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APPLICATION NUMBER: ***09/145,323***
FILING DATE: ***September 01, 1998***

THE COUNTRY CODE AND NUMBER OF YOUR PRIORITY APPLICATION, TO BE USED FOR FILING ABROAD UNDER THE PARIS CONVENTION, IS ***US09/145,323***

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A

PATENT APPLICATION

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"Express Mail" mailing label number EE 718068798US
Date of Deposit SEP 1 1998
I hereby certify that this application is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231
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CASE 1-1-1

TITLE Pulse DC Reactive Sputtering Method

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

SIR:

NEW APPLICATION UNDER 37 CFR 1.53(b)

Enclosed are the following papers relating to the above-named application for patent:

Specification
4 Informal sheets of drawing(s)
Information Disclosure Statement

CLAIMS AS FILED				
	NO. FILED	NO. EXTRA	RATE	CALCULATIONS
Total Claims	18 – 20 =	0	x $22 =	$0
Independent Claims	3 – 3 =	0	x $82 =	$0
Multiple Dependent Claim(s), if applicable			$270 =	$0
Basic Fee				$790
			TOTAL FEE:	$790

Please file the application and charge **Lucent Technologies Deposit Account No. 12-2325** the amount of $790, to cover the filing fee. Duplicate copies of this letter are enclosed. In the event of non-payment or improper payment of a required fee, the Commissioner is authorized to charge or to credit **Deposit Account No. 12-2325** as required to correct the error.

The Assistant Commissioner for Patents is hereby authorized to treat any concurrent or future reply, requiring a petition for extension of time under 37 CFR § 1.136 for its timely submission, as incorporating a petition for extension of time for the appropriate length of time if not submitted with the reply.

Please address all correspondence to **Docket Administrator (Room 3C-512), Lucent Technologies Inc., 600 Mountain Avenue, P. O. Box 636, Murray Hill, New Jersey 07974-0636.** However, telephone calls should be made to me at 908-582-3246.

Respectfully,

John M. Harman
Reg. No. 38173
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Date: 9-1-98
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PT 13 12/97

PULSE DC REACTIVE SPUTTERING METHOD FOR FABRICATING PIEZOELECTRIC RESONATORS

Background of the Invention

1. Field of the Invention

The invention relates to piezoelectric resonators. More particularly, the invention relates to deposition techniques used in fabricating piezoelectric resonators and the piezoelectric resonators made by those deposition techniques.

2. Description of the Related Art

Piezoelectric resonators are devices comprising a wafer of piezoelectric material such as quartz, zinc oxide (ZnO), aluminum nitride (AlN) or ceramic material mounted or otherwise formed on a substrate (e.g., silicon or aluminum oxide). Upon the application of a voltage to the piezoelectric material, e.g., via electrodes, the piezoelectric material vibrates in a certain vibrational mode depending on the orientation or polarization of the piezoelectric material and at a certain (resonant) frequency depending on the thickness of the piezoelectric material.

Piezoelectric resonators provide clearly defined mechanical resonances and are useful, e.g., for discriminating between signals based on frequency diversity (i.e., a filter). Also, piezoelectric resonators are useful in providing stable frequency signals, e.g., as a frequency stabilizing feedback element in an oscillator circuit.

Typically, the resonant frequency of the piezoelectric material is inversely proportional to its thickness. Accordingly, for piezoelectric resonators to operate at high frequencies, e.g., frequencies greater than approximately 700 Megahertz (MHz), the thickness of the piezoelectric material must be reduced to the point of depositing a thin piezoelectric film on the substrate. Conventional deposition techniques for depositing such piezoelectric films include, e.g., chemical vapor deposition (CVD) and sputter deposition such as RF sputter deposition.

Sputter deposition involves a vacuum deposition process in which a sputtering target is bombarded with ions, typically an ionized noble gas such as argon, and the atoms of the target material are mechanically freed by momentum transfer and available for coating a nearby substrate. Suitable target materials include, e.g., aluminum, silicon and titanium. In a reactive sputtering process, a reactive gas is introduced into the deposition chamber and reacts with the target material to produce a target insulating film that subsequently is sputtered onto the substrate or reacts with freed target material to form a coating material that is sputtered onto the substrate. Suitable reactive gases include oxygen, nitrogen, ammonia and hydrogen.

In DC reactive sputtering, the target material and the reactive gas react in a plasma to produce the coating material. The plasma is formed by the noble gas when an direct current (DC) electric potential is applied within the sputtering chamber. For example, aluminum atoms from an aluminum target react with nitrogen (reactive gas) at the target to produce an insulating film of aluminum nitride (AlN), which is sputtered onto the substrate with ions of argon (noble gas). Other suitable coatings include, e.g., oxides such as aluminum oxide (Al_2O_3), carbides such as silicon carbide (SiC), and nitrides such as titanium nitride (TiN) or zinc oxide (ZnO).

However, sputter deposition and reactive sputtering techniques including DC reactive sputtering often do not provide adequate deposition rates. Accordingly, such techniques take longer to perform, which is undesirable from the standpoint of required processing time and ultimately is undesirable from an economic standpoint. Also, the relatively lengthy deposition period increases the introduction of impurities into the piezoelectric film being deposited.

One specific type of reactive sputtering that often is used in, e.g., silicon processing methods, is pulse DC reactive sputtering. Since the target insulating film is an insulator (e.g., AlN), the noble gas ions tend to accumulate on its surface, reducing the sputter rate and ultimately terminating the sputter process. In pulse DC reactive sputtering, the electric potential formed between the cathode and the anode in the chamber is reversed periodically to prevent charge accumulation on the target insulating film. More specifically, the positive portion of the applied voltage neutralizes accumulation of the noble gas ions on the surface of the target insulating film, and the negative portion of the applied voltage, if sufficient, causes ions from the noble gas to impinge upon the target insulating film formed on the target material, physically removing ions thereof and allowing them to accumulate on the substrate. This forms the deposited layer or coating.

In addition to silicon processing, pulse DC reactive sputtering techniques also are useful in depositing, e.g., wear resistant coatings such as tungsten carbide (WC) or titanium nitride (TiN) on, e.g., drill bits, wear plates and valve spindles. See generally, e.g., U.S. Pat. Nos. 5,651,865 and 5,718,813. In pulse DC reactive sputtering, the major qualitative concerns are the ultimate film constituency (i.e., reduced impurities introduced into the deposited film), film stress and film texture. Film texture generally characterizes the physical structure of the film resulting from the shape, arrangement and proportions of its components.

With respect to the deposition of thin piezoelectric films such as aluminum nitride (AlN), an important consideration includes the crystal orientation of the atoms within the final deposited film. That is, the crystal structure cannot be amorphous; it must be of a single crystal nature. This is because piezoelectricity occurs from the alignment of the atomic dipoles within the film, and an amorphous film produces random dipole moments with no macroscopic response. Also, it is desired that the film orientation be perpendicular to the substrate to facilitate the launching of longitudinal waves in a structure. It is believed that current deposition techniques are concerned primarily with deposition rates and consideration such as crystal structure are not taken into account.

Accordingly, it is desirable to have available an improved technique for depositing thin films of piezoelectric material such as aluminum nitride (AlN) on a substrate that provides piezoelectric films with improved control of film constituency, stress and texture.

Summary of the Invention

The invention is embodied in a pulse DC reactive sputtering method for thin film deposition. The inventive method is used, e.g., for depositing thin films of piezoelectric materials such as aluminum nitride on substrates with patterned electrodes during the fabrication of piezoelectric resonators. Embodiments of the invention include the steps of providing a target material such as aluminum within the sputtering chamber, positioning a substrate such as silicon within the sputtering chamber, providing a noble gas such as argon into the sputtering chamber, directing a reactive gas such as nitrogen within the sputtering chamber, applying a pulsed DC voltage across the electrodes within the sputtering chamber sufficient to cause ions from the noble gas to impinge upon the thin insulating layer (e.g., AlN) formed on the target material, physically removing ions thereof and allowing them to accumulate on the substrate. According to embodiments of the invention, the pulse width of the positive portion of the applied voltage is adjusted based on its effect on the desired film constituency, stress, and texture. By comparison, conventional arrangements establish pulse widths based on their effect on improving deposition rates, regardless of its effect on the film texture. Alternatively, embodiments of the invention adjust the direction and delivery of the reactive gas within the sputtering chamber, e.g., toward the target material, to further enhance the desired film constituency, stress, and texture through more efficient reaction by the reactive gas.

Brief Description of the Drawings

In the drawings:

Figs. 1a-b are simplified side, cross-sectional views of non-via, Bragg reflection piezoelectric resonators;

Fig. 2 is a simplified schematic diagram of a pulse DC reactive sputtering arrangement;

Fig. 3 is a simplified block diagram of a method for fabricating piezoelectric resonators according to embodiments of the invention;

Fig. 4a is a graphical diagram of the voltage applied to the electrodes of a pulsed DC reactive sputtering arrangement according to an embodiment of the invention; and

Fig. 4b is a graphical diagram of the voltage applied to the electrodes of a conventional pulsed DC reactive sputtering arrangement.

Detailed Description

Although specific features, configurations and arrangements are discussed hereinbelow, it should be understood that such is done for illustrative purposes only. A person skilled in the relevant art will recognize that other steps, configurations and arrangements are useful without departing from the spirit and scope of the invention.

Embodiments of the invention include piezoelectric resonators with improved piezoelectric film quality and control of methods for making such piezoelectric resonators using pulse DC reactive sputtering for the deposition of thin films of piezoelectric material on substrates. Embodiments of the invention are based on the realization that varying or adjusting the pulse width of the positive portion of the applied DC voltage improves the control and crystallinity of the deposited piezoelectric material. Alternatively, adjusting the direction and delivery of the reactive gas within the sputtering chamber further enhances such desired results. Typically, such adjustments are at the expense of deposition rate, which drives conventional pulse DC reactive sputtering techniques. However, increased deposition rates, in general, produce metal-rich films that degrade the crystalline structure of the deposited piezoelectric material.

Referring now to Fig. 1a, a simplified diagram of a piezoelectric resonator 100 is shown. The piezoelectric resonator 100 comprises a substrate 110, a layer or body 120 of piezoelectric material, and an acoustic reflecting region 125 such as a Bragg reflecting region therebetween. Alternatively, as shown in Fig. 1b, the layer 120 of piezoelectric material is suspended above the substrate 110 by a suspended membrane 127 of, e.g., air or silicon nitride (SiN_x). A pair of electrodes 130, 135 are coupled or otherwise attached to piezoelectric material 120 of both arrangements, e.g., by conventional means.

The layer 120 of piezoelectric material is made of any suitable material that has piezoelectric qualities sufficient for the particular resonator application. Typical piezoelectric materials include, e.g., quartz, zinc oxide (ZnO), aluminum nitride (AlN) and ceramic materials such as lithium niobate ($LiNbO_3$), lithium tantalate ($LiTaO_3$), paratellurite (TeO_2) and lead titanate zirconate (PZT-SA). The substrate 110 is made of, e.g., silicon (Si), aluminum oxide (Al_2O_3) or other suitable materials such as quartz, sapphire, polysilicon and aerogel.

In use, the piezoelectric resonator 100 typically has a voltage potential applied across electrode 130, 135, which causes the layer 120 of piezoelectric material to vibrate at a resonant frequency, f_0, due to the piezoelectric effect, thus operating as a resonator. The operating frequency of the piezoelectric resonator 100 depends on the total thickness of the piezoelectric layer 120 and the electrodes 130, 135, which total thickness is due mostly to the thickness of the piezoelectric layer 120. More specifically, the operating frequency is inversely proportional to the thickness of the piezoelectric layer 120 and the electrodes 130, 135. Accordingly, for high operating frequencies, e.g., frequencies greater than approximately 700 Megahertz (MHz), the thickness of the piezoelectric layer 120 has been reduced to the extent that the piezoelectric layer 120 is merely a thin film deposited on the substrate 110. Typical thicknesses of the piezoelectric film range from approximately five hundred (500) nanometers (nm) to approximately ten (10) microns (μm).

As discussed previously herein, conventional sputtering techniques such as sputter deposition, reactive sputter deposition, and DC reactive sputtering do not provide adequate deposition rates. However, one type of conventional sputtering technique that often provides an adequate deposition rate is pulse DC reactive sputtering. Referring now to Fig. 2, a typical pulse DC reactive sputtering arrangement 200 is shown.

The conventional arrangement 200 includes a chamber 210 (e.g., a plasma chamber) and a pair of electrodes 220, 225 configured within the chamber 210. The electrodes 220, 225 are capable of supplying an electric potential therebetween, as indicated generally by the polarity signs associated therewith. The electric potential applied to the electrodes is controlled, e.g., by any suitable control means (shown generally as 230), including pulse width control.

The arrangement 200 includes a first source 240 capable of supplying a noble gas, e.g., argon (Ar), into the chamber 210. Other suitable noble gases include, e.g., xenon (Xe) and krypton (Kr). Also, the arrangement 200 includes a second source 250 capable of supplying a reactive gas into the chamber 210, e.g., via a gas delivery ring 255. The reactive gas is, e.g., oxygen, nitrogen or other suitable gas.

A (conductive) target 260 is positioned within the chamber 210, e.g., in electrical connection with one of the two electrodes 220. In this manner, the target 260 serves as the cathode during the sputter portion of the cycle when a negative electrical potential is applied across electrodes 220, 225. The target 260 is, e.g., a relatively flat plate of aluminum or other suitable material such as zinc.

The substrate 110 upon which the piezoelectric thin film is to be coated is positioned within the chamber 210, e.g., above the target 260 and the gas delivery ring 255. The substrate 110 is made of, e.g., silicon, aluminum oxide (Al_2O_3) or other suitable material such as quartz, sapphire, polysilicon and aerogel.

In operation, the first source 240 provides noble gas into the chamber 210. A second source 250 delivers reactive gas into the sputtering chamber 210. According to embodiments of the invention, the gas delivery ring 255 directs the delivery of the reactive gas at the target 260 (as will be discussed in greater detail hereinbelow). The reactive gas produces a relatively thin insulating film (e.g., AlN) on the target 260. Upon the application of a sufficient electric potential across the electrodes 220, 225, ionization of the noble gas occurs and ions therefrom sputter the thin nitride film on the target 260. Atoms of the nitride film on the target 260 are freed by the ion bombardment and thus are made available for coating the substrate 110.

Pulsed DC reactive sputtering arrangements offer an additional variation to the arrangement described in that the electric potential supplied between the electrodes includes a positive voltage pulse. Conventionally, the voltage is pulsed, e.g., to reduce the possibility of arching (see, e.g., U.S. Patent No. 5,651,865) and to prevent excessive accumulation of noble gas ions on the surface of the target material. However, according to embodiments of the invention, the pulse yields an extra degree of freedom in the film deposition to improve the film quality and reproducibility.

For example, conventional pulse DC reactive sputtering arrangements supply a positive DC voltage of approximately 50 volts typically for approximately 25% of the duty cycle and then a negative DC voltage of approximately 200-500 volts for remaining 75% of the duty cycle. The duty cycle ratio of positive DC voltage to negative DC voltage conventional is adjusted based on the effect it has on deposition rate and noble gas ion accumulation. As mentioned previously herein, the amplitude and pulse width of the applied DC voltage is controlled, e.g., by any suitable control means (shown generally as 230).

However, the conventional desire to neutralize accumulated charge on the target film and maximum deposition rate results in a film that is slightly metal-rich. This stoichiometry produces a relatively poor film texture. Therefore, according to embodiments of the invention, the pulse width is adjusted to produce a stoichiometry that improves the film texture.

In pulse DC reactive sputtering systems, whether it be in silicon processing or in fabricating piezoelectric resonators, other variables also are managed in an attempt to improve the deposition rate and the overall quality of the deposited films without sacrificing too much from either. Such variables include, e.g., substrate temperature, substrate bias, deposition, gas ratio and chamber pressure. However, just as with the pulse width, many of these variables are advantageous to one aspect and simultaneously are disadvantageous to another aspect. Therefore, many of the variables often are adjusted with such considerations in mind and, accordingly, are set in a manner that amounts to a compromise between the two conflicting aspects. In general, the more important variables are chamber pressure, reactive gas delivery, deposition power and gas ratio.

Embodiments of the invention are based on the realization that adjusting the pulse width of the positive portion of the applied DC voltage significantly increases the film texture for a given range of other deposition parameters. Furthermore, providing a gas delivery system that directs the reactive gas directly to the active sputter area further enhances the film texture. Accordingly, embodiments of the invention offer piezoelectric resonators having thin films of piezoelectric material with improved texture compared to similarly deposited films without the inventive pulse width adjustments and gas delivery.

Fig. 3 shows generally a method 300 for fabricating a piezoelectric resonator according to embodiments of the invention. Reference will be made periodically to the pulse DC reactive sputtering arrangement 200 shown in Fig. 2 during the discussion hereinbelow of the method 300. However, it should be remembered that the exemplary method 300 shown in Fig. 3 and the pulse DC reactive sputtering arrangement 200 shown in Fig. 2 are for illustration purposes only and are not meant to be a limitation of the invention.

The first step 310 of the inventive method 300 is to provide the target material 260 for use within the sputtering chamber 210 suitable for use in pulse DC reactive sputtering techniques. As discussed previously herein, the target material is, e.g., aluminum, zinc or other suitable (conductive) material. The next step 320 is to provide or otherwise position the substrate 110 within the sputtering chamber 210. The substrate 110 is positioned within the chamber 210, e.g., above the target 260. The substrate is made of, e.g., silicon, aluminum oxide (Al_2O_3) or other suitable material such as quartz, sapphire, polysilicon and aerogel.

The next step 330 is to introduce a noble gas (e.g., via the first source 240) into the sputtering chamber 210. The next step 350 is to introduce the reactive gas into the sputtering chamber 210. According to embodiments of the invention, the reactive gas is directed onto the target 260, e.g., by the gas delivery ring 255. The next step 340 is to apply a sufficient electrical potential across the electrodes 220, 225 to cause ions of the noble to be directed toward the target 260 along with reactive gas with sufficient energy to cause atoms of the target material and the insulating layer formed on the target 260 to be released from the target 260. The next step 360 is to adjust the pulse width to neutralize the accumulated charge on the surface of the target 260. As discussed previously herein, the reactive gas forms a thin film on the surface of the target 260, which is released and, in turn, coats the substrate and forms a layer thereon.

As discussed previously herein, pulse DC reactive sputtering arrangements provide a periodic positive DC voltage across the electrodes 220, 225 separated by periods in which a negative voltage potential exists across the electrodes and target sputtering occurs. The application of this periodic positive voltage pulse is done for a number of reasons, as discussed hereinabove, including to improve film texture and increase piezoelectric response.

According to embodiments of the invention, the method 300 includes an adjusting step 360 to adjust the pulse width of the applied periodic DC pulses for purposes of improving the crystalline quality of the coating or layer. The pulse width and other parameters associated with the applied voltage signal are controlled, e.g., by a control means 230, shown generally in Fig. 2.

According to embodiments of the invention, in general, with a given set of deposition parameters, adjusting the pulse width and directing the gas components to the active sputtering region on the surface of the target 260 improve the film texture of the final deposited layer. According to embodiments of the invention, the pulse width of the positive portion of the pulsed DC voltage is adjusted to be within the range from approximately 5-40% of the pulsed DC voltage duty cycle.

By comparison, conventional pulsed DC reactive sputtering arrangements often establish pulse widths based on increasing or maximizing deposition rates, with little if any regard for the crystalline quality of the deposited layer that ultimately is formed on the substrate. Conventional pulse widths typically are set to no more than approximately 25% of the duty cycle and typically remain at or near 25% of the duty cycle.

Figs. 4a-b illustrate the voltage applied between the electrodes in pulsed DC reactive sputtering arrangements according to embodiments of the invention (Fig. 4a) and according to conventional configurations (Fig. 4b). As shown in Fig. 4a, the applied voltage pulses according to embodiments of the invention typically are less than 25% of the duty cycle, which is smaller than the applied voltage pulses in conventional arrangements, as shown in Fig. 4b.

According to embodiments of the invention, regions of piezoelectric material are formed that have full width at half maximum (FWHM) rocking curves of less than approximately 2.5, but typically within the range from approximately 1.8 to 2.5. By comparison, conventional methods produce piezoelectric materials that have full width at half maximum rocking curves of at least 2.5, more typically within the range from approximately 3 to 5.

It will be apparent to those skilled in the art that many changes and substitutions can be made to the embodiments of the piezoelectric resonators deposition techniques herein described without departing from the spirit and scope of the invention as defined by the appended claims and their full scope of equivalents.

WHAT IS CLAIMED IS:

1. A method of pulse DC reactive sputtering, said method comprising the steps of:

providing a target material within a sputtering chamber;

positioning a substrate within said sputtering chamber;

introducing a noble gas into said sputtering chamber;

introducing a reactive gas into said sputtering chamber, wherein said reactive gas reacts with a portion of said target material to form an insulating film on said target material;

applying a pulsed DC voltage across a pair of electrodes that are positioned within said sputtering chamber in such a way that ions from said noble gas impinge upon the target material and the insulating layer formed on said target material, wherein the freed atoms of the target material and the insulating layer are available for accumulation on said substrate to form a coating thereon; and

adjusting the pulse width of said pulsed DC voltage to improve the crystalline structure of the coating formed on said substrate.

2. The method as recited in claim 1, wherein the pulsed DC voltage includes a positive portion and a negative portion, and wherein said adjusting step adjusts the positive portion of the pulsed DC voltage to be within the range from approximately 5-40% of the pulsed DC voltage duty cycle.

3. The method as recited in claim 1, further comprising the step of directing said reactive gas toward said target material within said sputtering chamber.

4. The method as recited in claim 1, wherein the pulsed DC voltage includes a positive portion and a negative portion, and wherein said applying step further comprises

applying the positive portion of the pulsed DC voltage sufficient to limit the accumulation of ions of said noble gas on said target material.

5. The method as recited in claim 1, wherein said reactive gas is selected from the group consisting of nitrogen, oxygen, ammonia and hydrogen.

6. The method as recited in claim 1, wherein said target material is selected from the group consisting of aluminum, quartz, zinc oxide (ZnO), aluminum nitride (AlN), lithium niobate ($LiNbO_3$), lithium tantalate ($LiTaO_3$), paratellurite (TeO_2) and lead titanate zirconate (PZT-SA).

7. The method as recited in claim 1, wherein said noble gas is selected from the group consisting of argon (Ar), xenon (Xe) and krypton (Kr).

8. The method as recited in claim 1, wherein said substrate is selected from the group consisting of silicon, aluminum oxide (Al_2O_3), quartz, sapphire, polysilicon and aerogel.

9. A method of making a piezoelectric resonator, said method comprising the steps of:

providing a sputtering chamber including a target material;

positioning a substrate within said sputtering chamber;

introducing a noble gas into said sputtering chamber;

directing a reactive gas within said sputtering chamber toward the target material, wherein said reactive gas reacts with a portion of said target material to form an insulating film on said target material;

applying a pulsed DC voltage across a pair of electrodes that are positioned within said sputtering chamber in such a way that ions from said noble gas impinge upon the target material and the insulating layer formed on said target material, wherein the freed atoms of the target material and the insulating layer are available for accumulation on said substrate to form a coating thereon; and

adjusting the pulse width of said pulsed DC voltage to improve the crystalline structure of the coating formed on said substrate.

10. The method as recited in claim 9, wherein said adjusting step adjusts the pulse width of the positive portion of the pulsed DC voltage to be within approximately 5-40% of the duty cycle.

11. The method as recited in claim 9, wherein said target material is selected from the group consisting of aluminum, quartz, zinc oxide (ZnO), aluminum nitride (AlN), lithium niobate ($LiNbO_3$), lithium tantalate ($LiTaO_3$), paratellurite (TeO_2) and lead titanate zirconate (PZT-SA).

12. The method as recited in claim 9, wherein said reactive gas is selected from the group consisting of nitrogen, oxygen, ammonia and hydrogen.

13. The method as recited in claim 9, wherein said noble gas is selected from the group consisting of argon (Ar), xenon (Xe) and krypton (Kr).

14. The method as recited in claim 9, wherein said substrate is selected from the group consisting of silicon, aluminum oxide (Al_2O_3), quartz, sapphire, polysilicon and aerogel.

15. A piezoelectric resonator, comprising:

a substrate;

a region of piezoelectric material;

an acoustic reflection region operably coupled between said substrate and said region of piezoelectric material; and

a pair of electrodes coupled to said region of piezoelectric material, wherein said region of piezoelectric material has a full width at half maximum (FWHM) rocking curve of less than approximately 2.5.

16. The resonator as recited in claim 15, wherein said region of piezoelectric material has a full width, half maximum rocking curve of within the range from approximately 1.8 to 2.5.

17. The resonator as recited in claim 15, wherein said substrate is selected from the group consisting of silicon, aluminum oxide (Al_2O_3), quartz, sapphire, polysilicon and aerogel.

18. The resonator as recited in claim 15, wherein said region of piezoelectric material is selected from the group consisting of aluminum, quartz, zinc oxide (ZnO), aluminum nitride (AlN), lithium niobate ($LiNbO_3$), lithium tantalate ($LiTaO_3$), paratellurite (TeO_2) and lead titanate zirconate (PZT-SA).

Abstract of the Disclosure

Embodiments of the invention include a pulse DC reactive sputtering method for thin film deposition. The inventive method is used, e.g., for depositing thin films of piezoelectric materials on substrates, e.g., during the fabrication of piezoelectric resonators. Embodiments of the invention include the steps of providing a target material such as aluminum within the sputtering chamber, positioning a substrate such as silicon within the sputtering chamber, providing a noble gas such as argon into the sputtering chamber, directing a reactive gas such as nitrogen within the sputtering chamber, applying a pulsed DC voltage across the electrodes within the sputtering chamber sufficient to cause ions from the noble gas to impinge upon the thin insulating layer (e.g., AlN) formed on the target material, physically removing ions thereof and allowing them to accumulate on the substrate. According to embodiments of the invention, the pulse width of the positive portion of the applied voltage is adjusted based on its effect on the desired film constituency, stress, and texture. By comparison, conventional arrangements establish pulse widths based on their effect on improving deposition rates, regardless of its effect on the film texture. Alternatively, embodiments of the invention adjust the direction and delivery of the reactive gas within the sputtering chamber, e.g., toward the target material, to further enhance the desired film constituency, stress, and texture through more efficient reaction by the reactive gas.

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5. OTHER: No Declarations

Fig. 1a

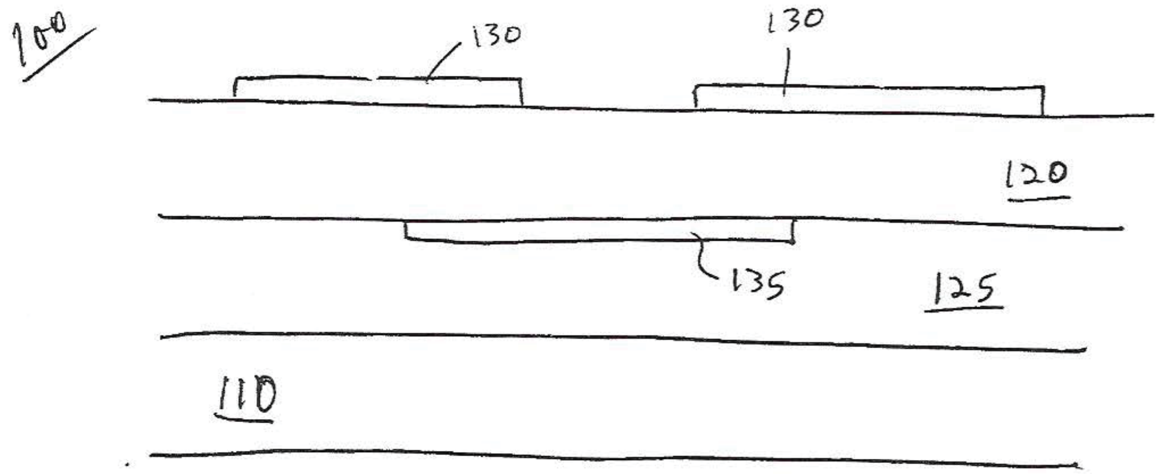
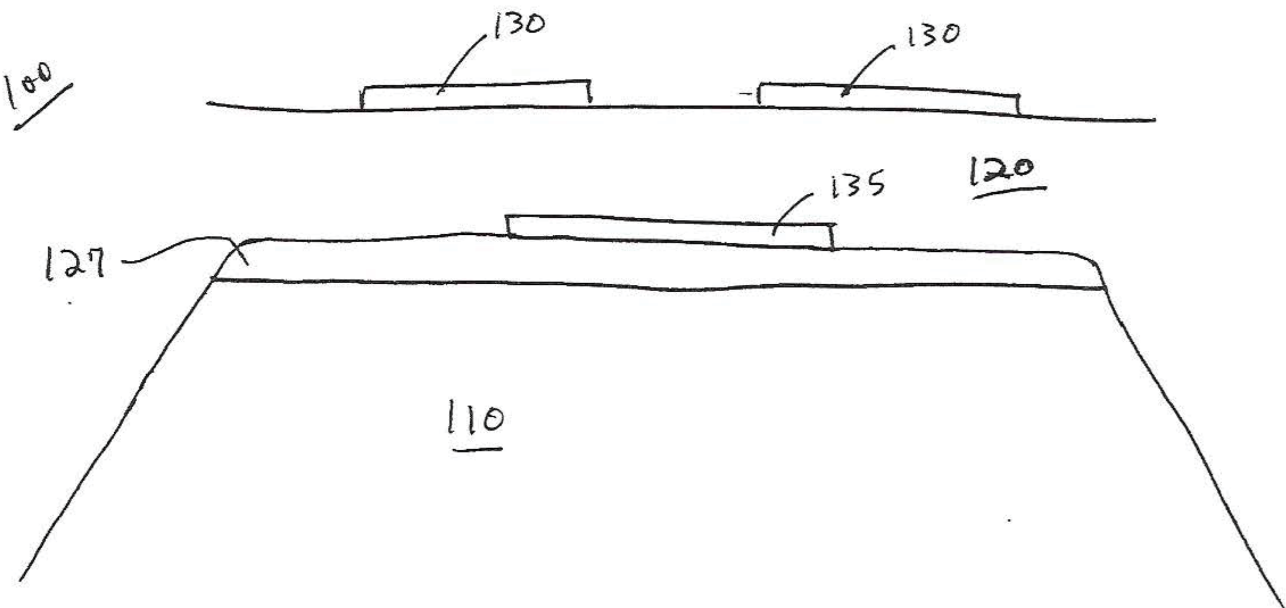


Fig. 1b



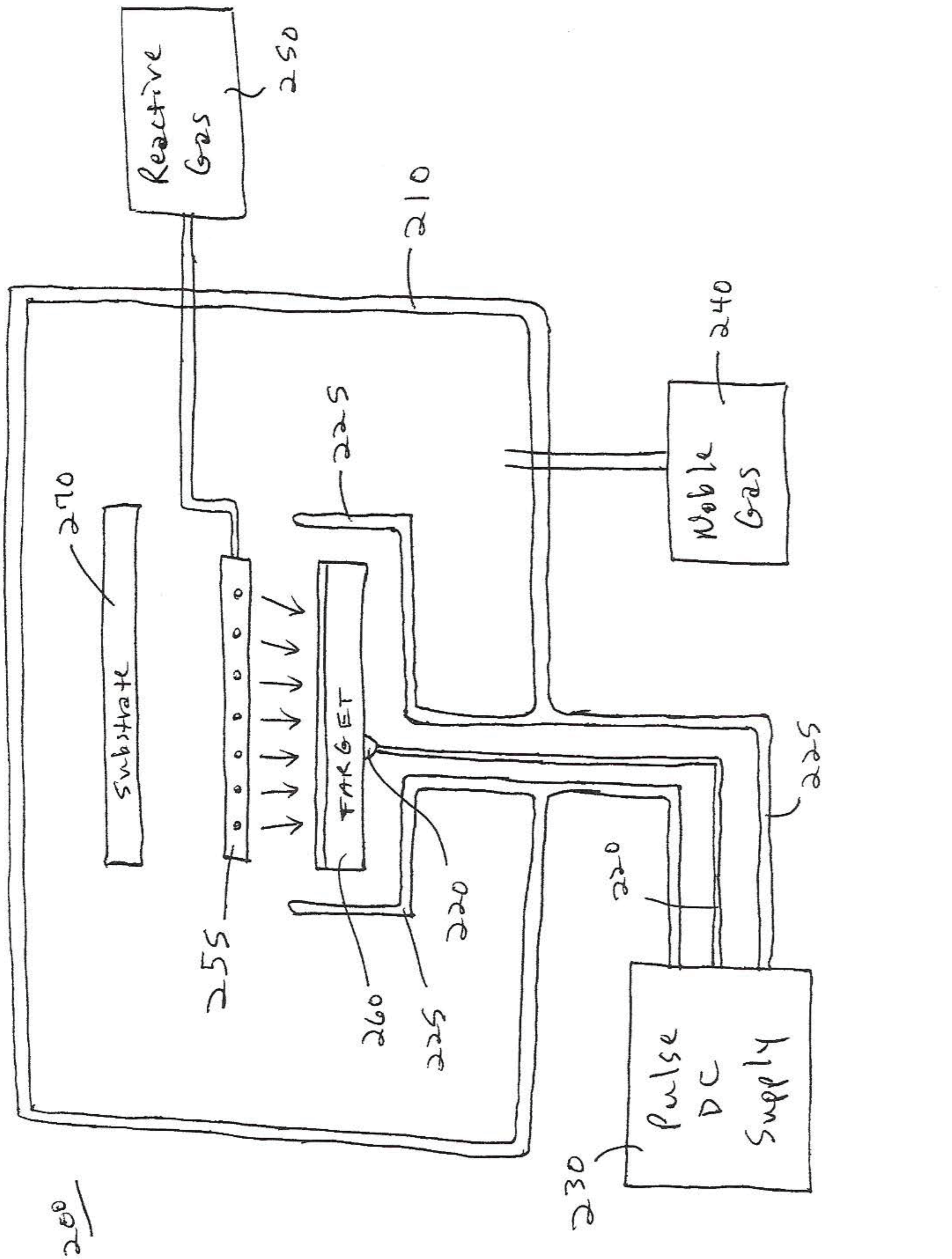

Reactive Gas
250
210
Noble Gas
240
270
Substrate
225
TARGET
255
260
220
225
220
225
230
Pulse DC Supply
200

Fig. 2

Fig. 3

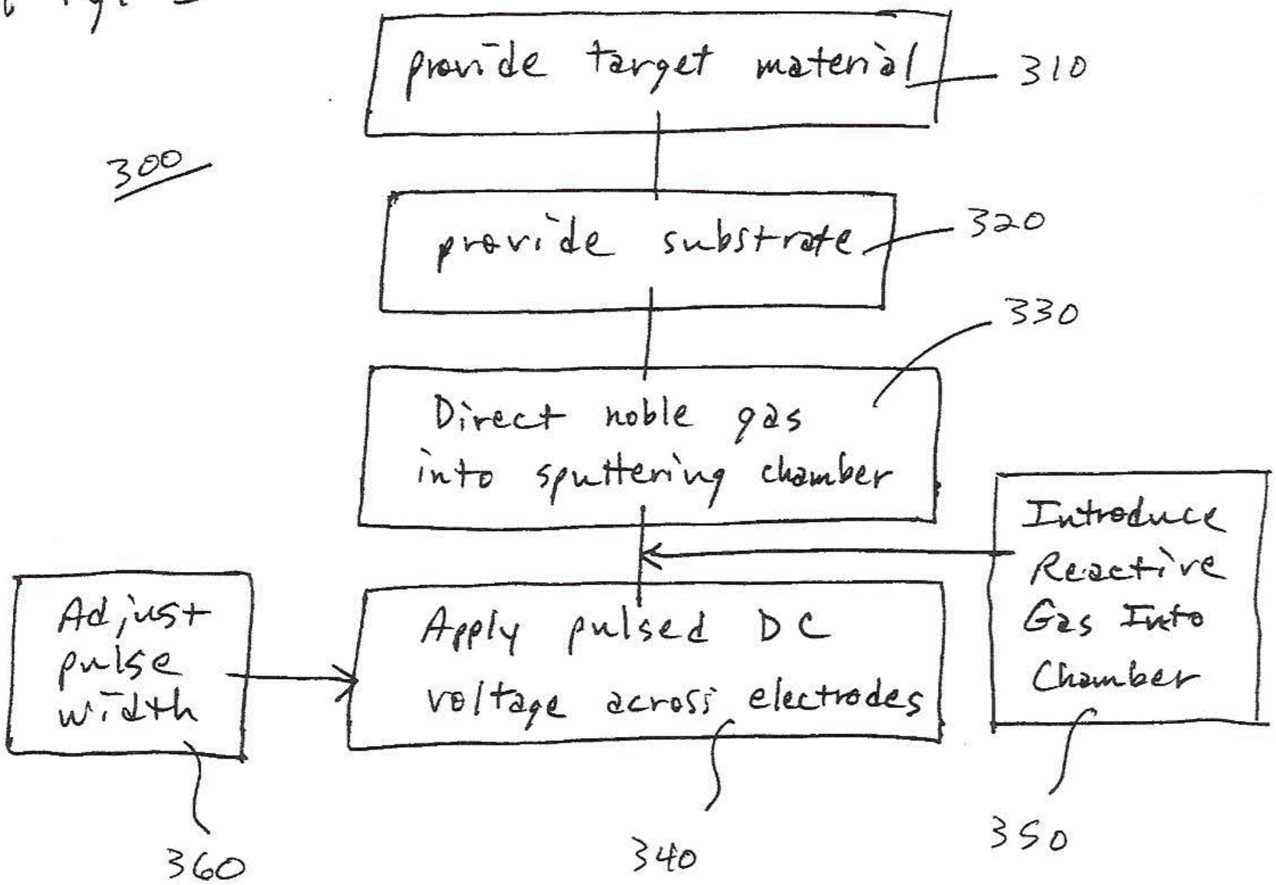

300
provide target material
310
provide substrate
320
330
Direct noble gas into sputtering chamber
Introduce Reactive Gas Into Chamber
Adjust pulse width
Apply pulsed DC voltage across electrodes
360
340
350

Fig. 4a

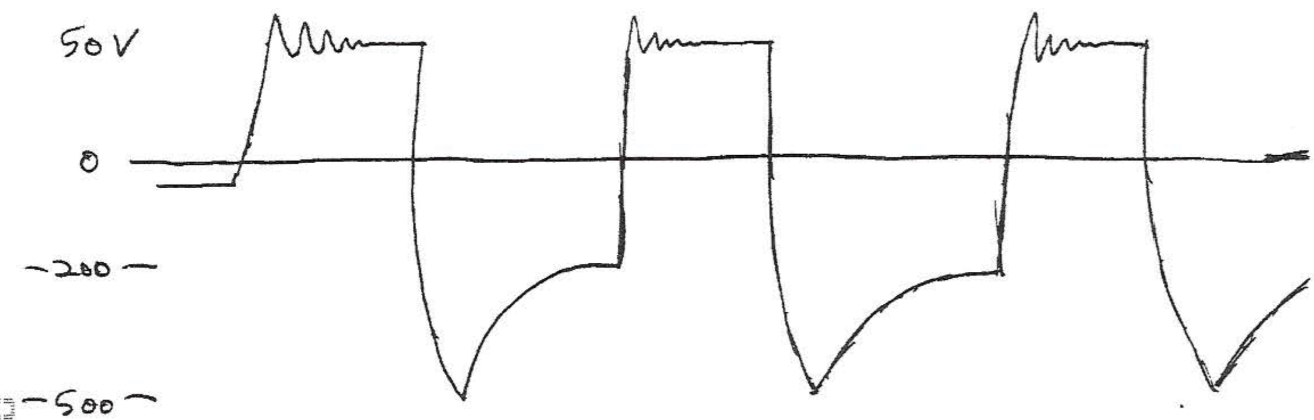


Fig. 4b