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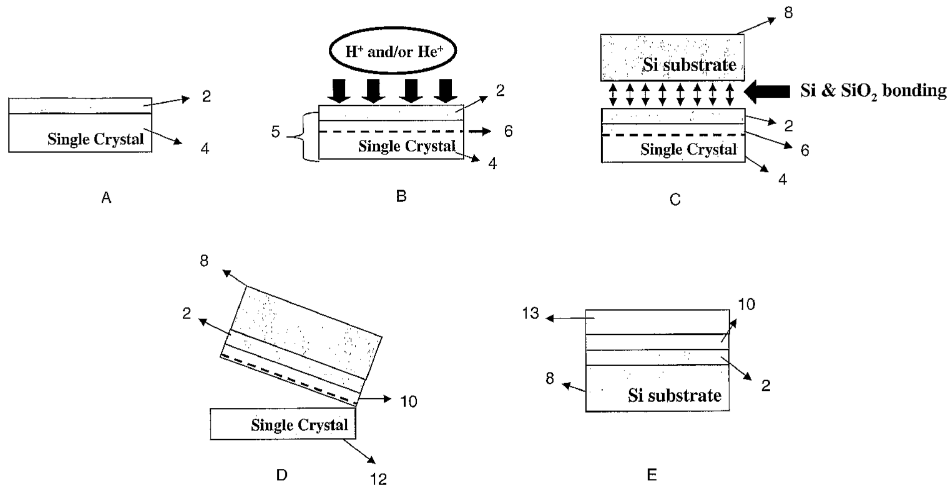
(54) **Title:** INTEGRATED BST MICROWAVE TUNABLE DEVICES USING BUFFER LAYER TRANSFER METHOD



(57) **Abstract:** A BST microwave device includes a single crystal oxide wafer. A silicon dioxide layer is formed on the single crystal oxide layer. A silicon substrate is bonded on the silicon dioxide layer. A BST layer is formed on the single crystal oxide layer.

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INTEGRATED BST MICROWAVE TUNABLE DEVICES USING BUFFER LAYER TRANSFER METHOD

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PRIORITY INFORMATION

This application claims priority from provisional application Ser. No. 60/610,996 filed September 17, 2004, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

10 The invention relates to the field of BST microwave tunable devices, and in particular to an integrated BST microwave tunable device using a buffer layer transfer method.

$(Ba,Sr)TiO_3$ (BST), $(Ba,Zr)TiO_3$ (BZT) $(Ba,Hf)TiO_3$ (BHT), $SrTiO_3$ (ST), $Bi_{1.5}Zn_{1.0}Nb_{1.5}O_7$ (BZN series, B : Bi, Ba) and related thin films are promising materials for tunable microwave devices application such as electronically tunable mixers, oscillators, and 15 phase shifters and filters. It will be appreciated by those of skill in the art that BST is representative of one or more related perovskite-like tunable dielectric materials.

An objective of the invention is to integrate tunable components into monolithic microwave integrated circuits (MMICs). Although microstrip planes are the most common transmission line component for microwave frequencies, the ground-plane is difficult to access 20 for shunt connections necessary for active devices, when used in MMICs. The CPW (Coplanar Waveguide) is an attractive alternative, especially due to the ease of monolithic integration, as the ground plane runs adjacent to the transmission line. The possibility of creating BST microwave tunable devices on oxide substrates has been demonstrated in recent years. There is a great incentive to replicate these achievements on silicon-based wafers for integrated 25 microwave device applications.

Much work has been done to obtain epitaxially grown ferroelectric thin films on Si substrates. Currently, chemical vapor deposition methods such as MBE (Molecular Beam Epitaxy) and ALD (Atomic Layer Deposition) and as well as physical vapor deposition methods such as pulsed laser deposition have been used. However, it has not been easy to 30 obtain high quality buffer films without residual stress and defects resulting from a dimensional misfit between the crystal lattices.

SUMMARY OF THE INVENTION

According to one aspect of the invention, there is provided a BST microwave device. 35 The BST microwave device includes a single crystal oxide wafer. A silicon dioxide layer is

formed on the single crystal oxide layer. A silicon substrate is bonded on the silicon dioxide layer. A BST layer is formed on the single crystal oxide layer.

According to another aspect of the invention, there is provided a method of forming BST microwave device. The method includes providing a single crystal oxide wafer and
5 forming a silicon dioxide layer on the single crystal oxide layer. A silicon substrate is bonded on the silicon dioxide layer. Also, the method includes forming a BST layer on the single crystal oxide layer.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIGs. 1A-1E are schematic diagrams illustrating wafer bonding and ion cutting of SiO_2 covered single crystals; and

FIGs. 2A-2C are schematic diagrams illustrating wafer bonding of SiO_2 covered double side polished single crystals and Si-micromachining with/without ion implantation.

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DETAILED DESCRIPTION OF THE INVENTION

Single crystal (MgO, $SrTiO_3$, $LaAlO_3$, Al_2O_3, $MgAl_2O_4$, YSZ, CeO_2) buffer layers, with low loss, are first separated from the single crystal oxide wafers by a hydrogen or helium induced cutting method and then transferred to a Si wafer using wafer bonding
20 technology. The basic structure for BST or $Bi_{1.5}Zn_{1.0}Nb_{1.5}O_7$ (BZN series, B : Bi, Ba) microwave devices are developed in one of the two following methods: (1) wafer bonding and ion cutting of SiO_2 covered single crystals, with ion implantation or (2) wafer bonding of SiO_2 covered double side polished single crystals and Si-micromachining (with/without ion implantation).

25 FIGs. 1A-1E are schematic diagrams illustrating wafer bonding and ion cutting of SiO_2 covered single crystals. FIG. 1A shows a SiO_2 thin or thick layer 2 that is deposited on a single crystal oxide wafer 4 (e.g. MgO, $SrTiO_3$, $LaAlO_3$, Al_2O_3, $MgAl_2O_4$, YSZ, CeO_2) using PECVD, LPCVD, and/or ALD for purposes of subsequent wafer bonding to the Si wafer 8. Note Si-SiO_2 or SiO_2-SiO_2 bonding is much easier, if one achieves very clean
30 surfaces. FIG. 1B shows hydrogen being implanted into the SiO_2 covered single crystal 5 to a desired depth 6 (the hydrogen stopping range) at which cleavage is desired. Note that He can also be used for implantation. FIG. 1C shows a receiver Si (or SiO_2/Si) substrate 8 being bonded to the SiO_2 deposited single crystal 5 through direct wafer bonding technology. FIG. 1D shows the bonded wafers 12 being separated along the hydrogen implantation stopping

region 6 by heat treatment, resulting in the transfer of a thin pure single crystal oxide 10 to the Si substrate 8. FIG. 1E shows high quality BST thin films 13 being deposited onto the single crystal oxide layer 10 bonded to the Si substrate 8. This film 13 is suitable for the fabrication of microwave tunable components such as resonator, phase shifter, tunable
5 bandpass filter, or the like.

FIGs. 2A-2C are schematic diagrams illustrating wafer bonding of SiO_2 covered double side polished single crystals and Si-micromachining with/without ion implantation. FIG. 2A shows a thin or thick SiO_2 layer 14 being deposited onto various single crystal oxide wafers 16 (e.g. MgO, $SrTiO_3$, $LaAlO_3$, Al_2O_3, $MgAl_2O_4$, YSZ, CeO_2) using PECVD,
10 LPCVD, and/or ALD. FIG. 2B shows a receiver substrate 18, such as Si or thick SiO_2/Si, being bonded to the SiO_2 deposited single crystal 14 through direct wafer bonding technology. If a thin buffer layer is needed, one can polish back the oxide single crystal 14. FIG. 2C shows high quality BST thin films 20 being deposited on the single crystal oxide layer 16. This film 20 is suitable for the fabrication of microwave components such as
15 resonator, phase shifter and tunable bandpass filters, or the like. To reduce loss through the Si substrate 18, a portion of the Si substrate 18 below the microwave device is removed by micro-machining methods, for example, anisotropic KOH chemical etch. Note that Au electrodes 22 are formed on the BST layer 20 to complete microwave circuits.

The invention is an alternative to the buffer layer transfer technique by wafer bonding
20 and ion cutting method. The advantage of the invention is the provision of the same environment as with single crystal substrate growth, for example, low surface roughness and high quality material.

Although the present invention has been shown and described with respect to several preferred embodiments thereof, various changes, omissions and additions to the form and
25 detail thereof, may be made therein, without departing from the spirit and scope of the invention.

What is claimed is:

CLAIMS

1 1. A BST microwave device comprising:
2 a single crystal oxide wafer;
3 a silicon dioxide layer that is formed on said single crystal oxide layer;
4 a silicon substrate that is bonded on said silicon dioxide layer; and
5 a BST layer that is formed on said single crystal oxide layer.

1 2. The BST microwave device of claim 1, wherein said single crystal oxide wafer comprises
2 MgO, $SrTiO_3$, $LaAlO_3$, Al_2O_3, $MgAl_2O_4$, YSZ, or CeO_2.

1 3. The BST microwave device of claim 1, wherein said silicon dioxide layer is formed by
2 depositing silicon dioxide using CVD, PECVD, LPCVD, or ALD.

1 4. The BST microwave device of claim 1, wherein said silicon substrate is bonded to silicon
2 dioxide layer using direct wafer bonding technology.

1 5. The BST microwave device of claim 1, wherein said BST layer suitable for the fabrication of
2 an optical component.

1 6. The BST microwave device of claim 4, wherein said silicon dioxide layer is exposed to
2 hydrogen or helium ion implantation.

1 7. The BST microwave device of claim 1, wherein said silicon substrate comprises a removed
2 portion so as to reduce microwave loss in said BST microwave device.

1 8. The BST microwave device of claim 7, wherein said removed portion is formed using KOH
2 chemical etch.

1 9. The BST microwave device of claim 5, wherein said optical component comprises a
2 microwave tunable component.

1 10. The BST microwave device of claim 9, wherein said microwave tunable component
2 comprises a resonator, phase shifter, or tunable bandpass filter.

1 11. A method of forming BST microwave device comprising:
2 providing a single crystal oxide wafer;
3 forming a silicon dioxide layer on said single crystal oxide layer;
4 bonding a silicon substrate on said silicon dioxide layer; and
5 forming a BST layer on said single crystal oxide layer.

1 12. The method of claim 11, wherein said single crystal oxide wafer comprises MgO,
2 $SrTiO_3$, $LaAlO_3$, Al_2O_3, $MgAl_2O_4$, YSZ, or CeO_2.

1 13. The method of claim 11, wherein said silicon dioxide layer is formed by depositing silicon
2 dioxide using CVD, PECVD, LPCVD, or ALD.

1 14. The method of claim 11, wherein said silicon substrate is bonded to silicon dioxide layer
2 using direct wafer bonding technology.

1 15. The method of claim 11, wherein said BST layer suitable for the fabrication of an optical
2 component.

1 16. The method of claim 14, wherein said silicon dioxide layer is exposed to hydrogen or
2 helium ion implantation.

1 17. The method of claim 11, wherein said silicon substrate comprises a removed portion so as
2 to reduce microwave loss in said BST microwave device.

1 18. The method of claim 17, wherein said removed portion is formed using KOH chemical etch.

1 19. The method of claim 15, wherein said optical component comprises a microwave tunable
2 component.

1 20. The method of claim 19, wherein said microwave tunable component comprises a resonator,
2 phase shifter, or tunable bandpass filter.

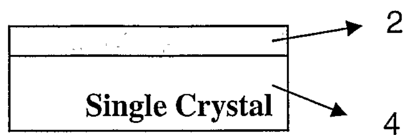

FIG. 1A

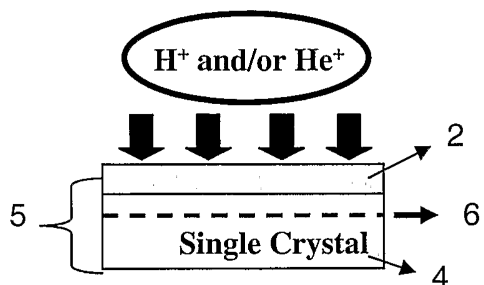

FIG. 1B

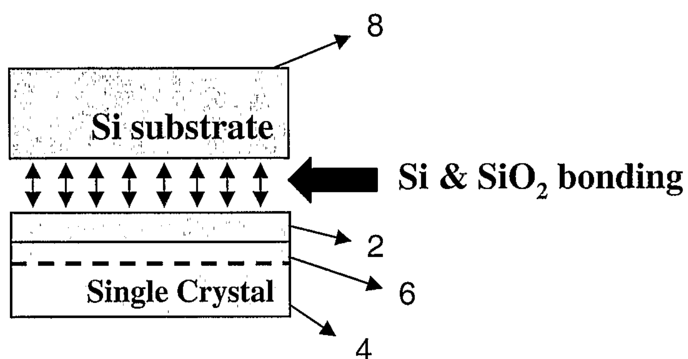

FIG. 1C

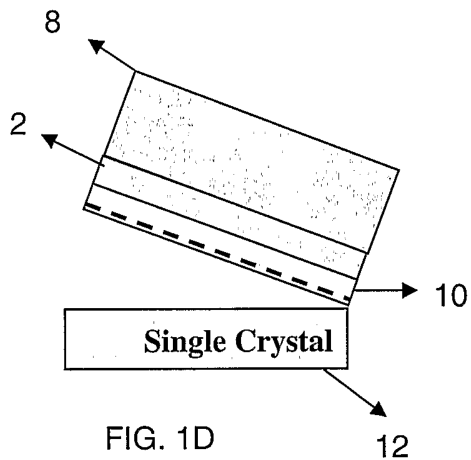

FIG. 1D

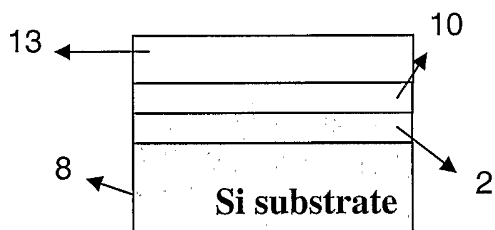

FIG. 1E

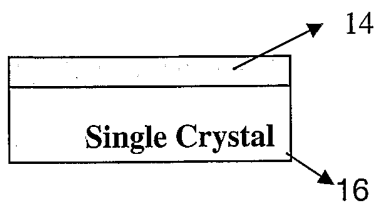

FIG. 2A

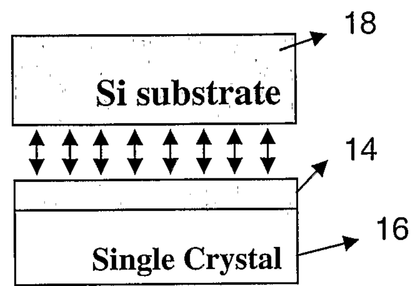

FIG. 2B

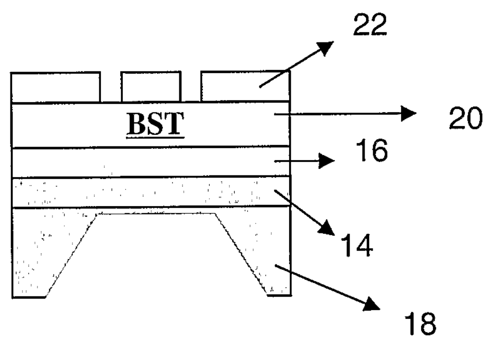

FIG. 2C