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Research paper

The Variation of Propagation Velocity According to Substrate Material of Band Pass Filter

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Abstract

Background/Objectives: The SAW filter has a frequency characteristic determined by the geometry of the IDT electrode, and is widely used as a band-pass filter for passing only a signal having a specific frequency.
Methods/Statistical analysis: The features of this filter are high stability and reliability and enable mass production using semiconductor processes.
Findings: The MCB process lift off method was used to fabricate the filter to solve the difficulties of the SAW filter process. In particular, we fabricated ZnO thin films with excellent c-axis preferential orientation, high resistivity of more than $10^6\Omega$cm, and flat surfaces, and fabricated SAW filters using ZnO thin films as deposition conditions suitable for application to SAW filters. ZnO thin films deposited under conditions of RF power of 150W, chamber pressure of 10mTorr, substrate temperature of 200 ° C and gas mixture ratio of Ar/O_2 of 50/50 as sputtering gas have excellent c-axis preferential orientation, high specific resistance and flat surface shape. Then, ZnO piezoelectric thin film was deposited on SiO_2 substrate by RF magnetron sputtering method and the SAW filter was fabricated by the MCB lift off method to analyze the frequency characteristics. And compared with the SAW filter fabricated on the $LiNbO_3$ substrate, which is a piezoelectric substrate.
Improvements/Applications: The propagation speed of the SAW filter using the ZnO thin film was determined by the variation of the center frequency due to the deposition of the ZnO thin film.

Keywords: *SAW filter, MCB process lift off method, ZnO thin film, c-axis preferential orientation, RF magnetron sputtering method*

1. Introduction

In recent years, the information and communication field has been rapidly developing, leading the mobile communication and in the future, this trend is expected to continue. A surface acoustic wave (SAW) filter arranges an Interdigital Transducer (IDT) on a piezoelectric substrate. Then, the input signal is transmitted to the surface acoustic wave by the piezoelectric effect, and then the electrical signal is detected again. That is, according to the electrode structure and the piezoelectric substrate, the input electric signal is converted to a surface wave on a substrate, and the surface wave is again converted into an output electric signal[1-3].

At this time, it is the basis of the operation to pass only a specific frequency signal. Such a surface acoustic wave filter is often used as a band-pass filter for determining a frequency characteristic by the geometry of an IDT electrode and passing only a signal of a specific frequency. The characteristics of the surface acoustic wave filter are small, light and thin, and it is a single pattern with no adjustment, so it is stable and reliable and can be mass-produced by various applications (TV, mobile communication, satellite communication, military etc.) and semiconductor processing. Piezoelectric substrate materials that propagate the acoustic wave are mono-crystalline materials (SiO_2, $LiNbO_3$, $LiTaO_3$, etc.) and ZnO polycrystalline thin films[4,5]. From all over the world the frequency domain used in the field of communication is becoming increasingly high frequency due to increase of information amount, transmission speed, distance, and the like. Therefore, development of systems and components is becoming more important. The objective of this study is to study the application of SAW filter, the characteristics of piezoelectric thin film and the design of IDT by designing pass band filter using ceramic piezoelectric thin film technology as SAW filter which is core high frequency component. A photolithography technique was applied to fabricate the SAW filter. The characteristics of the SAW filter are high productivity and high reliability because the photolithography technology is applied to the manufacturing. Photolithography is a technique for implementing a pattern designed on a mask on a wafer under a process control standard[6-8].

That is, a photochemical reaction occurs by exposing light having a specific wavelength to a photoresist-coated wafer through a pattern formed mask. Next, during the development process, the pattern is formed by a chemical reaction. The formed photoresist pattern is removed by a chemical action in an etch method or a lift-off method[9, 10].

2. Fabrication Process of SAW Filter

Substrate contamination on $LiNbO_3$ piezoelectric substrates can affect photolithography and Al deposition. Therefore, in order to prevent this contamination, it was ultrasonically cleaned in acetone, alcohol and DI water for 30 minutes, respectively, and then blown dry with nitrogen. In order to implement a pattern designed on a mask on a substrate the necessary photographic process is spin, soft bake, alignment and exposure, development, and hard bake. A schematic diagram of the photolithography process is shown in Fig 1.

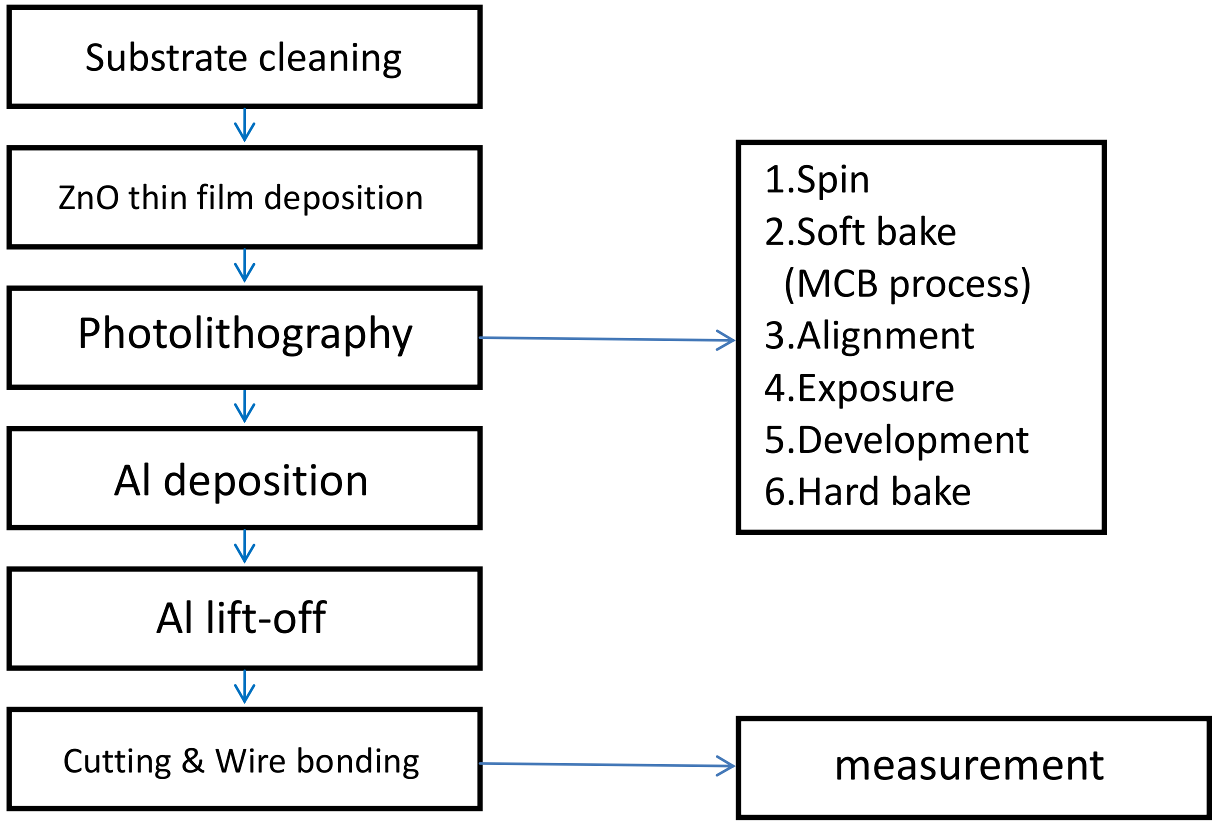

Figure 1: Fabrication process chart of ZnO thin film SAW filter

A part of interest mainly in wafer surface treatment is a treatment method which improves the adhesion of the photosensitive agent. Because the surface of the wafer can be changed not only by silicon but also by silicon dioxide, silicon nitride, poly-silicon, and metals the adhesiveness of the photosensitive agent is changed in each process. When the adhesive strength of the photosensitive agent is reduced, the developed pattern falls off during development, or the pattern of the photosensitive agent is peeled off when etching, so that the undesired portion is etched and the chip itself is discarded. In this experiment, in order to increase the adhesion between $LiNbO_3$ and SiO_2 wafers and photosensitizers HMDS was coated at 500 rpm for 10 seconds and 3500 rpm for 35 seconds and then coated with a photosensitizer. The ability of the photosensitizer is closely related to the film thickness. Proper film thickness is important and the coated film should also have a uniform thickness over the entire wafer surface. For this purpose, spin coating was used among various coating methods and various parameters were adjusted to obtain uniform film thickness through spin coating. In this experiment, PR (Photoresist) coating uses a positive photoresist that develops in the exposed area, and the pattern remains in the unexposed area. Hoechst AZ1518 was used for $LiNbO_3$ wafers, AZ1512 was used for SiO_2 wafers followed by PR coating at 500 rpm for 10 seconds and 3500 rpm for 35 seconds. The PR thickness at this time was about 1 ㎛. When spinning is completed, the disperse finishes and after only 2-3 seconds, the photosensitive agent spreads to the front side of the wafer and a coating film is formed. However, in any manufacturing process, the rotation continues for more than 20 seconds. Therefore, the solvent remaining in the thin film is removed and the shape and thickness uniformity of the thin film is maintained when the soft bake process is performed after application. Typical photoresist solvents evaporate 70-80% while spinning. A soft bake is applied to remove the remaining solvent. Soft bake is a process of drying the photoresist, improving the adhesion between the substrate and the photoresist, and relieving stress by thermal annealing. Therefore, the soft bake should take into account this role and select the conditions that the solvent can be sufficiently removed and the photosensitive material is not pyrolyzed at high temperature. Normally, when convection oven is used, the condition of soft bake is about 70-95℃ for 10 minutes to 30 minutes. In this experiment, MCB(mono chloro benzene) treatment was performed in the soft bake process. The MCB treatment was conducted in a convection oven at 80℃ for 25 minutes and then exposed to MCB for 8 minutes. After 30 minutes of natural drying, it was again dried in an oven at 80℃ for 10 minutes. There are various exposure methods. The main method used in the semiconductor manufacturing process is the step-and-repeat method. This is advantageous in that it is excellent in production yield, mask protection, ease of mask making, resolving power, and can be applied to severe topology formed on a wafer. In the stepper, the wavelength of the light and the numerical aperture (NA) of the lens are important parameters for increasing the resolution ability. For optimized exposure conditions, the photoresist should be improved, the mask itself modified, and the stepper modified. In this experiment, a mask Aligner (MJB21, Karl Suss) was used to expose $LiNbO_3$ wafers for 12 seconds and SiO_2 wafers for 13 seconds at 300W in proximity mode. When exposed, the incident light and the light reflected from the wafer surface reinforce each other and cancel each other out. This results in non-uniform exposure between the exposed and unexposed boundaries, resulting in poor post-development patterns. This shape is especially noticeable when the pattern size is small. This phenomenon causes the outer wall of the pattern to become wavy due to the interference of light. In the post exposure bake, unevenly distributed PACs must be diffused and moved by applying heat to eliminate the biased structure. The temperature and time are usually 100-120℃, 60-120 seconds, slightly higher than the soft bake temperature. The puddle method, the spray method, and the dipping method are used as the method. In this experiment, AZMD-s and 300MFL were developed to develop the titration time. The ratio of developer to DI water was 1 : 4 for $LiNbO_3$ wafers and 3 : 1 for SiO_2 wafers. Thereafter, it was thoroughly washed with DI water and blow-dried with nitrogen. Hard bake is a process of removing the residual solvent to dry the photoresist and increasing the adhesion of the photoresist to the substrate. This is a process for removing the water contained in the pattern formed after the development and making the pattern stable. Usually, the mechanical strength is improved by heating at a temperature below the flow point of the photosensitive agent. Once the pattern of the desired photosensitizer is developed, metal or impurities are injected onto the wafer to form a film. In this experiment, the hard bake was dried at 115℃ for 30 minutes. The photoresist that has completed its role in the wafer must be completely removed. Semiconductor processes for forming patterns on wafers include etching and lift-off methods. In the etching method, a developer and a rinse are used to remove the photoresist existing in the portion to be etched. Etching includes wet etch using chemicals and dry etch using oxygen plasma to burn the organic photosensitizer. This can be achieved by precise pattern formation, but it is difficult to process because it involves complex physical and chemical reactions with many process variables. In particular, aluminum substrates are often under-exposed in order to avoid reflection problems which cause the photoresist to be severely damaged. Therefore, a lift-off method that can solve this disadvantage is used. This method uses a photoresist removal solution to remove the metal film deposited on the photoresist and form only the desired metal pattern. However, if the line width is small, it is difficult to form a precise pattern.

In order to solve these drawbacks, the present research has implemented accurate IDT patterns on $LiBO_3$and ZnO/SiO_2wafers by MCB treatment. That is, when a pattern is formed by exposing a photosensitive agent applied on a substrate in a fine pattern implementation the angle between the top of the pattern and the substrate should be 90°. However, if the MCB process is not performed, an obtuse angle is formed and it is difficult to realize a precise metal pattern. When MCB treatment is performed, an acute angle is formed between the uppermost surface of the pattern and the substrate, so that even when the line width of the IDT is minute, an accurate metal pattern can be formed. In this study, the MCB process lift off method was used in the process of fabricating the filter. In the etching method, when ZnO is deposited on a substrate and aluminum is deposited on a ZnO substrate at the time of etching, weak acid ZnO is removed together with aluminum. Thus, there is a process difficulty in which ZnO must be etched later. On the other hand, the lift-off method is quite simple in comparison with the etching method, but it cannot accurately realize a fine pattern, resulting in a reduction in the process rate. Therefore, this study solves the difficulties of the filter process by the MCB process lift-off method. In this experiment, uniform IDTs were used to measure the frequency response, propagation velocity and insertion loss of $LiNbO_3$ SAW and ZnO/SiO_2 SAW filters. The IDT is a single electrode. The IDT wavelength is 70μm and the number of electrodes is 4 pairs. The ratio of the thickness of the ZnO thin film and the wavelength was set at 0.2. Then, the thickness of the ZnO thin film was 20μm. An Al thin film for the formation of IDT was deposited on a substrate by pulsed dc reactive sputtering system. And an Al target (5N) having a diameter of 2" and a thickness of 1/4" were used as a target. The distance between the target and the substrate is 90mm, the substrate temperature is R T., the initial vacuum is below 3×10^{-6}Torr. Under this condition, Al thin film of about 1000Å was deposited at a DC power of 20W and a sputtering pressure of 2mTorr. Fig 2 shows the SAW filter fabricated by these processes.

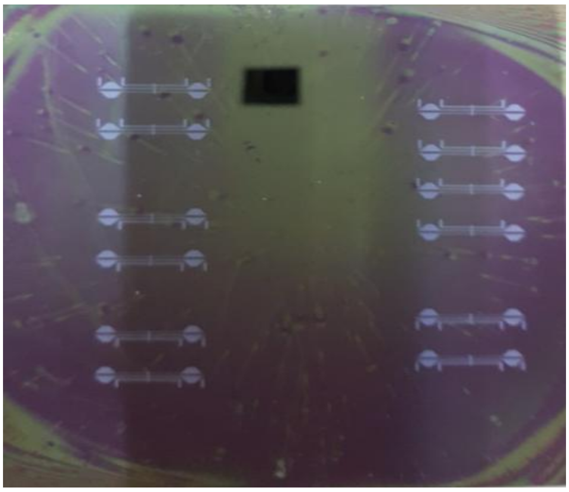

Figure2: Fabrication of ZnO thin film SAW filter by Photolithography

In this study, ZnO thin films with excellent piezoelectric properties were deposited on silicon substrates by RF magnetron sputtering. The effects of deposition parameters such as RF power, substrate temperature, chamber pressure, Ar/O_2 gas ratio, and target-substrate distance on the physical properties of thin films were investigated. In particular, ZnO thin films with excellent c-axis preferential orientation, high resistivity values of more than 106Ωcm, and smooth surfaces were fabricated and the conditions of piezoelectric thin film deposition suitable for application to SAW filters were suggested. XRD, Rocking curve, and Alpha-step were used for the crystallization of ZnO thin films. SEM was used for microstructure and AFM was used for surface analysis. In order to analyze the electrical characteristics of the thin films, ZnO thin films were deposited on the Pt substrate, and the resistivity was measured by RT66A after depositing aluminum as the upper electrode using dc sputter system. Fig 3 shows the SAW filter of Fig2 for cutting and wire bonding and measuring the frequency characteristics.

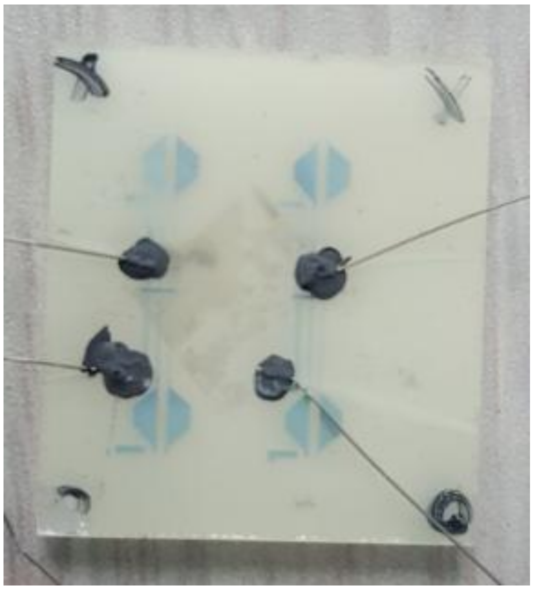

Figure3:. Cutting and wire bonding of ZnO thin film SAW filter

The ZnO thin films prepared in this experiment exhibited excellent c-axis preferential orientation with (002) crystal planes perpendicular to the substrate under all manufacturing conditions. Especially, the SAW filter could be fabricated with ZnO thin film deposited at 150W RF power, chamber pressure 10 mTorr, substrate temperature 200℃, and gas mixture ratio of Ar/O_2 as a sputtering gas as 50/50. That is, excellent c-axis preferential orientation, high resistivity, and smooth and uniform surface profile were obtained. And, as the oxygen content increased more than 50%, the surface roughness became worse. It can be seen that the resistivity and surface morphology are greatly influenced by the incoming oxygen.

3. Conclusion

To measure the frequency response, impulse response, and S-parameter of SAW filter, we measured using HP Network Analyzer 3577A (5Hz-200MHz). In particular, in order to minimize the influence of external electromagnetic waves, the SAW filter was connected to a measurement system after proper packaging. The insertion loss was the loss value at the peak point in the S21 parameter of the SAW filter, and the pass bandwidth was taken at the point where it decreased by 3dB at the maximum point, and the center frequency was the frequency value of the center point of the 3dB bandwidth. The frequency response of the SAW filter fabricated in the form of a single electrode IDT on a $LiNbO_3$ substrate was 51.07 [MHz] and the propagation velocity calculated using the center frequency was 3574.9[m/sec]. It is found that the propagation speed of the IDT is about 75[m/sec], which is slightly lower than that of the IDT designed at the center frequency of 50[MHz]. The insertion loss was about 30[dB], but it could be seen that there is some waveform distortion in the form of the frequency band.

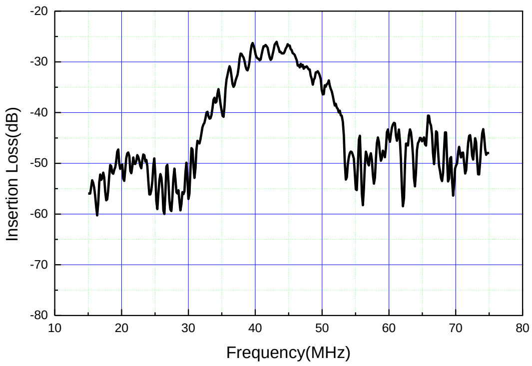

Fig 4: Frequency response of ZnO(20㎛)/Al/SiO_2 SAW filter

And to investigate the change of frequency characteristics of ZnO thin film SAW filter IDTs were formed on a SiO_2 substrate by an MCB process lift-off method, and aluminum was deposited to a thickness of 1000Å by DC sputtering. The electrode pad was exposed using a shadow mask, and the thickness of the ZnO thin film was deposited to 20μm by RF magnetron sputtering. It is known that the frequency characteristics of the ZnO thin film SAW filter are excellent under the condition that the ratio of the ZnO thin film thickness (h) to the SAW wavelength (λ) is 0.2 or more. In Fig 4, the center frequency at 20μm is 42.02[MHz] and the insertion loss is about 27[dB]. The propagation velocity calculated using the center frequency is 2941.4[m/sec]. That is, the change of the propagation speed can be seen by the change of the center frequency of the ZnO thin film SAW filter.

Acknowledgment

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