Chapter 1 Introduction

1．1 Study motive

Semiconductor integrated circuit has rapid development in recent years, the scale of these systems has moved from LSI to VLSI, and further to ULSI, which has over one million unit systems in it. It is predicted that ULSI system will become the trend of electrical mechanical devices and tool systems before the early 21 century. However, when the physical limit of semiconductor device miniaturization is approached, it becomes more difficult to develop this technology. Nowadays, semiconductor manufacturers are forced to invest more on new equipments and the new technology development which might have breakthrough on the technology bottleneck. In USA, Semiconductor Institute of America (SIA) has made a national semiconductor roadmap (table1.1), and SEMATECH is the leader in area of major investment and evaluation, its goal is to enhance the planning of infrastructure of microlithography and the development of next generation technology.

If we look back at the microlithography development trend, we know that the improvement of microlithography technology is the key which produces improvement on process integration. The improvement on optical lithography technology for process and equipment is on going, it will be still the mainstream in microlithography technology for the future semiconductor industry.

After understanding the current microlithography development trend, what we need to do now is to accelerate the R&D of microlithography technology and let it become a technology of mass production, besides, how to match it with the current optical microlithography system is challenge the future semiconductor industry has to face.

1．2 Research direction

Due to the rapid progress in process technology, the technology in 1997 has achieved 0.25μm process technology which is expected to be reached in 1998, therefore, the original integrated density increasing cycle of three years is changed to two years. Until 2003, the original technology forwarding cycle for one technology generation is then changed back to three years again, SEMATECH proposes a DELPHI milestone chart to enhance its planning on microlithography infrastructure and the development of next generation technology(2).

If we take a look at the spec defined by ITRS in 2001 for optical microlithography process, we know that it will head toward the development of smaller critical dimension and stricter tolerance. Therefore, it is obvious that the whole semiconductor industry is approaching the physical limit of optical microlithography process (Table 1.2).

Phase shift mask technology is a crucial technology for the manufacturing of ULSI IC. In the development process of manufacturing ULSI IC, when the mask line width used in the microlithography is shrunk to that of exposure light source, optical diffraction effect will lead to blurring pattern transferred by mask, the correct electrical layout is thus difficult to be defined and the whole IC process will be affected. However, phase shift mask technology does not need to change the original process and exposure equipment, therefore, it becomes a hot international research topic in recent years.(4~8)

The principle behind phase shift mask is that there will be phase difference of 180 degrees between optical beams pass through phase shift layer and non-phase shift layer, destructive interference is thus induced and the resolution of photo resist is enhanced and Depth of Focus (DOF) is increased.

Microlithography is mainly affected by three major optical parameters (17~18)

Wherein resolution (R) and depth of focus (DOF) is derived from Rayleigh relationship, the relationship is as in the followings:

λ is the wavelength of exposure optical source, K_1, K_2 is the coefficient related to photo resist materials, NA is the Numerical Aperture of lens. R value is as small as possible in terms of process, and DOF is as large as possible. In the process technology trend of moving toward smaller wavelength of exposure optical source, larger NA tends to get better imaging resolution. But larger NA will turn the DOF smaller, therefore, K_1 value must be reduced and K_2 value must be increased to get appropriate resolution and DOF.

The definition of coherence, σ, is explained by figure 1.1(19), it is the ratio of Diameter of Source Image to Effective Diameter of Projector; or it is the ratio of light emitting to the NA of projector. The effective coherence is in the range of 0~1, coherence 0 means the most perfect optical consistency and the strongest interference; when coherence approaching ∞, the optical consistency is worst and the interference is weakest. Through the control of coherence in the microlithography process, one can obtain better resolution and DOF.

Along with the IC manufacturing technology miniaturization in the wafer foundry, current photo mask company uses PSM (Phase Shift Mask) ask mask material for process below 0.35 μm, the mainstream process will moves into 0.25μm in next year.

In 1965, White and Voltmer deposit interdigital transducer, IDT, on the surface of piezoelectric substrate, through the use of piezoelectric characteristic, the input electromagnetic wave signal is transformed into mechanical energy, this is to excite surface wave and it is transferred to the IDT transducer at the output end through piezoelectric substrate, then the mechanical energy is transformed into electromagnetic wave signal in order to filter out unnecessary signal and enhance signal reception quality, surface acoustic wave device is thus become an indispensable electronic element. Since the surface acoustic wave device has an insertion loss of over 6dB, it thus can not be used as the filter at radio frequency, RF, in the wireless communication system. Along with new development in the new piezoelectric materials and IDT design technology, the insertion loss of surface acoustic wave filter, SAW filter, has been reduced to 1~3dB, it is thus widely used in the wireless signal processing field of wireless communication system. Since the SAW filter has the features such as compact size, low loss, good filtering effect and suitability for mass production, etc., it is thus widely used in the mobile communication system global positioning satellite system.

Along with rapid advancement of new technology, communication system of high data communication rate becomes more and more important, therefore, how to enhance the characteristic of its key related component, SAW device, is thus becoming a very important research topic currently. SAW device is an important wireless communication component currently in shortage, these include, SAW duplexer, SAW resonator, RF and IF SAW filter, etc. To a SAW device, the way to enhance work efficiency is to reduce finger or line width of electrode or through the use of piezoelectric materials of higher wave speed; the reduction of line width is limited by the process capability, it needs to be done through the microlithography technique.

1. 3 Research goal

This study will be focusing on Surface Acoustic Wave Devices manufactured through the use of technologies such as: Near-Field Photolithography, Polydimethylsiloxane, abbreviated as PDMS, Phase Shifting Mask, abbreviated as PSM, etc. The use of near field photolithography technology and Polydimethylsiloxane (PDMS) phase shifting mask has the following advantages as compared to other photo mask technologies:

(1) Simple and low cost process.

(2) Mask with line width of micron scale can be used to manufacture pattern with line width of of nanometer scale.

(3) PDMS mask is of soft material, it can have a perfect contact to the exposure surface.

Based on the above advantages, we thus try to find appropriate materials to manufacture mask which meets the requirement of PSM in order to be used in the optical lithography technology of next generation.

1. 4 Introduction to the thesis structure

This thesis is divided into five chapters. The content in each chapter is briefly described as in the followings:

Chapter 1: Motive, direction and goal of the study will be introduced.

Chapter 2: First, the important characteristics and related materials characteristic analysis of Polydimethylsiloxane, abbreviated as PDMS, will be introduced, besides, the related principles and characteristics of near field photolithography and Surface Acoustic Wave Devices will be introduced.

Chapter 3: Experimental system, the sample allocation, setting of experimental system and the experimental process will be introduced.

Chapter 4: Related descriptions will be stated based on the detected experimental data, analysis and investigation will be performed on the experimental results.

Chapter 5: conclusion.

Chapter 6: Future perspectives.

Chapter 2 Literature review

2.1 Introduction to Surface Acoustic Wave

Surface Acoustic Wave, SAW, device has many features such as: compact size, good performance, high reliability, etc., it is thus widely used in 3C products such as: Communication, Computer and Consumer. Among them, the largest demand is the SAW filter used in the mobile phone. SAW device has played an important role in the communication industry, one of the key component SAW device used in the mobile phone is thus so crucial, its future development has drawn attention from every direction.

2.2 Principle of surface acoustic wave

Surface acoustic wave is elastic wave transmitted along the solid surface, it is elliptical trace comprising of Longitudinal wave and Shear wave. The working principle of surface acoustic wave device it to input the reverse electrical effect of IDT to convert the electrical signal into acoustic wave signal, the signal is then propagating through piezoelectric substrate, and the output IDT then converts the acoustic wave signal into electrical signal again for output. This input and output IDT converts the input signal of electromagnetic wave into mechanical energy through the piezoelectric effect of piezoelectric substrate, then the mechanical energy is converted back into electrical signal. The main advantages of SAW device are: compact size, light weight and perfect transmitted wave form, but the high Insertion Loss in the early stage prevents its widespread application in the electronic industry.

2.2.1 Piezoelectric effect

Piezoelectric effect includes forward piezoelectric effect and negative piezoelectric effect, the former receives mechanical force or stress to generate electric charge or voltage output, the latter receives electrical power input to an object to generate output of mechanical energy or stress.

The basic type surface acoustic wave filter is as shown in figure 2.1, wherein finger electrode is a transducer (electric signal---surface acoustic wave). Since the substrate has Piezoelectric characteristic, it can convert the input RF electric signal into acoustic wave signal, based on the piezoelectric effect and through the finger electrode on the input end. After that, the surface acoustic wave will propagate along the surface of the piezoelectric substrate (a direction perpendicular to the electrode), then the acoustic wave signal is converted back to RF electric signal for output through the finger electrode on the output end through the piezoelectric effect on the finger electrode on the output end.

Generally speaking, the following equation can be used to decide

[23]

Wherein V the rate of surface acoustic wave

f_0 is the center frequency of surface acoustic wave

λ is the wavelength of surface acoustic wave ($4d=\lambda$ is the general design rule)

Besides, for the filter, the 3dB bandwidth is a very important parameter, here we describe it by a simple design formula as in the following:

2.2.2 Important parameters of surface acoustic wave filter

The related important parameters for the frequency response of surface acoustic wave filter include: Center frequency, insertion loss, bandwidth, etc., as shown in figure 2.1, the design parameters affecting these performance include:

There are many types of piezoelectric material, they are classified as in the followings [24]:

Take the surface acoustic wave device as an example, the frequently used piezoelectric substrate include: quartz, $LiNbO_3$, $LiTaO_3$, etc., each of them has different e1ectromechanical coupling coefficient K_e^2, wave velocity v_o of the surface acoustic wave and temperature coefficient of delay, TCD, α_T. K_e^2 represents the square of the conversion ratio between electrical energy and mechanical energy of the material, it is called the e1ectromechanical coupling coefficient K_e^2.

Wherein v_0 is the wave velocity of the surface acoustic wave of the piezoelectric substrate at open circuit.

v_S is the wave velocity of the surface acoustic wave of the piezoelectric substrate at open circuit.

Electromechanical coupling coefficient $K_e{}^2$

2.3 The application scope of surface acoustic wave devices

Waves propagating in solid can be mainly divided into two types: the wave propagating inside is called the bulk wave, and the wave propagating on the surface is called surface wave. Surface acoustic wave belongs to Rayleigh wave, it is propagating within one acoustic wavelength underneath the free surface of the piezoelectric material.

(1) Compact size, light weight.

(2) Wide device operating frequency, from 10MH to 2-3GLIz.

(3) The process technology of the device is similar to the process of semiconductor integrated circuit, it is suitable for mass production with high reproducibility.

(4) It is suitable for very complicated signal processing.

(5) There is no need for additional adjustment when the device is in use and the power consumption is low too.

(6) The device can be operated in harmonic mode.

Four types can be classified based on the application fields:

(1) Emitting/reception end of the wireless RF module, such as: remote control, coder/decoder, etc.

(2) Wireless communication such as: mobile phone, pager, etc.

(3) Digital signal processing of medium frequency, such as: local oscillator circuit, optical fiber communication, data transmission, etc.

(4) Video broadcasting such as: filter circuit of medium frequency, cable

TV converter, HDTV, etc.

Table 2.1 is the major application scope of SAW device, which include, mobile phone, pager, wireless telephone, satellite communication system, the tuner and harmonizer of TV, etc.

Types of surface acoustic wave device	Major application scope
Filter	(1).IF Filters：Important key components in wireless telephone, mobile phone, Cable Modem. (2).RF Filters：The important devices used in the front end of wireless telephone, mobile phone, pager, and wireless local area network system（WLAN）. In the future, the development in CDMA will require this product more and more. (3).Other filters: Data ＆ Audio product.
Resonator	Car security system, remote control, CATV Tuner, wireless key board, wireless earphone, wireless communication or the sequencer in the high speed computer.
Delay Line	Non-dispersive; Dispersive; Multi-tap SAW Delay Lines
Oscillator	Fixed frequency; VCXO, VCSO for Phase-Lock Application
Subsystem of module of surface acoustic wave	(1)SAW Based Multi-chip Modules Channelized filter banks; Switched filter/delay modules; Pulse expansion/compression High speed clock module (2).Digital／SAW Pulse Compression Systems, SAW Subsystem for Military Application
Sensor or acousto-optical	Sensors

surface acoustic wave	

Table 2.1 The major application scope of surface acoustic wave device

SAW filters can basically divided into two types based on their operating principles: Transversal SAW filter and resonator SAW filter (as shown in figure 2.3) **[29]**. Transversal SAW filter is made up of two IDTs on the piezoelectric material (as shown in figure 2.4), wherein IDTs are used as input and output electrodes, and both sides on the surface of the substrate are covered with acoustic wave absorbers to prevent the reflection of the wave. Resonator SAW filters can be divided into, based on the locations the resonators are placed, vertically coupled resonator models and horizontally coupled resonator models (as shown in figure 2.4). Horizontally coupled resonator models SAW filter has high and narrow bandwidth, it is commonly used in the IF frequency range of mobile phone; however, vertically coupled resonator models SAW filter, is widely used in RF frequency range due to its wide bandwidth.

The preparation of SAW device can be divided into two major parts, these include device circuit simulation and design and the semiconductor device fabrication process (as shown in figure 5). After the spec is verified, the pattern of IDT is designed; first, all the needed parameters should be verified according to the acoustic wave characteristic of the substrate (as in table 2.2) **[30]**.

After the pattern of the above IDT is converted into pattern on the mask, device fabrication process is then performed. Usually the mask number of SAW device is limited to less than three, but most semiconductor device, due to the gradual strict spec requirement on the product function and the design requirement, will require mostly more than 10 masks.

Since the photolithography line width is highly related to accuracy requirement, exposure machine and manufacturing cost, therefore, the product design requirement on line width and uniformity has to be verified first in order to select the optimum manufacturing process and equipment combination. The required electrode line width of the IDT of general SAW device depends on its usage frequency, the higher the frequency of usage, the narrower the required line width, take the 1GHz frequency as an example, the required line width is about 1μm, therefore, the designed line widths IF SAW Filter, SAW Resonator and most RF SAW Filter are all above of 1μm, the general front end processes are Contact Aligner and Lift-off or Wet Etching. However, along with the popularity of dual frequency and multiple frequency mobile phone, the RF SAW Filter needed in the frequency range 1.7-1.9GHz thus becomes a key component. To meet such high frequency spec requirement, the line width of SAW device must be as small as 0.5μm, therefore, Contact Aligner can not meet this required spec, the appropriate process or equipment is Stepper accompanied with Lift-off or Dry Etching process.

In the application field of mobile and communication product, due to the difference in design and the system used, the average surface acoustic wave devices needed for each mobile phone are as shown in table 2.3.

2.5 Near field phase shift lithography, NFPSL

In the photolithography process of semiconductor, photo mask plays a role as pattern transfer. Along with the requirement in device characteristics, line width is gradually reduced, in the photo lithography process, light will generate optical diffraction effect in nearby circuit which will in turn make the pattern unclear and the resolution reduced. The concept of using phase shift mask technology to increase the pattern resolution was proposed in 1982 by M.D. Levenson et al.(31)(32). In the traditional mask pattern, phase shift layer which is transparent and can reverse the optical beam by 180° is placed at the adjacent optically transparent region, it can greatly increase the resolution or DOF of the exposure system, the imaging of the exposure system is to collect the optical beam diffracted by the mask pattern onto the chip through lens set.

If a special material (transparent and can reverse the optical beam for 180° in phase) is placed on the transparent zone, then the above two patterns will have reverse electric field distribution (destructive interference), therefore, after the addition of the electric fields, zero electric field points will be formed between the two. Besides, zero electric (optical) field intensity points will be formed between the two, therefore, the two patterns can be clearly resolved on the photo resist plane of the wafer. According to this process, the resolution is enhanced to about double, and the contrast of the image is improved too, the DOF is increased to double as shown in figure 2.6(33).

The traditional Cr film mask comprises of transparent and non-transparent zone, when optical beam passes through the mask, only the optical amplitude passed can be controlled, the positive or negative sign of the amplitude (phase) can not be controlled. But phase shift mask can control both, besides, it has smaller Proximity Effect.

2.6 The optical requirements on phase shift mask

The optical requirement of phase shift mask is to contain capability to reverse the phase by π and the capability to decay optical intensity, the requirements on the film of the phase shift mask based on the above requirements are as in the followings:

The thickness of this film must satisfy λ/2 wavelength difference (relative to the air medium), therefore, the thickness relationship is as in the following formula:

n is the refractive index of the material, λ is the wavelength of the incident light, as shown in figure 2.7(33).

We know that even the traditional photolithography technology of the best resolution is still limited by the diffraction limit, there are two conditions to break through the diffraction limits:

(1) Optical decay wave.

(2) Since the decay exists only in near field, therefore, sample and the optical source must be close enough, in the near field optics, the non-destructive property and all kinds of contrast mechanisms of light still exist, because it is still a technology based on optics, the limit of its resolution is the width of optical hole and the distance between optical hole and object to be tested, it is immune from the diffraction limit of traditional optical microscopic technology.

Near field optics is an optics field which is not limited by diffraction and wavelength, the measurement or recording is performed at a distance far smaller than the working wavelength used, since the wave property of the light is not displayed yet, the near field optics recording is a new optics recording method which is not limited by diffraction limit. Figure 2.8 is the difference between near filed and far field optical intensity.(33)

2.7 Characteristic and application of PDMS

2.7.1 PDMS

PDMS (polydimethylsiloxane) is one type of siloxane polymer, it is commonly called silicone, the property of polysiloxane is that it has very good thermal stability, difficult to get oxidized, soft molecular chain (except PDPS), low glass transition temperature (for example, -120° C for PDMS), good oxygen permeability and low surface energy, can be used to improve the surface hydrophilic property of polymer, good wear resistance, good air permeability, good thermal resistance, good processing property and toughness, etc., the commonly siloxane products are, for example, silicone oil in high temperature oil bath, contact lenses, silicone rubber pad, etc.

PDMS is very important material in the preparation of micro devices, it is a tough and transparent material, it meets the requirement of optical detection technology.

2.7.2 The surface structural change of PDMS

Generally speaking, PDMS is a polymer most commonly used to fabricate micro device, its original hydrophobic property can be changed to hydrophilic property through the processing of oxygen plasma, it is a great advantage for a micro fluid device, it makes PDMS a popular choice from many polymers in the fabrication of micro devices.

2.7.3 The cross-linking reaction in PDMS

Three dimensional silicone resin induces silicone resin cross-linking reaction between SiVi and SiH of the polymer through hydrosilylation reaction, it can be represented by the following reaction formula:

The property and concentration of active catalyst and inhibitor and the concentration of ethyl group and SiH [36，37] will all affect the cross-linking reaction rate.

PDMS main agent is added with platinum activated catalyst and inhibitor and blended homogeneously, at a high temperature of 150 ^{o}C, hydrosilylation cross linking reaction takes place rapidly as shown in reaction (2)

[36] . This reaction mechanism first needs catalyst hydrolysis of SiH:

At this moment, the newly formed SiOH catalyst gets reacted along with SiH, Si-O-Si bonds are thus formed through cross-linking reaction:

The platinum catalyst reaction (2) and (3) is slower than (1). The expected cross-linking reaction (4) is much slower that SiH reaction (2 and 3).

Chapter 3 Experimental

3.1 Near field phase shift photolithography process

This thesis uses near field phase shift photo lithography process to prepare high frequency surface acoustic wave device, the photo mask is made by Taiwan Mask Corporation, it is 5μm and 10μm, two patterns of double finger, respectively. Table 4.1 is two types of surface acoustic wave devices, the mask design is as shown in figure 3.1～3.2.

Next, the near field phase shift photolithography technology and the equipment, system, materials and process used to fabricate surface acoustic wave device through PDMS mask are described.

After the system, machine, materials are introduced, the most important key manufacturing process will be introduced, this is as shown in figure 3.9, figure 3.10 is near field phase shift photo lithography manufacturing process 1 and 2, figure 3.11 is an exposure illustration of near field phase shift photo lithography.

3.4 Mold preparation of surface acoustic wave device

1 Specimen cleaning

For the Qz, LT Wafer used in the experiment, in order to prevent the absorption of impurities on the surface such as dust, oil stain, which might affect the device property, the specimen thus needs to be well cleaned. The impurity existed will cause defect which will in turn increase the possibility of change in the film deposition process, in the worse case, pattern transfer error will be induced on PDMS-PSM, therefore, the cleanliness of the specimen is very important to the film deposition process, cleanliness of the specimen is the key to the film deposition process.

2、Plasma Clean

To remove water and particle on the wafer.

3、HMDS coating

Coat HMDS on the wafer can increase the adhesion of the photo resist to the wafer.

4 Photo resist coating

Coat the photo resist evenly on the Qz Wafer.

5 Exposure

Send the designed 5um and 10um surface acoustic wave device mask into the stepper, use the I line stepper for exposure.

6 After-exposure baking

Bake the wafer after exposure to reduce the standing wave effect.

7 Developing

Use the developer to perform pattern transfer.

8 Plasma Clean

To remove the photo resist and particle on the wafer

9 Evaporation

Evaporation machine is used to deposit metal electrode, the deposition of Ti and Al film meets the depth of phase shift.

10 Lift off peeling

Use NMP to strip the unnecessary photo resist.

11 Use surface profiler to measure the mold of the completed Qz surface acoustic wave device (see chapter 4 for details) to check if the phase shift depth has been reached.

To summarize, we know that through the above-mentioned procedures, we can finish the preparation the mold of surface acoustic wave device, see figure 3.12～3.14 for details.

3.5 Preparation of PDMS phase shift mask for surface acoustic wave device

3.5.1 Preparation of samples

In the preparation process of PDMS polymer, certain proportion of additive is usually added depends on the specific need. In the sample of this experiment, PDMS needs to be added with cross-linking agent to harden the sample. This sample uses a ratio of 10：1 in the preparation of siloxane, the sample is fully blended and placed still for 4 hours, then observe if there are still bubbles left on it and coat it evenly on the mold of the surface acoustic wave device. The coated sample is placed still on 150°C hot plate for a heating of 15 minutes to let it fully harden. Then peel off PDMS from the Mold to get PDMS phase shift mask as shown in figure 3.15 and 3.16.

To conclude, we know that the preparation of PDMS phase shift mask can be accomplished through the procedures mentioned above, the detailed process flow is as shown in figure 3.17 and 3.18.

3.6 The preparation of high frequency surface acoustic wave device

11 Then use network analyzer and probe analyzer to measure the frequency response of the completed L T wafer surface acoustic wave device.

12 Then the preparation of near field phase shift photolithographic high frequency surface acoustic wave device is completed (see chapter 4 for the detailed Pattern).

To conclude, through the above-mentioned process, we can complete the preparation of surface acoustic wave device, the detailed process flow is as shown in figure 3.19～3.21.

To conclude, through the three processes in the above 3.4～3.6, we can complete the fabrication of high frequency surface acoustic wave device by using near field phase shift photolithographic technology, the detailed process flows can be used as a reference for the future researchers.

Chapter 4 Test and analysis

4.1 Test and analysis on the measured results

For the test and analysis on the measured results, please follow chapter 3, near field phase shift photolithographic preparation process flow to complete the preparation of surface acoustic wave device, please also see the experimental test and analysis process flow（figure 4.1）. Use first the Spectrophotometer (figure 4.2) to perform transmission measurement on PDMS to ensure that the 365nm optical source can pass through PDMS main body smoothly（figure 4.3）, then use 365nm Stepper to prepare the mold of surface acoustic wave device, then measure the mold by using surface profiler to see if the phase shift depth has been reached, this is as shown in figure 4.4 and 4.5, if the depth meets the thickness, PDMS is used for mold reverse operation on the mold and the preparation of PDMS phase shift mask is then completed, the high frequency surface acoustic wave device prepared by using near field phase shift photolithographic PDMS mask is as shown in figure 4.10～4.13, we can see that the edge of the mold is illuminated by optical source of 365nm Lamp to generate a phase shift of 180 degrees, this leads to an intensity of zero, a space of 200nm is thus formed. This proves that a successful preparation result is obtained, the high frequency surface acoustic wave device prepared by using near field phase shift photolithographic PDMS mask is then measured by using network analyzer and probe analyzer for the signal measurement.

Field emission scanning electron microscope (SEM)（figure 4.6）, surface profiler（figure 4.4）and network analyzer 8753ET and probe analyzer(figure 4.7） are used to complete the signal measurement job. The surface acoustic wave device preparation process this time uses 4 inch $LiTaO_3$ wafer, figure 4.14～4.18 are frequency response measurement results.

We can see from the measurement results that the signal is enhanced to about 2.4GHz, in the 5μm and 10μm line widths traditional process, the frequency response can only reach 200MHz and 100MHz, but surface acoustic wave device prepared by using near field phase shift photolithographic PDMS mask can be upgraded to 2.4GHz rapidly. We can also see from figure 4.14 and 4.17 different harmonic frequencies, the frequency used can be selected according to the need of the product, I the next step, we are going to experiment on the reduction of the line width design to achieve higher frequency response.

Chapter 5 Conclusion

The same as the above-mentioned research trend, the purpose of this thesis is to use Near-Field Phase Shift Photolithography, NFPSL and Polydimethylsiloxane (PDMS) Phase Shifting Mask, PSM, to prepare surface acoustic wave devices to be applied in the next generation photolithography process. The following we conclude the experimental results:

1. For PDMS phase shift mask, as displayed in the literature, the optical beam passes through phase shift layer and that passes through non-phase shift layer has a phase difference of 180 degree, a destructive interference thus occurs and the resolution of photo resist is enhanced, the Depth of Focus, DOF, is increased. The use of phase shift mask technology could improve the unclearly defined pattern

due to optical diffraction effect, which in turn could lead to the disadvantage of difficulty to define the correct electronic layout.

2. As shown in the Field emission SEM microstructure of chapter 4, we can clearly see that there is a phase shift effect of 180 degrees in the phase shift layer after the exposure of the phase shift mask, the line width is pushed to 200nm, it breaks the traditional photolithographic optical source limit (I-Line 365nm), this NFPSL technology can be widely used in the photolithographic engineering of the next generation, a giant step in the semiconductor photolithographic process is achieved.
3. For surface acoustic wave device, due to the photolithographic process limit and cost concern, very few companies use stepper of I-Line 365nm to prepare this device because of the cost of almost several hundreds of millions NTD for the machine. This thesis uses NFPSL technology to successfully prepare high frequency surface acoustic wave device, as the measured device frequency mentioned above, line widths of 5μm and 10μm can promote the frequency up to 2.4GHz, this high frequency is even beyond normal design theory, here in the following is a brief calculation:

   Wherein V is the velocity of surface acoustic wave (LT = 4172 m/s)

   F is the central frequency of surface acoustic wave

   λ is the wavelength of surface acoustic wave (4d=λ is incorporated in the general design)

   The working frequency of 5μm and 10μm surface acoustic wave device is 200MHz and 100MHz, it is a large difference with the great result achieved by this thesis.
4. Due to the self defects of PDMS mask, we can see from the checking of the prepared device that electrode can easily get stuck to each other or get broken, if the sticking occurs at the interdigital transducer electrode part, the whole device will then become short circuit and no surface acoustic wave can be excited. Besides, due to the difference between intensity at the optical center and the edge, the electrode width will become non-uniform, this will reduce the capability of interdigital transducer electrode to excite and receive surface acoustic wave, and the performance of the whole device will

in turn be affected.

5. The design of mold mask for the surface acoustic wave device in this thesis is a beta version, it can push the line width from 5um and 10um further to 2.5um or 1um or even 0.5um to prepare PDMS phase shift mask. Through further application of NFPSL technology, we expect that the working frequency of surface acoustic wave device should be able to be further pushed to 5G, or even to 10GHz, this is going to be a revolution in surface acoustic wave industry.
6. The near field phase shift photolithographic process technology applied in this thesis can be used for the preparation of surface acoustic wave filter, the design processes of the device can be used as a design reference in the related research units.

Chapter 6 Future perspective

In the experimental processes, we find that after a few times of the use of the PDMS near field phase shift mask for exposure, particle and photo resist will be left on the PDMS mask. This will limit the lifetime of use of PDMS mask, it further affects the pattern profile after exposure and the electrical property of SAW device. In the research process, I have read related literature on how to resolve this problem, many experiments have been done on this topic, but the problem is not improved, further investigation is going to be performed in the future so that some good results can be published for the reference by the academy.

PDMS polymer material, as mentioned in the literature, has been widely used in the academy and the industry, it appears in many journals and periodicals and medical field. This thesis uses only a small part of function of PDMS, in the future, more extensive studies on the material property of PDMS are going to be performed, such as: the hydrophilic and hydrophobic property of PDMS, surface re-structuring, anti-sticking characteristics, etc., we hope to find better research directions from such studies.

6.1. Characteristic studies on PDMS

6.1.1 The measurement of contact angle [34, 38]:

The surface potential energy of substance will decide its hydrophilic or hydrophobic property, and contact angle is a measurement method targeting at the surface potential energy status of the sample. Water drop is first dropped on the sample surface, the tangential angle between the water drop and the surface is the contact angle, the larger the angle, the smaller the free energy, and the sample become more hydrophobic.

In the experimental processes, many contact angle measurements are performed on the patterns of PDMS. From table 6.1, we can clearly see that the contact angle of the pattern obtained with reverse printing on PDMS is larger than its main body, among them, the SAW Pattern has largest contact angle as shown in figure 6.4, the lower the surface free energy, the more hydrophobic the sample is. The obtained result can prove the experimental bottleneck we face, when we use PDMS phase shift mask with SAW pattern printed on it for exposure, we always have the problem of bad contact between the mask and the wafer, which in turn leads to the bad exposure. Therefore, if plasma surface cleaning can be applied to the PDMS SAW pattern phase shift mask, we can enhance the surface free energy to let the sample become more hydrophilic and the contact between the wafer and the mask is thus greatly enhanced, bad exposure problem can thus be solved.

6.2 Future topics

For porous polymer PDMS surface, in the trend of device miniaturization, the effect of generating gaps and particles sticking are worth observing, this thesis uses near field photolithographic technology to prepare high frequency SAW device, in the future, Trimethylchlorosilance might be used to solve the particle sticking problem.

Solving the diffraction limit in the semiconductor photolithographic process is a crucial trend to go, to take care of both technological aspect and cost, the technological research and development thus plays an important role. How to go back to the view point of original physics science to analyze and solve the problem, how to find a tradeoff between cost and competitiveness is the real goal of this thesis.