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(54) **SYSTEM AND METHOD FOR FABRICATING SUPER CONDUCTING CIRCUITRY ON BOTH SIDES OF AN ULTRA-THIN LAYER**

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H01L 39/24 (2006.01)

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CPC *H01L 39/24* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,578,226 A * 11/1996 Chan H01L 39/24 216/101
2012/0299175 A1* 11/2012 Tran B82Y 10/00 257/712

* cited by examiner

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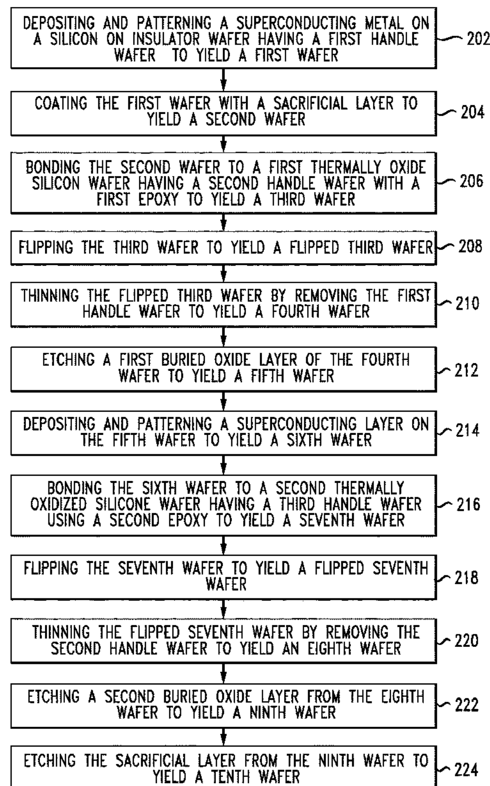
(57) **ABSTRACT**

A method of fabricating circuitry in a wafer includes depositing a superconducting metal on a silicon on insulator wafer having a handle wafer, coating the wafer with a sacrificial layer and bonding the wafer to a thermally oxide silicon wafer with a first epoxy. The method includes flipping the wafer, thinning the flipped wafer by removing a handle wafer, etching a buried oxide layer, depositing a superconducting layer, bonding the wafer to a thermally oxidized silicon wafer having a handle wafer using an epoxy, flipping the wafer again, thinning the flipped wafer, etching a buried oxide layer from the wafer and etching the sacrificial layer from the wafer. The result is a wafer having superconductive circuitry on both sides of an ultra-thin silicon layer.

18 Claims, 4 Drawing Sheets



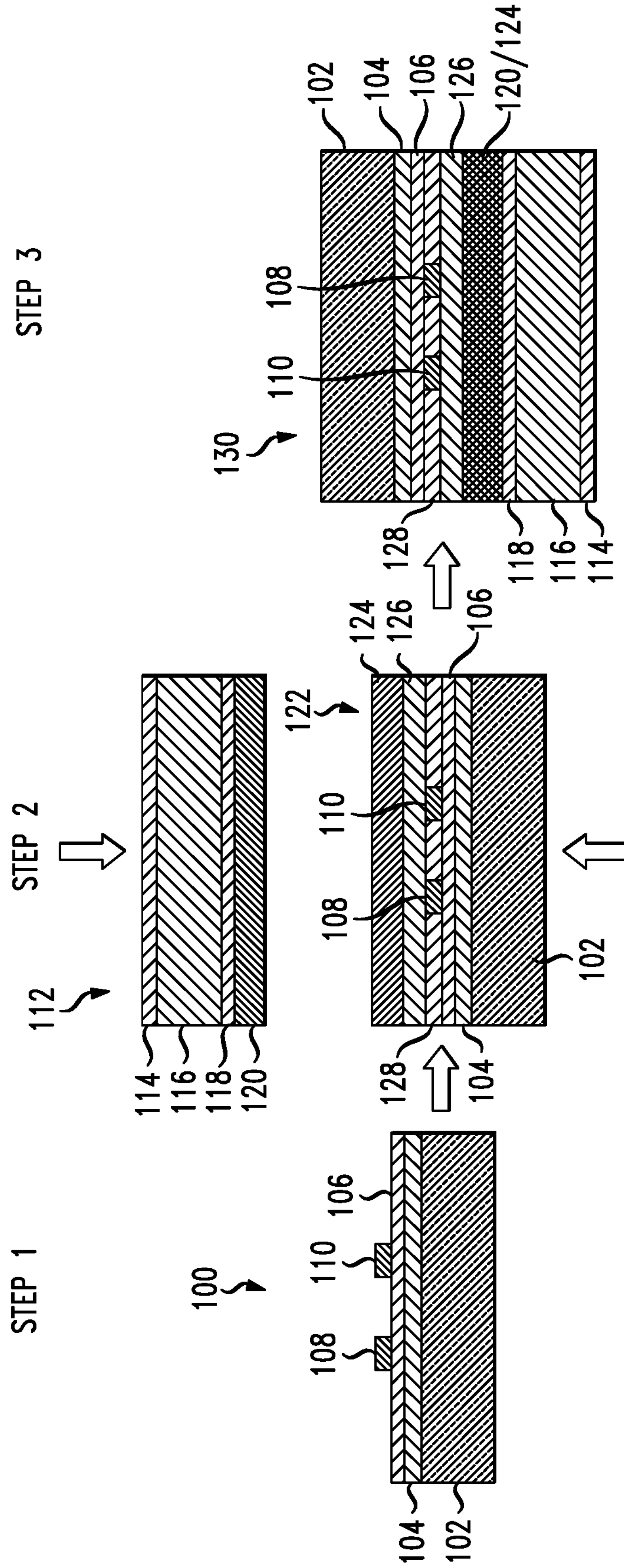


FIG. 1A

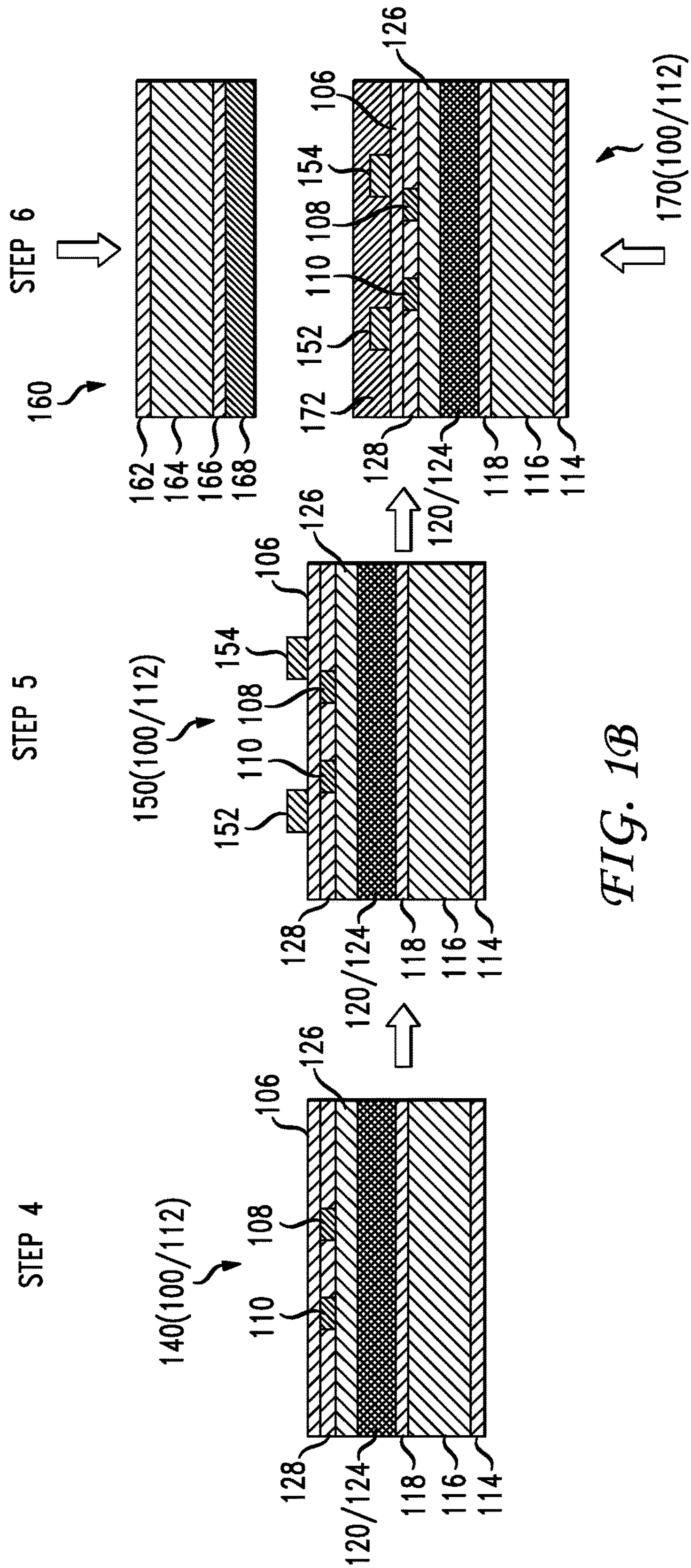


FIG. 1B

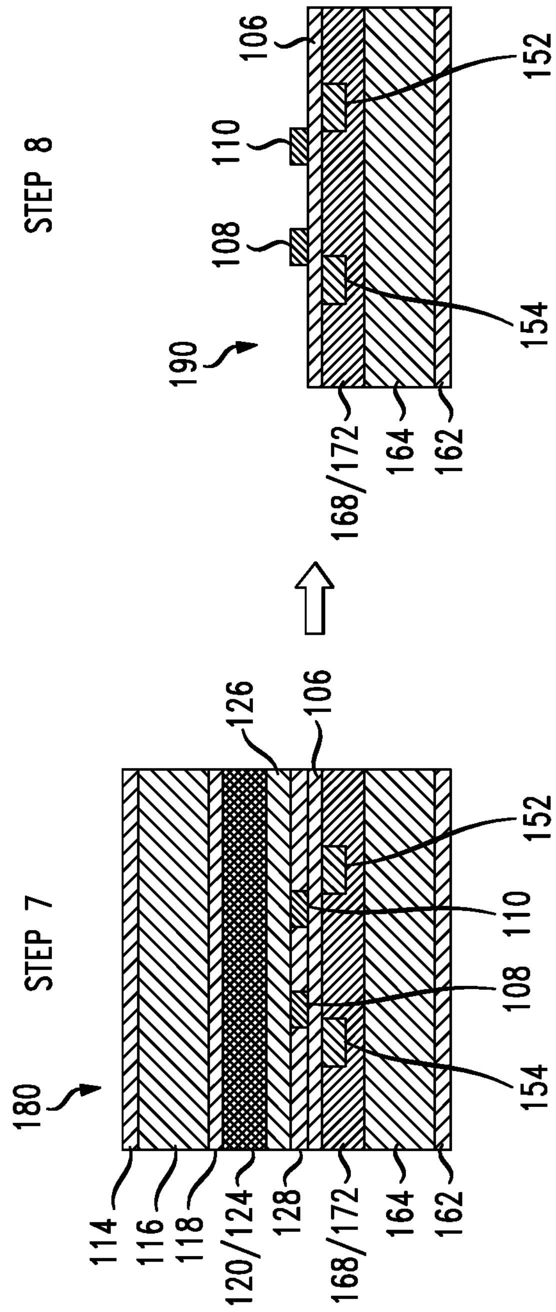


FIG. 1C

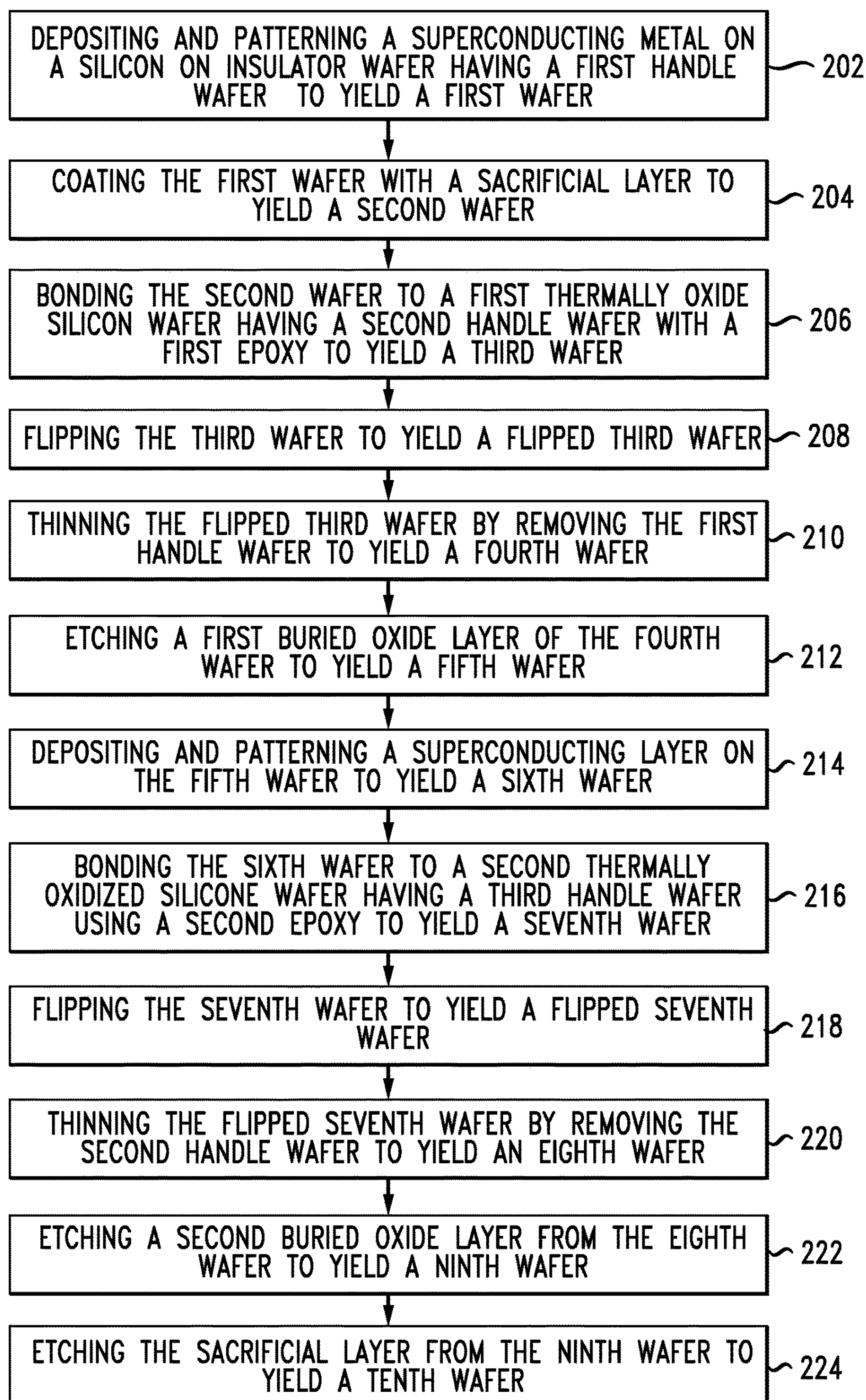


FIG. 2

SYSTEM AND METHOD FOR FABRICATING SUPER CONDUCTING CIRCUITRY ON BOTH SIDES OF AN ULTRA-THIN LAYER

BACKGROUND

1. Technical Field

The present disclosure relates to fabricating superconductive circuitry and more specifically to a system and method of fabricating superconductive circuitry on both sides of an ultra-thin silicon layer.

2. Introduction

The present disclosure relates to fabricating superconducting circuitry. Certain applications require the fabrication of superconducting circuitry on both sides of an ultra-thin silicon wafer. Such a requirement can apply especially where ultra-low loss transmission lines and/or ultra-low crosstalk between superconducting sensors is required. A unique aspect of the problem that exists in this scenario is that the silicon wafer is so thin that handling it during the fabrication process is difficult with conventional tools. For example, a backing "handle wafer" is often required and some of the superconducting circuitry necessitates deposition on a heated substrate surface. Current processes focus on deposition of superconducting circuitry on both sides of an ultra-thin silicon wafer by depositing metal layers on one side of the device layer of a silicon on insulator wafer, bonding the front side of the wafer to a handle wafer with a polymeric epoxy, thinning the handle wafer on the silicon on insulator wafer, etching the buried oxide of the silicon on insulator wafer, and deposition of metal layers on the opposite side of the device there of a silicon on insulator wafer. The problems with this approach is that deposition of metal layers on one side of the silicon on insulator wafer have to be conducted at ambient temperatures in order to prevent damage to the polymer epoxy layer. Therefore, superconducting material deposited at high substrate temperature (such as temperatures greater than 200° C.) exhibit certain undesirable properties, such as a high conducting transition temperature or low microwave loss, and cannot be used successfully. Accordingly, what is needed in the art is an improved system and method related to how to fabricate superconducting circuitry on both sides of an ultra-thin silicon wafer.

SUMMARY

Additional features and advantages of the disclosure will be set forth in the description which follows, and in part will be obvious from the description, or can be learned by practice of the herein disclosed principles. The features and advantages of the disclosure can be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims. These and other features of the disclosure will become more fully apparent from the following description and appended claims, or can be learned by the practice of the principles set forth herein.

Disclosed are systems, methods, and non-transitory computer-readable storage media for fabricating circuitry in a wafer. The method includes depositing and patterning a superconducting metal on a silicon on insulator wafer having a first handle wafer to yield a first wafer, and coating the first wafer with a sacrificial layer to yield a second wafer. The depositing can be performed at a high temperature. The range of temperatures encompassed would be known to one of skill in the art. The sacrificial layer can include a bi-layer having a first sacrificial layer of an anti-reflection coating and a second sacrificial layer of a copper thin film. This approach enables one to thin down the handle layer without damaging the silicon on insulator device layer. The reason for this disclosed process is to avoid roughing up or etching any part of a particular layer of the wafer.

The method further includes bonding the second wafer to a first thermally oxide silicon wafer having a second handle wafer with a first epoxy to yield a third wafer and flipping the third wafer to yield a flipped third wafer and thinning the flipped third wafer by removing the first handle wafer to yield a fourth wafer. The method includes etching a first buried oxide layer of the fourth wafer to yield a fifth wafer, depositing and patterning a superconducting layer on the fifth wafer to yield a sixth wafer, bonding the sixth wafer to a second thermally oxidized silicon wafer having a third handle wafer using a second epoxy to yield a seventh wafer and flipping the seventh wafer to yield a flipped seventh wafer. After the flipping, the method includes thinning the flipped seventh wafer by removing the second handle wafer to yield an eighth wafer, etching a second buried oxide layer from the eighth wafer to yield a ninth wafer and etching the sacrificial layer from the ninth wafer to yield a tenth wafer.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A, **1**B and **1**C illustrates the various stages of development of the silicon chip according to the present disclosure; and

FIG. **2** illustrates a method example.

DETAILED DESCRIPTION

A system, method and computer-readable media are disclosed which related to a process for fabricating circuitry on a wafer. The particular approach uses a sacrificial layer at a certain place in the fabrication process to enable the ability to thin down or remove certain layers while avoiding damage to a silicon on insulator (SOI) device layer.

Various embodiments of the disclosure are described in detail below. While specific implementations are described, it should be understood that this is done for illustration purposes only. Other components and configurations may be used without parting from the spirit and scope of the disclosure.

FIGS. **1**A, **1**B, **1**C and **2** illustrate the various aspects of this disclosure and show the wafer at different steps in the process and FIG. **2** illustrates a method according to an aspect of this disclosure. As the figures are closely tied together, we shall discuss FIG. **2** with many references to features of FIGS. **1**A, **1**B and **1**C. As shown in FIG. **2**, a method of fabricating circuitry in a wafer, the method include depositing and patterning a superconducting metal on a silicon on insulator wafer having a first handle wafer **102** to yield a first wafer (**202**). This step **1** is shown in FIG. **1**A in which the wafer **100** includes a silicon on insulator (SOI) handle wafer **102**, a buried oxide layer **104**, a SOI device wafer **106** and the superconducting metal **108**, **110**. The primary purpose of the concepts disclosed herein is to provide a fabrication process that prevents roughing or etching of the SOI device wafer **106**. The use of the various handle wafers disclosed herein

The method further includes coating the first wafer with a sacrificial layer **126**/**128** to yield a second wafer **122** (**204**). FIG. **1**A illustrates, as part of step **2**, the coating of the first wafer **100** with the sacrificial layer **126**/**128**. The sacrificial layer **126**/**128** can include a polymeric sacrificial layer comprises an O_2 ash polymeric sacrificial layer. In another

example, the sacrificial layer **126/128** is a bi-layer having a first sacrificial layer **128** of an anti-reflection coating (called Gen-Arc) and a second sacrificial layer **126** of a copper thin film. These layers are also interchangeable. The use of the sacrificial layer enables the manufacturer to thin down the sacrificial handle wafer **116** without damaging the silicon on insulator device layer **106**. In the process, one does not want to rough in or etch any part of the SOI device wafer **106**. The use of the sacrificial bi-layer and the flipping process disclosed herein enables the deposition of superconducting material on both sides of SOI device wafer **106** without damage.

Next, the method includes bonding the second wafer **122** to a first thermally oxide silicon wafer **112** having a second handle wafer **116** with a first epoxy **120/124** to yield a third wafer (**206**). Feature **112** is a separate substrate that is bonded to substrate **122**. Note that the entire wafer **112** can also be termed a sacrificial handle wafer. The sacrificial handle wafer **112** also can include layers of a thermal silicon dioxide **114**, **118** which can be, for example, on either side of the second handle wafer **116**. The second handle wafer **116** is a sacrificial wafer as shall be seen. The use of the various handle wafers or handle layers is because the layer **106** can be 2 microns thick. The SOI device layer **106** is so thin, the various handle layers are needed for mechanical support for the creation of the final product.

With feature **106**, one example material is to use silicon to make the layer. One could use, however, a silicon nitride layer, a sapphire layer or a silicon dioxide layer. The feature of using the sacrificial layer prevents the damage to whatever material is made for layer **106**. One example application of the process is to make wafers that provide ultra-low-loss superconducting transmission lines. Any damage to the underlying substrate in this application results in loss due to the damaged region. If the substrate is damaged, the result is an increased surface area which increases dielectric loss. The surface area of interest is the interface between the atmosphere and the dielectric region. The goal in reducing damage is to reduce this surface area. Other applications can be to make superconducting resonator based spectrometers and superconducting parametric amplifiers. Any of these resulting devices can be example products. The disclosure covers also any product made by the process disclosed herein.

Next, the method includes flipping the third wafer to yield a flipped third wafer **130** (**100/112**) (**208**). As used herein, where a particular version of the product is referenced with other layers also referenced in parenthesis, it means that the new product includes at least in part a combination of some previous layers. For example, the third wafer **130** includes the basic SOI wafer **100** plus the sacrificial handle wafer **112**. Wafer **130** is shown in FIG. **1**A with the SOI handle wafer **102** now on top whereas before step **3**, the SOI handle wafer **102** was on the bottom. Note the blending of the epoxy layers as feature **120/124**. The epoxy used for layers **120**, **124** can be, for example, a BCB (benzocyclobutene) epoxy layer. The method includes thinning the flipped third wafer by removing the first handle wafer **102** to yield a fourth wafer (**210**). The method next includes etching a first buried oxide layer **104** of the fourth wafer to yield a fifth wafer **150** (**100/112**) (**212**) as is shown in Step **4** of FIG. **1**B. The etching can occur, for example, by placing the substrate in hydrochloric acid. Next, lithographic processing is applied to layer **106** by depositing and patterning a superconducting layer **152/154** on the fifth wafer to yield a sixth wafer (**214**) as is shown in step **5** of FIG. **1**B. The superconducting layer **152/154** can be a metallization layer. Many circuits require pattern superconducting metal on both sides of the layer like layer **106**.

The method next includes bonding the sixth wafer **170** (**100/112**) to a second thermally oxidized silicon wafer **160** having a third handle wafer **164** using a second epoxy **168/172** to yield a seventh wafer (**216**) as is shown in steps **6** and **7** of FIGS. **1**B and **1**C. To achieve the bonding, a step of applying an adhesive **168** to substrate **160** and an adhesive **172** to substrate **170** can be performed. The bonding is preferably achieved through the use of a bonding tool as would be known in the art. The third handle wafer **162** can include a layer of thermal silicon dioxide **162** and a second layer of thermal silicon dioxide **166**. The second layer of oxide **168/172** can be made from BCB and/or CR-200 as an adhesive layer. The epoxy layers disclosed herein can be made from any adhesion. The method includes flipping the seventh wafer to yield a flipped seventh wafer **180** (**100/112/160**) (**218**) as shown in Step **7** of FIG. **1**C. The method further includes thinning the flipped seventh wafer by removing the second handle wafer **116** to yield an eighth wafer (**220**) and etching a second buried oxide layer **118** from the eighth wafer to yield a ninth wafer (**222**) and etching the sacrificial layer **126/128** from the ninth wafer to yield a tenth wafer **190** (**100/112/160**) (**224**). The etching includes removing the dioxide layer **114** and the adhesive layer **120/124** as well. The sacrificial layer **126** can be a Cu (copper) layer, for example, and the sacrificial layer **126** can be a Gen-Arc sacrificial layer.

According to several other features, the epoxy can be a polymeric epoxy. Etching the sacrificial layer from the ninth wafer further includes etching a metallic sacrificial layer from the ninth wafer to yield an interim wafer and etching a polymeric sacrificial layer from the interim wafer to yield the tenth wafer.

The resulting product is shown as feature **190** (**100/112/160**) and includes the SOI device layer substrate **106** with metallization layers **152**, **154** on one side of the substrate **106** and metallization **108**, **110** on the top side of the substrate **106**. As noted above, the resulting product can have many applications that require low loss.

Embodiments within the scope of the present disclosure may also include tangible and/or non-transitory computer-readable storage media for carrying or having computer-executable instructions or data structures stored thereon. Such tangible computer-readable storage media can be any available media that can be accessed by a general purpose or special purpose computer, including the functional design of any special purpose processor as described above. By way of example, and not limitation, such tangible computer-readable media can include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to carry or store desired program code means in the form of computer-executable instructions, data structures, or processor chip design. When information is transferred or provided over a network or another communications connection to a computer, the computer properly views the connection as a computer-readable medium. Thus, any such connection is properly termed a computer-readable medium.

Computer-executable instructions include, for example, instructions and data which cause a general purpose computer, special purpose computer, or special purpose processing device to control a group of components to perform a certain function or group of functions. Such components can include a spin coater, a wafer bonder, a physical vapor

deposition tool—for instance, a sputtering deposition system, a mechanical lapper, a deep reactive ion etcher, and a programmable hot plate. Other components can also be used which would be known to those of skill in the art. Computer-executable instructions also include program modules that are executed by computers in stand-alone or network environments. Generally, program modules include routines, programs, components, data structures, objects, and the functions inherent in the design of special-purpose processors, etc. that perform particular tasks or implement particular abstract data types. Computer-executable instructions, associated data structures, and program modules represent examples of the program code means for executing steps of the methods disclosed herein. The particular sequence of such executable instructions or associated data structures represents examples of corresponding acts for implementing the functions described in such steps.

Other embodiments of the disclosure may be practiced in network computing environments with many types of computer system configurations, including personal computers, hand-held devices, multi-processor systems, microprocessor-based or programmable consumer electronics, network PCs, minicomputers, mainframe computers, and the like. Any such computing device will include the basic hardware components such as a processor, a bus, memory, input/output devices, and so forth. Embodiments may also be practiced in distributed computing environments where tasks are performed by local and remote processing devices that are linked (either by hardwired links, wireless links, or by a combination thereof) through a communications network. In a distributed computing environment, program modules may be located in both local and remote memory storage devices.

The various embodiments described above are provided by way of illustration only and should not be construed to limit the scope of the disclosure. Various modifications and changes may be made to the principles described herein without following the example embodiments and applications illustrated and described herein, and without departing from the spirit and scope of the disclosure.

We claim:

1. A method of fabricating circuitry in a wafer, the method comprising:

depositing and patterning a superconducting metal on a silicon on insulator wafer having a first handle wafer to yield a first wafer;

coating the first wafer with a sacrificial layer to yield a second wafer;

bonding the second wafer to a first thermally oxide silicon wafer having a second handle wafer with a first epoxy to yield a third wafer;

flipping the third wafer to yield a flipped third wafer;

thinning the flipped third wafer by removing the first handle wafer to yield a fourth wafer;

etching a first buried oxide layer of the fourth wafer to yield a fifth wafer;

depositing and patterning a superconducting layer on the fifth wafer to yield a sixth wafer;

bonding the sixth wafer to a second thermally oxidized silicon wafer having a third handle wafer using a second epoxy to yield a seventh wafer;

flipping the seventh wafer to yield a flipped seventh wafer;

thinning the flipped seventh wafer by removing the second handle wafer to yield an eighth wafer;

etching a second buried oxide layer from the eighth wafer to yield a ninth wafer; and

etching the sacrificial layer from the ninth wafer to yield a tenth wafer.

2. The method of claim **1**, wherein the depositing is performed at a high temperature.

3. The method of claim **1**, wherein the sacrificial layer comprises a polymeric sacrificial layer comprises an O_2 ash polymeric sacrificial layer.

4. The method of claim **1**, wherein the sacrificial layer comprises a bi-layer having a first sacrificial layer of an anti-reflection coating and a second sacrificial layer of a copper thin film.

5. The method of claim **1**, wherein the epoxy is a polymeric epoxy.

6. The method of claim **1**, wherein etching the sacrificial layer from the ninth wafer further comprises etching a metallic sacrificial layer from the ninth wafer to yield an interim wafer and etching a polymeric sacrificial layer from the interim wafer to yield the tenth wafer.

7. A system comprising:

a processor; and

a computer-readable storage device storing instructions which, when executed by the processor, cause the processor to perform operations comprising:

depositing and patterning a superconducting metal on a silicon on insulator wafer having a first handle wafer to yield a first wafer;

coating the first wafer with a sacrificial layer to yield a second wafer;

bonding the second wafer to a first thermally oxide silicon wafer having a second handle wafer with a first epoxy to yield a third wafer;

flipping the third wafer to yield a flipped third wafer;

thinning the flipped third wafer by removing the first handle wafer to yield a fourth wafer;

etching a first buried oxide layer of the fourth wafer to yield a fifth wafer;

depositing and patterning a superconducting layer on the fifth wafer to yield a sixth wafer;

bonding the sixth wafer to a second thermally oxidized silicon wafer having a third handle wafer using a second epoxy to yield a seventh wafer;

flipping the seventh wafer to yield a flipped seventh wafer;

thinning the flipped seventh wafer by removing the second handle wafer to yield an eighth wafer;

etching a second buried oxide layer from the eighth wafer to yield a ninth wafer; and

etching the sacrificial layer from the ninth wafer to yield a tenth wafer.

8. The system of claim **7**, wherein the depositing is performed at a high temperature.

9. The system of claim **7**, wherein the sacrificial layer comprises a polymeric sacrificial layer comprises an O2 ash polymeric sacrificial layer.

10. The system of claim **7**, wherein the sacrificial layer comprises a bi-layer having a first sacrificial layer of an anti-reflection coating and a second sacrificial layer of a copper thin film.

11. The system of claim **7**, wherein the epoxy is a polymeric epoxy.

12. The system of claim **7**, wherein etching the sacrificial layer from the ninth wafer further comprises etching a metallic sacrificial layer from the ninth wafer to yield an interim wafer and etching a polymeric sacrificial layer from the interim wafer to yield the tenth wafer.

13. A computer-readable storage device storing instructions which, when executed by a processor, cause the processor to control a group of components to perform operations comprising:

depositing and patterning a superconducting metal on a silicon on insulator wafer having a first handle wafer to yield a first wafer;

coating the first wafer with a sacrificial layer to yield a second wafer;

bonding the second wafer to a first thermally oxide silicon wafer having a second handle wafer with a first epoxy to yield a third wafer;

flipping the third wafer to yield a flipped third wafer;

thinning the flipped third wafer by removing the first handle wafer to yield a fourth wafer;

etching a first buried oxide layer of the fourth wafer to yield a fifth wafer;

depositing and patterning a superconducting layer on the fifth wafer to yield a sixth wafer;

bonding the sixth wafer to a second thermally oxidized silicon wafer having a third handle wafer using a second epoxy to yield a seventh wafer;

flipping the seventh wafer to yield a flipped seventh wafer;

thinning the flipped seventh wafer by removing the second handle wafer to yield an eighth wafer;

etching a second buried oxide layer from the eighth wafer to yield a ninth wafer; and

etching the sacrificial layer from the ninth wafer to yield a tenth wafer.

14. The computer-readable storage device of claim 13, wherein the depositing is performed at a high temperature.

15. The computer-readable storage device of claim 13, wherein the sacrificial layer comprises a polymeric sacrificial layer comprises an O_2 ash polymeric sacrificial layer.

16. The computer-readable storage device of claim 13, wherein the sacrificial layer comprises a bi-layer having a first sacrificial layer of an anti-reflection coating and a second sacrificial layer of a copper thin film.

17. The computer-readable storage device of claim 13, wherein the epoxy is a polymeric epoxy.

18. The computer-readable storage device of claim 13, wherein etching the sacrificial layer from the ninth wafer further comprises etching a metallic sacrificial layer from the ninth wafer to yield an interim wafer and etching a polymeric sacrificial layer from the interim wafer to yield the tenth wafer.

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