B; B82B; G04F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPI, CNPAT, CNKI: atomic, clock, mems, CPT, coherent, population, trapping, cavity, alkali, vapor, cell

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	CN 103864007 A (NO 55 INST CN ELECT SCI & TECH) 18 June 2014 (18.06.2014) see claims 1-5	1-5
A	"Microfabricated alkali atom vapor cells" (Li-Anne Liew et al.) APPLIED PHYSICS LETTERS, May 2004, see volume 84, issue 14, page 2694-2696, ISSN 0003-6951	1-5
A	US 2007034809 A1 (LAL AMIT et al.) 15 February 2007 (15.02.2007) see the whole document	1-5
A	US 2005007118 A1 (JOHN KITCHING et al.) 13 January 2005 (13.01.2005) see the whole document	1-5
A	CN 102515083 A (UNIV SOUTHEAST) 27 June 2012 (27.06.2012) see the whole document	1-5

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

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"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&"document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 November 2014	16 December 2014

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Form PCT/ISA /210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2014/000816

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	"A Review of Processing Technics on CPT Clock s Miniature Cell" (JING, Yanfeng et al.) Journal of Time and Frequency, June 2010, see volume 33, issue 1, page 47-53, ISSN 1001-1544	1-5

Form PCT/ISA /210 (continuation of second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2014/000816

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
US 2005007118 A1	13 January 2005	None	
US 2007034809 A1	15 February 2007	US 7666485 B2	23 February 2010
CN 103864007 A	18 June 2014	None	
CN 102515083 A	27 June 2012	None	

Form PCT/ISA /210 (patent family annex) (July 2009)