Development of Surface Acoustic Wave Device Sensor Using Optical Lithography

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Abstract: *This work is aimed at developing Surface Acoustic Wave (SAW)-based wireless passive sensors for sensing volatiles, humidity, temperature and pressure. The development of this inexpensive passive SAW sensor would create a wide range of gas sensing applications. The SAW devices consist of a piezoelectric substrate such as quartz and interdigitated (IDT) transducers formed by optical lithographic patterning of a thin metal layer. The optical lithography employs 365 nm UV light source, exposing the geometric pattern mask onto a 2 µm layer thickness of AZ5214E positive photoresist, a new epoxy product from Microchemicals. The lithographic processes were optimised to achieve IDT feature size of 39 µm for 20.2 MHz RF signal transmission.*

Keywords: Surface acoustic wave, passive sensor, optical lithography, AZ5214E positive epoxy photoresist, quartz substrate

1. INTRODUCTION

The surface acoustic wave (SAW) device is a tool that transmits signal waves through the surface of piezoelectric substrate. SAW devices can be used for various sensing tasks depending on its configurations. In this work, a wireless SAW device that functions as a gas sensor was designed and fabricated. This device has three main components: the interdigital transducer (IDT), sensing material and reflector. There are two types of IDT, which are receiver and emitter.[1–3] The receiver IDT is able to convert electric signal to mechanical motion.[6] The second component is a thin sensing material film coated on the piezoelectric substrate, located in between the IDT and the reflector. The velocity and attenuation of the propagating SAW are very sensitive to certain properties, such as mass and viscoelasticity, of thin sensing material films coated on the device surface. The third component is a reflector that has split fingers constructed at a quarter wavelength (λ/4) of the signal,[1,2] which will reflect waves propagated on the surface to the emitter IDT. The emitter IDT will convert the mechanical motion to electric signals.[3]

Piezoelectric material such as lithium niobate and quartz can be used to generate the motion because they have an elastic molecule bond.[2] These devices have been widely used in smart phones, remote controls, agricultural sensors for crop monitoring and automation.[1,4] The biggest advantage of SAW device is its ability to sense various parameters such as humidity and pressure and convert them into high quality and precision signals. This allows them to be commonly used in high precision measurement system at low costs with high reliability in heavy conditions.[1] In this work, a SAW device using 20.2 MHz radio frequency (RF) signal was designed and fabricated on quartz substrate. The material used for IDT and reflector components was an aluminium thin film. The split fingers width of each component is 39 µm. Hence, the usage of optical lithography technique to fabricate 20.2 MHz SAW device structure was explored and optimised.

2. EXPERIMENTAL

The fabrication of the SAW device on quartz substrate began with the mask-making process. The device geometries were first printed on a transparent polymer film by a scale of 5 times of the intended dimensions, where it will be placed on the mask-making system, together with a blank emulsion glass mask.

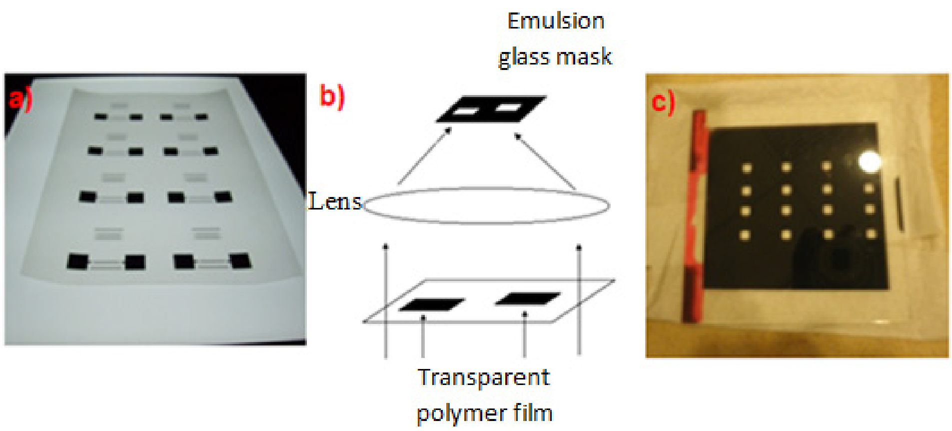

Figure 1: The mask-making process: (a) the patterned transparent polymer film, (b) the schematic of mask exposure system, and (c) the result; negative of emulsion glass mask.

Figure 1 shows the mask-making process flow where the fluorescent with 550 nm wavelength light source is exposed onto the transparent polymer film. The projected images were transmitted through optical lens that shrank the images by 5 times. After being exposed for 4 s, the emulsion glass was occasionally lifted in and out of developer solution beaker for a few minutes. It was then soaked in distilled water for 2 min, fixer solution for 10 min and finally put through running tap water for 30 min.

The optical lithography process started with the cleaning of 12×12 mm^2 quartz substrate using solvents to eliminate impurities and contamination on the substrate surface. The AZ 5124E positive photoresist from MicroChem was used in patterning process. This photoresist was diluted in 1-Methoxy-2-propanol acetate (PGMEA) solvent. Using datasheet from MicroChem AZ photoresist, the substrate was spun coated with AZ photoresist at spinning speed of 2000 rpm for 45 s to achieve a coating thickness of 1.98 μm. The samples were then baked for 50 s at temperature 110°C on a hotplate. Then, the samples were exposed with a 60W UV lamp, at 7.08 mW cm^{-2} light intensity and 365 nm wavelength of optical lithography system using the prefabricated photomask to mask the patterns. In the exposure process, the pattern on the mask was placed onto the photoresist layer to minimise light diffraction while exposing the patterns, so that, the uncovered region will be cured and polymerised. After that, the samples were soaked in AZ 326 developer solution where the non-polymerised AZ photoresist was dissolved.

RF atmosphere plasma was used to etch the residual layer of AZ photoresist on the substrate after the exposure to UV light. The RF plasma would not etch the sidewall of the AZ photoresist. Then, by using vacuum thermal evaporation machine, the aluminium was deposited onto an AZ photoresist pattern for a few seconds until a thickness of 2 μm was reached. The evaporation process of the metal must be done in a vacuum chamber to avoid the metal ion combining with any gaseous ion and being deposited on the substrate. As the fabrication of the device has a lift-off technique, care should be made to maintain the substrate and the aluminium metal within a tolerable distance. This is to ensure that the metal will coat on the surface and not on the sidewall of the pattern. In the lift-off step, dimetylsulfoxide (DMSO) is used to remove AZ photoresist and metal is left deposited on the substrate. The DMSO is used because it is a strong solvent to polymer and has a high degree of stability of acids and bases at elevated temperature.

3. RESULTS AND DISCUSSIONS

The mask formation is the initial step of optical lithography. The creation of patterns on immersion glass can give more accurate and precise features as compared to the conventional printing. The emulsion mask has a latent layer on the bottom surface and the pattern generated on this layer is a reversal or negative to the transparent polymer film. When exposed to fluorescent light, the latent layer cured the uncover region, and the cover region dissolve with film developer solution. Figure 2(a) shows the supposed pattern and Figure 2(b) is the fingers IDT of the mask.

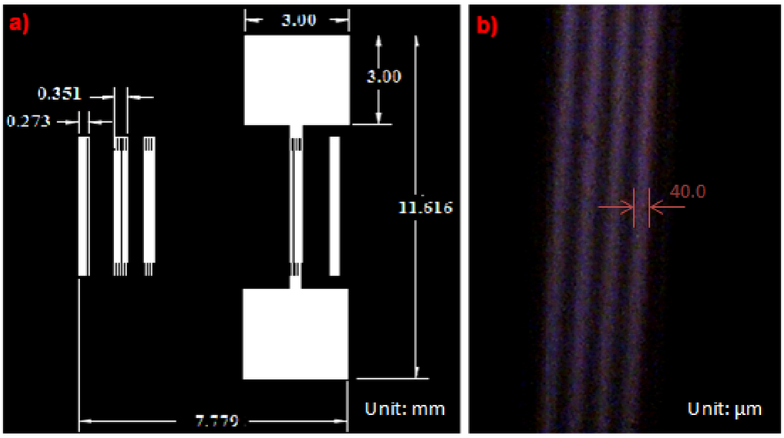

Figure 2: Illustrations of: (a) schematic of device and (b) the IDT finger from original mask.

The AZ5214E photoresist is a positive-tone photoresist. This means, when exposed to UV light, the molecules at the exposed region absorb sufficient energy to break the crosslinking between molecules and later dissolve in AZ 326 developer. In other words, AZ photoresist chains scission the exposed region when exposed to the UV light to generate the desired pattern. The flood energy exposure of the AZ photoresist is in the range 150 up to 500 mJ cm^{-2}. As recommended by MicroChem, the optimum flood energy is 200 mJ cm^{-2}. The intensity of exposure equipment system is 7.1 mW cm^{-2} and the recommended developing time is 30 s. Unfortunately, the fingers pattern of 39 µm do not appear. The exposure doses are further changed until the desired feature is obtained.

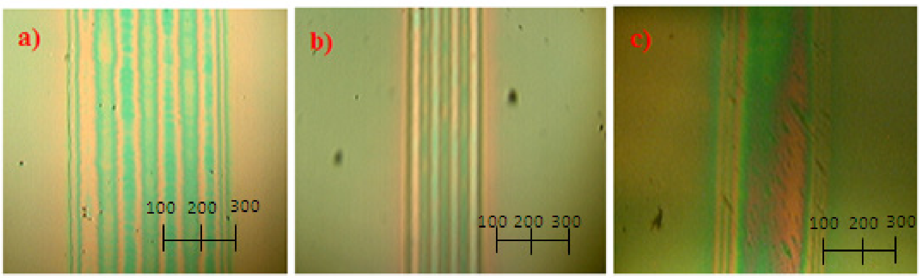

Figure 3: Optical microscopy images of the patterned IDT structure using UV dosages of: (a) 369.2 mJ cm^{-2}, (b) 390.5 mJ cm^{-2} and (c) 404.7 mJ cm^{-2}.

Figure 3 shows the three conditions of exposure steps in constant development process parameter. To break the crosslinked molecules, the AZ photoresist must absorb sufficient light energy without changing the feature size. If the exposure time is too low, fewer molecules can break the crosslink because the AZ photoresist absorbs less light energy. This explains why the continuous line patterns did not appear when 369.2 mJ cm^{-2} of UV dosage was used [Figure 3(a)]. Figure 3(b) shows the exposure time of 390.5 mJ cm^{-2}, where the pattern clearly appears on the AZ photoresist due to sufficient energy absorbed from the UV light. If AZ photoresist is exposed for a longer time, it will absorb too much energy. This energy will be dissipated to unexposed regions, which is not supposed to be soluble, as shown in Figure 3(c) when exposed at 404.7 mJ cm^{-2}.

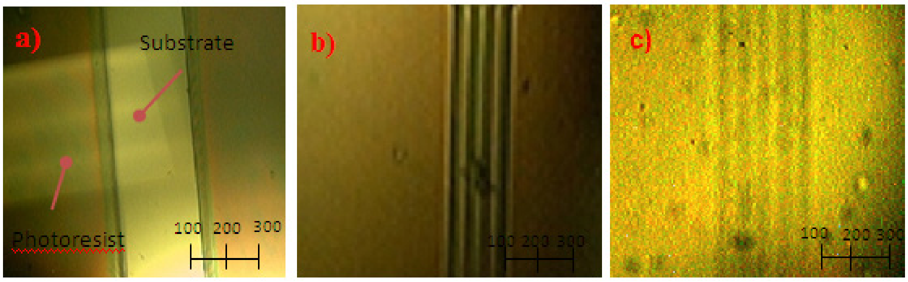

Figure 4: Optical microscopy images of development for: (a) 45 s, (b) 40 s and (c) 35 s.

When the sample is soaked in the developer solution, the solution will dissolve the weak AZ photoresist molecule crosslinks proportional with the time. If the developing time in AZ developer solution is too long, there is a high possibility the desired pattern will not be achieved, as shown in Figure 4(a). Figure 4(c) shows an unclear pattern due to short developing time. Based on the patterns observed, the optimum exposure time is 55 s, with 40 s development of the sample soaked in the developer solution as shown Figure 4(b).

The next process is the plasma ash and the deposition of thin aluminium layer using thermal evaporator. For transmission wavelength of 156 µm, the thin aluminium layer needs to be deposited to the required thickness of 1.56 µm. To achieve this thickness, the aluminium is evaporated for 8 s and the resulting thickness measurement using Filmetrix is 1.357 µm.

Figure 5 shows the result of the aluminium layer deposition after the lift-off step. The deposited aluminium only appears on the patch antenna, while none appears on the IDT fingers. The fingers IDT do not appear because the presence of photoresist residual layer blocks the aluminium deposition onto the substrate surface. This occurs due to the contrast level of mask used to transmit the UV light through AZ photoresist.[6] The range of shades affects the developed thickness of photoresist when exposed to UV light. If the range of shades is higher or darker, the penetration on photoresist is low, which will form the residual layer of photoresist on the pattern. After the lift-off process, the metal is left stuck with photoresist. Figure 5(b) shows the over-exposed reflector after aluminium deposition, which also fails during the lift-off process.

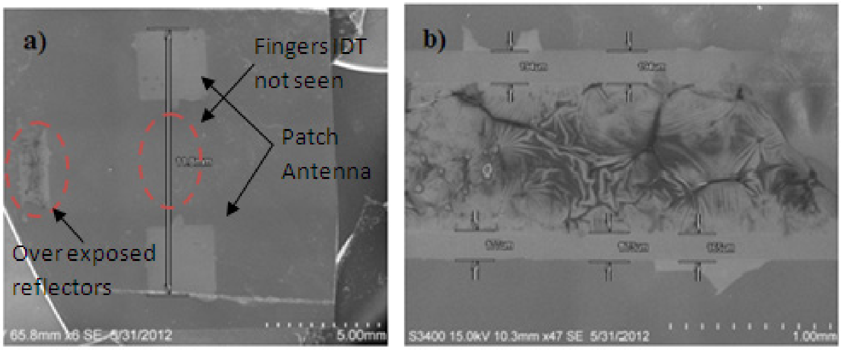

Figure 5: The SEM analysis of the pattern after lift-off process: (a) full view of the device and (b) the overexposed reflectors.

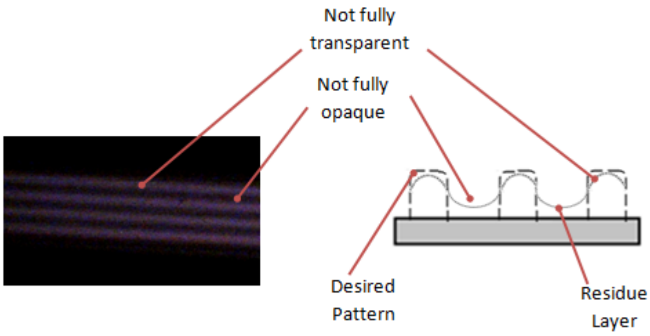

Figure 6: The IDT pattern on the mask and the profile effect from grayscale.

The bad mask contrast creates the grayscale effect of the mask pattern, which reflects the percentage of energy passing through the AZ photoresist and breaks the crosslinks of the molecules. Figure 6 shows the effect of grayscales and the profile of AZ photoresist thickness that can be penetrated by the UV light. The transparent pattern on the masks will allow most UV light transmitted through AZ photoresist layer while grey and dark pattern will allow certain percentage of UV light to be transmitted through. This will cause low contrast on the developed pattern edge.

4. CONCLUSION

The optical lithography optimisation process was performed to fabricate a 39 μm size SAW device for 20.2 MHz RF signal transmission. From the experimental study using 60 W UV light source, 7.08 mW cm^{-2} intensity and 365 nm wavelength optical lithography system for the optimised UV exposure time is 55 s. The optimised development time in AZ 326 developer by soaking is 40 s and deposition time of aluminium for 1.357 μm thickness is 8 s. The fabricated device from these processes is expected to be able to perform as designed.

5. REFERENCES

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