DEVELOPMENT OF MICRO HEATING ELEMENT BY OPTICAL LITHOGRAPHY ON ALUMINA SUBSTRATE

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DECLARATION

Statement 1

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed ……………………………………......... (TAN TEONG SHENG)

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Statement 2

This article is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references.

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Supervisor's Declaration

I hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by Universiti Sains Malaysia.

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ABSTRAK

Litografi optik telah digunakan untuk deposit lapisan fotoresis dengan corak yang dikehendaki pada substrat rata biasanya wafer silikon. Namun, perhatian sedikit telah diberikan kepada pembangunan aloi Fe-Cr-Al pada alumina substrat. Oleh itu, kepentingan tertentu telah diberikan kepada kajian Fe-Cr-Al aloi pemendapan pada substrat alumina sebagai elemen pemanas mikro julat suhu rendah penukar tenaga ion haba. Ciri-ciri elemen pemanasan mikro telah dicetak pada substrat alumina untuk membentuk topeng SU-8 fotoresis dengan kaedah litografi optik. Elemen pemanas mikro Fe-Cr-Al aloi yang diperoleh oleh pelucutan SU-8 fotoresis selepas penyejatan haba, telah dikaji dan diukur oleh SEM. Fotoresis pada alumina substrat tidak dilucutkan sepenuhnya walaupun menggunakan pelarut NMP sebagai pelarut lift-off. Penyelewengan permukaan dan keliangan alumina as-tersinter telah menyebabkan fotoresis untuk meresap ke dalam liang dan berpegang teguh kepada permukaan alumina. Fotoresis di permukaan substrat alumina walaupun selepas pergolakan ultrasonik digunakan untuk tenaga proses pelucutan. Ciri dimensi elemen pemanasan mikro pada menyimpang substrat alumina dari dimensi yang dikehendaki kerana permukaan yang kasar membawa kepada penyelewengan corak.

ABSTRACT

Optical lithography has been used to deposit resist coatings with desired pattern on flat substrate typically silicon wafer. Yet, rather little attention has been given to the development of Fe-Cr-Al alloys on alumina substrate. Thus, a particular interest has been given to the study of Fe-Cr-Al alloys deposition on alumina substrate as micro heating element of low temperature range thermionic energy converter. The features of micro heating element were printed on alumina substrate to form a SU-8 resist mask by optical lithography method. Micro heating element of Fe-Cr-Al alloy obtained by stripping the SU-8 resist after thermal evaporation, have been studied and measured by SEM. The resist on alumina substrate were not stripped completely even using NMP solvent as the lift-off solvent. The surface irregularities and porosity of as-sintered alumina has caused the resist to diffuse into the pores and adhere strongly to the alumina surface. The resist remains on the surface of alumina substrate even after ultrasonic agitation was used to energies the stripping process. The feature dimension of micro heating element on alumina substrate deviate from the desired dimension due to surface irregularities which leads to pattern deviation.

CHAPTER 1 INTRODUCTION

Diminishing fossil fuel resources and growing global energy demand are among the factors that urge the development of renewable and clean energy to reduce the dependency on traditional energy resources. Other than harnessing solar energy in which the conversion is rather inefficient, energy conversion from thermal energy directly to electricity could be a better alternative. This alternative should not be neglected as heat energy is easily obtained from various thermally-intensive processes and no mechanical work is involved in thermal energy to electricity which in turn eliminate losses that reduces the overall conversion efficiency.

Researchers and engineers have always been engaged in the work of improving the conversion efficient of energy conversion devices to minimize the wastage of high quality energy. In the context of lean manufacturing, the idea of minimizing the waste by seeking a use for what otherwise would be wasted is prominent. In TRIZ, a popular Russian strategy for inventive problem solving in which one of the universal design principles is to “retain the available” [1]. The concept of finding uses for what normally is wasted should not only limited on manufacturing but should extend to the topic of clean energy harvesting.

In the basic form, a thermionic energy converter (TEC) comprises an electric load, an electrical connection and two electrodes. For the two electrodes, one is an emitter and another one is a collector. An emitter which will be heated to a sufficiently high temperature to emit high-energy electrons whereas a collector receives the emitted electrons and is operated at a significantly lower temperature. The emitter and collector are separated from one another by an interelectrode gap, which can be filled by vacuum, vapor, or plasma [2], [3]. A heat source is connected to the emitter, to supply the thermal energy to the electron inside the emitter whereas the collector is connected to the heat sink in order to remove the heat from the collector [4].

This thesis presents the development of the micro heating element which serves as the heat source to the emitter for low temperature range TEC in actual application. The micro heating element is designed by CAD software to produce a master mask film.

The master mask film is used to fabricate the emulsion mask for contact mode lithography. The pattern of master mask film was printed onto the alumina and silicon substrates. The micro heating element was metalized onto the substrate by thermal evaporation. The resist film is then removed by lift-off process.

1.1 Problem Statement

Alumina is a material with good thermal efficiency, which can be rapidly heated up to desired high temperature, making it suitable to be substrate of micro hotplate. It has good electrical insulation and long-life cycle due to its excellent chemical resistance and oxidation-proof on resistive material. However, there is lacking research work currently which micro heating element are fabricated on alumina substrate by optical lithography and thermal evaporation method. Thus, micro heating element will be designed and fabricated to heat up the emitter for low temperature range thermionic emission. Fe-Cr-Al alloys will be deposited onto the substrate by evaporation method.

1.2 Research Objectives

i. To design and develop a micro heating element of 60 μm width on alumina and silicon wafer substrate by optical lithography and physical vapor deposition (PVD) techniques.

ii. To compare the dimension and pattern of deposited microstructure formed on both alumina and silicon wafer substrate with original design.

iii. To construct the micro heating element which can achieve 600 ˚C as the heat source for low temperature range thermionic energy converter.

1.3 Thesis Outline

This thesis is composed of five chapters. The organization of the chapters are as follow:

Chapter 1 provides a brief overview of the research and problem statement. The research objectives are described in this chapter.

Chapter 2 highlights the detailed literature review of previous and relevant works on micro heating element, optical lithography and metallization methods

Chapter 3 is concerned with the materials and methodology used for this study. The procedures and parameters, equipment and precautionary measure are described

Chapter 4 presents and analyses the results of this research work. The result of heating element deposition on alumina substrate and silicon substrates lifted off by two different resist-stripping solvents was compared.

Chapter 5 reports the conclusions and recommendations for future studies that resulted from this study.

CHAPTER 2 LITERATURE REVIEW

2.0 Introduction

This chapter provides the review of previous research that is related to this final year project. There are previous researches on micro heating element using different metals, substrate and other methods of fabrication.

2.1 Thermionic Energy Converter

Kishore Uppireddi et. al. deposited nanocrystalline diamond (NCD) films on molybdenum substrate using hot filament chemical vapor deposition (HFCVD). A low temperature direct thermionic energy converter in the temperature range from 700 ˚C to 900 ˚C was constructed with NCD films of a consistent low work function of approximately 3.3 eV [5].

S. Meir [6] has argued that resistive heating filament emitter induces a significant voltage drop across the filament for high temperature of about 1000 ˚C to 1500 ˚C thermoelectronic converter with emitter work function ranging from 2eV to 3eV. The resulting potential drop gives rise to electrostatic field which disturbs the movement of emitted electrons significantly. As a result, a better way was to build an indirect heated emitter with flat emitting surface which thermally connects to resistive heating element instead of directly heated, wound filament.

2.2 Micro Heating Element

Research on micro heating elements have been conducted broadly due to their wide applications in gas sensors, flow rate sensors, surface acoustic wave (SAW) based sensor and infrared source. Extensive efforts have been carried out to obtain temperature uniformity on the micro heater. There are several approaches to create uniform temperature distribution on micro heaters: using a thicker silicon island underneath the micro-hotplate membrane [7], [8], placing heat distributor layer on top of the heater [9] and employing various geometries heating element on the dielectric membrane [10].

The geometry patterns of heating element have been studied extensively to create a uniform temperature distribution. Researchers have widely used meander pattern on their heater design as depicted in [8], [11], [12]. B. Souhir et. al. simulated a meander heating film of 100nm thickness with optimized heating element thickness and inter track width. D. Briand et. al. simulated the meander-shaped micro hotplate with optimized thickness of silicon island underneath the membrane of micro hotplate for gas sensing applications. Meander shape heater element as shown in figure 1 was used by A.V. Singh to fabricate a micro-hotplate for application as an infrared emitter. O. Sidek et al. explored and evaluated the effect of heater geometry as shown in table 1 on the temperature distribution on a micro-hotplate using ConventorWare MemMech Analyzer simulation software [13]. The simulation results, however showed that the most uniform heat distribution was achieved by the geometries which comprises parallel and meander pattern (Type 1 as shown in table 1) among four proposed geometries.

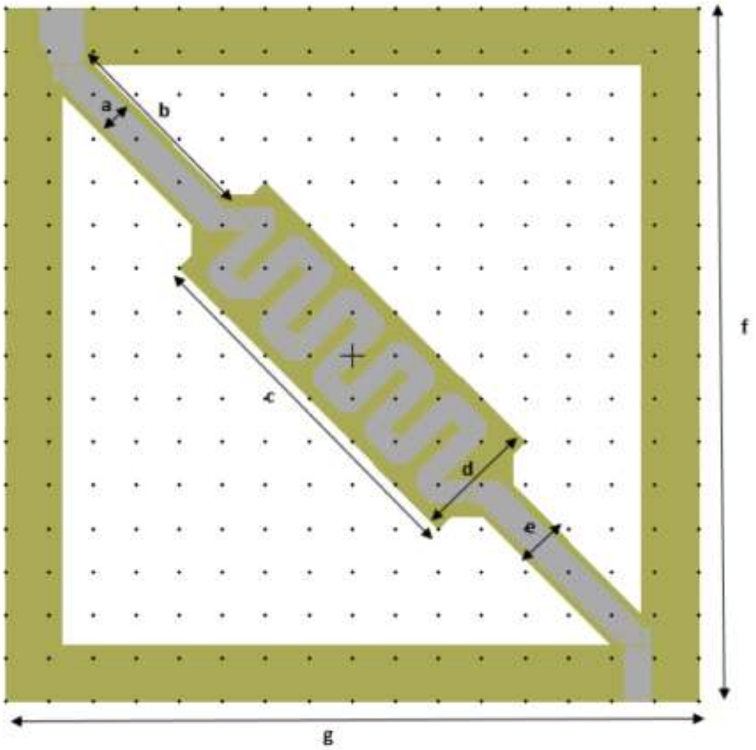
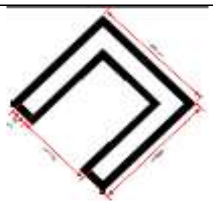


Figure 1. Meander shape heater element.
(Source: A. V Singh, Copyright ©2015)

Table 1. Four different heater geometries

Type	1	2	3	4
Geometry	 Combined of parallel and meander geometries	 Parallel geometry	 Meander geometry	 Double meander geometry

(Source: Sidek, Copyright © 2011, IEEE)

Silicon wafer is widely employed as the substrate as the substrate should be a good heat conductor and electrical insulator [11]. Alumina is rarely used as the substrate for micro-heater despite being a good heat conductor and electrical insulator. Platinum is commonly used as material of heating element due to its attributes depicted in [13], [14]. Due to the high resistivity, low temperature coefficient of resistance (TCR), corrosion and oxidation resistant, Nichrome Ni-Cr (80/20) is employed as the heater material by A. Singh. There is no research on micro heating element that used metal alloys such as Fe-Cr-Al alloy. Some of the materials that have been used as the heater and substrate are tabulated in table 2.

Table 2. Summary of heater material and substrate used in the past

Reference	[11]	[15]	[16]	[17]	[18]	[19]
Heater element	NiCr	Ti/Pt	PolySi	Pt	Pt	Pt
Substrate	Si Wafer	Si wafer	Si wafer	Si Wafer	Si Wafer	Si Wafer

2.3 Optical Lithography

Optical lithography, also termed as photolithography or UV lithography is a conventional approach in microfabrication to transfer pattern from a photomask to a light-sensitive chemical (photoresist) on the substrate. Photolithography is widely used as a pattern transferring technique as it allows the exact control on the shape and dimension of the features [20]. As illustrated in figure 2, a typical steps of an optical lithography process includes substrate preparation, photoresist spin-coating, prebake, alignment and exposure, post exposure bake and development [21].

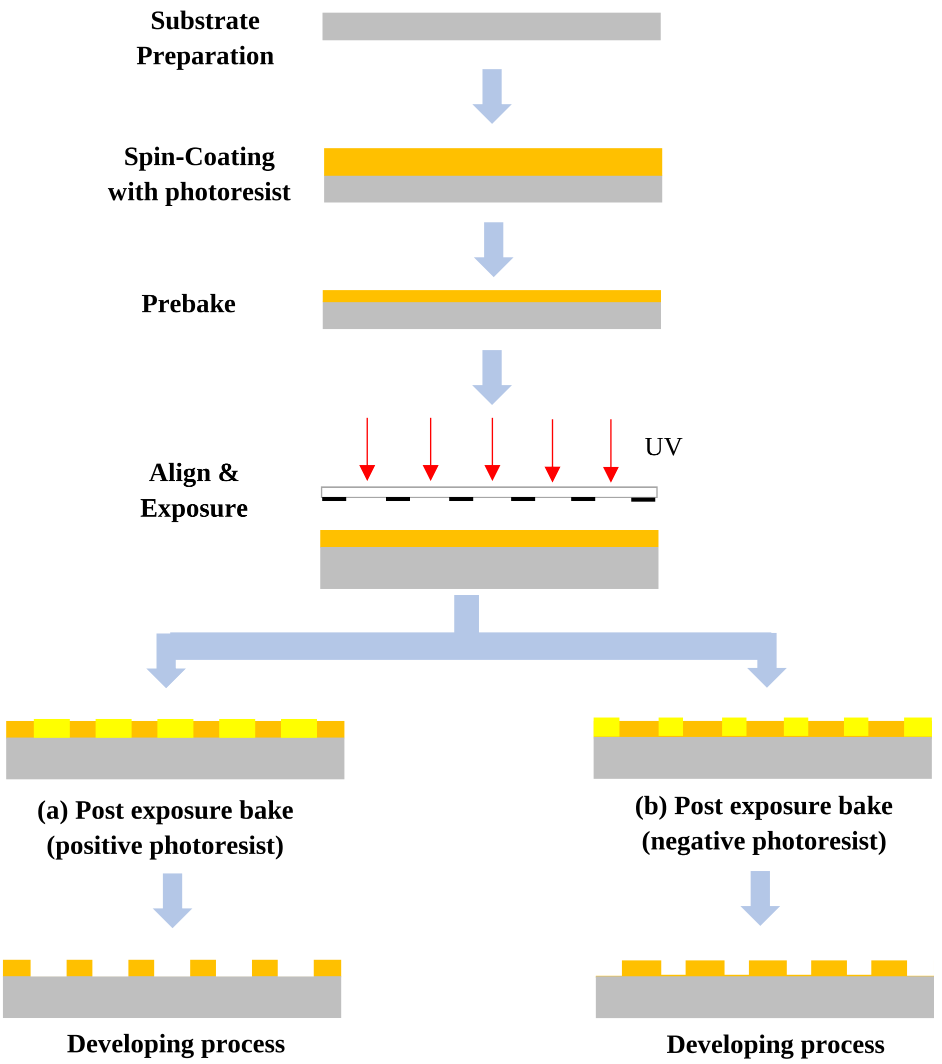


Figure 2. Typical process sequence of optical lithography on a substrate by using (a) positive photoresist, and (b) negative photoresist

2.3.1 Substrate Preparation

Substrate preparation is meant to enhance the adhesion of the photoresist onto the substrate and prevent the presence of contaminant in resist deposition film [21]. The presence of impurities in the forms of contaminant films, discrete particles and adsorbed gas particles leads to poor adhesion of photoresist on the silicon wafer substrate [22].

Contaminant in the form of particles leads to defects in the final resist pattern whereas film contaminants result in poor adhesion, affecting the linewidth control [21]. The RCA cleaning method was first put forward by Kern in 1990 as a procedure to decontaminate the organic residue and film from silicon wafer. The cleaning mechanism is based on sequential oxidative desorption and complexing with H_2O_2-NH_4OH-H_2O [22]. This cleaning method, which also termed as RCA-1 clean or Standard Clean-1 (SC-1) has been widely employed as a standard cleaning and preparation step by semiconductor processing industry. Followed by RCA-1, RCA-2 clean is used with 6 H_20:1 H_2O:1 HCl to further enhance the cleaning of the silicon wafer surface.

Solvent cleaning is another type of widely used technique which applicable for metallic and non-metallic materials due to its advantages as discussed in [23]. Ultrasonic agitation is normally employed to facilitate the solvent cleaning technique. The degree of surface cleanliness can be measured by the degree of hydrophilicity of its surface, characterized by the contact angle (CA) of water droplets on the surfaces. As illustrated in Figure 3, the surface is hydrophilic if the contact angles less than 90 ˚ whereas a hydrophobic surface has contact angles that more than 90˚ [24]. Experimental work showed that the contact angle was reduced to 30˚-20˚ by sequential cleaning of silicon wafer with acetone, ethanol and deionized water, and by performing the cleaning in a sonicated vessel, the angle was further decreased down to approximately 10˚.

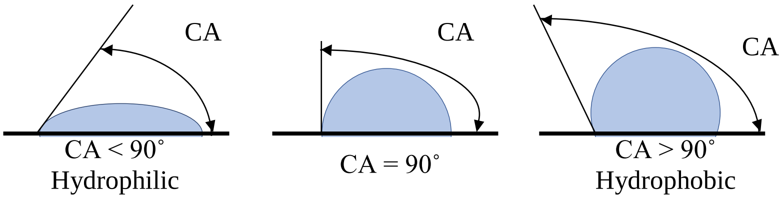


Figure 3. Contact angle measurement showing hydrophilic (CA<90 ˚) and hydrophobic (CA>90 ˚) surface

2.3.2 Photoresist Spin-coating

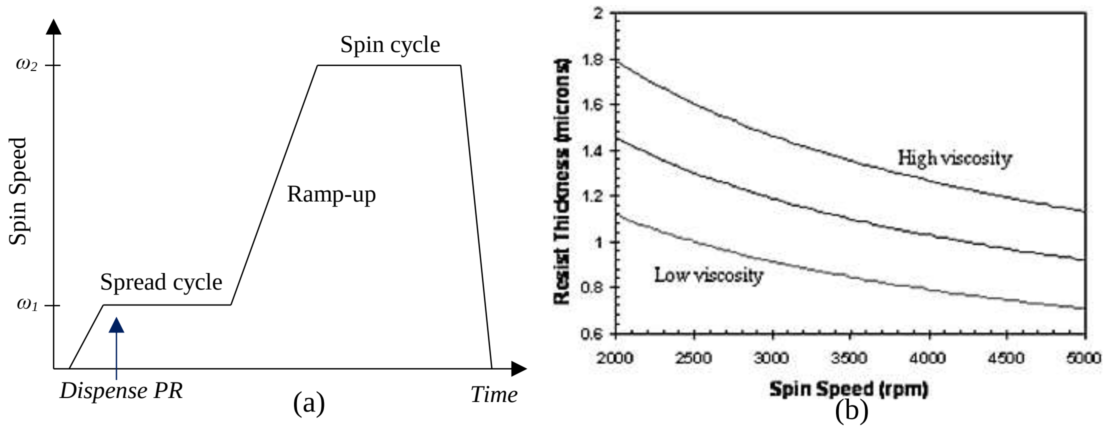
The photosensitive material used in optical lithography is a photoresist (PR). According to Madou, the main components of photoresist are a polymer (base resin), a sensitizer and a casting solvent. The structure of polymer changes upon exposed to radiation, the sensitizers initiates the photochemical reaction in the polymeric phase and the solvents aid in spin-coating to create a uniform thin layer on the substrate [25].

If the unexposed region of the resist is soluble in the developer and the exposed region is resilient to the developer, it is considered as a negative

For positive (also positive tone) photoresist, the polymer is weakened by scission of the main and side polymer chains during exposure, the exposed resist becomes soluble in its developer solution. If the photoresist is negative (or negative tone) type, exposure initiate photochemical reaction which strengthen the polymer by random cross-linkage of main or side chains, making the exposed material insoluble in the developer and the unexposed region is etched away [25].

The photoresist is dispensed onto the substrate placing on the platen, which is then spun at a high speed to produce the film with desired thickness. A spread cycle at about 500 rpm is commonly used to disperse the resist over the substrate. After the spread cycle, it is normally ramped up to a relatively high speed to thin the resist to near its final desired thickness. Typical spin speeds for this spin cycle range from 1500 rpm - 6000 rpm. Fast spin speed dries the resist film and minimizes further flowing to avoid non-uniform coating thickness [26]. Recommended photoresist spin-coating cycle is presented in graphical representation in figure 4.

Yang and Chang claimed that PR temperature and chamber humidity have significant influence on mean thickness and uniformity of resist film based on the ANOVA result [27]. However, C. Mack suggested that the variation in PR thickness and uniformity with the process parameter are identified experimentally though rheological theory of spin coating process exists [21]. The appropriate spin speed to obtain the desired resist thickness can be acquired from photoresist spin speed curve provided by respective PR supplier.



(a) (b)

Figure 4. (a) Recommended PR spin coat cycle, (b) PR spin speed curve [21]

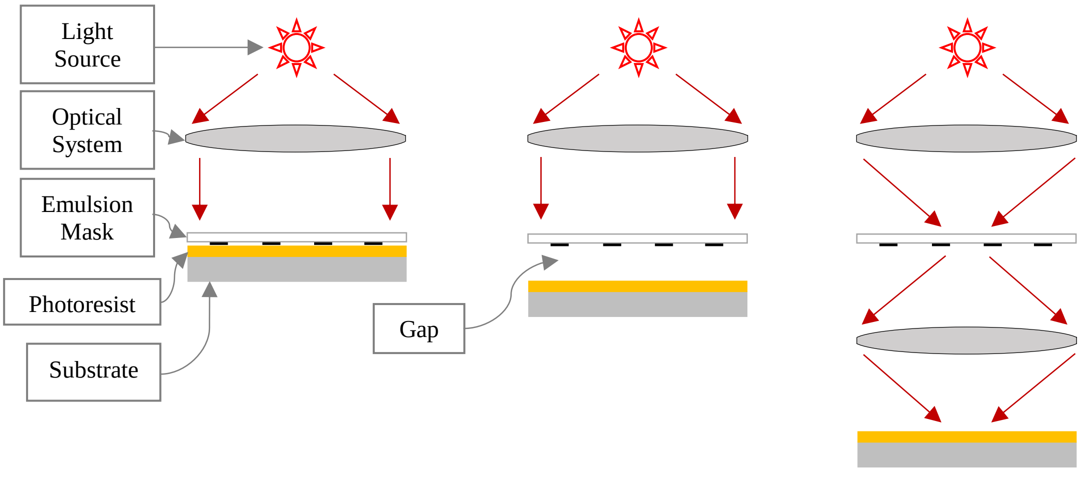
2.3.3 Prebake

After spin-coating, Madou (2011) stated that the resist film contains up to 15% solvent and likely to have built-in stresses. Prebake is therefore needed to dry the photoresist after spin-coating by minimizing excess solvent in the resist film. C. Mack stated that there are four main effects of eliminating the solvent from resist film: (1) reduction of film thickness, (2) changing of post bake and development properties, (3) enhancement of adhesion and (4) formation of less tacky resist film which minimizes the contamination by particles [21]. The common practice of SU-8 prebake is usually conducted at 95 ˚C. However, baking at elevated temperature has destructive effects on the resist. Photoactive compound decomposes at temperature higher than 70 ˚C and the resin will crosslink or oxidize at high temperature. Photoresist was baked with convection oven baking typically during 1970s and early 1980s. Hot plate is widely used for baking currently as it is faster and relatively controllable than convection oven does [28].

2.3.4 Alignment and Exposure

The resist-coated substrate is then moved to an exposure system where it is aligned with the pattern on emulsion mask. Fundamentally, exposure to light alters the solubility property of photoresist in the developer. UV exposure generates photoacid which subsequently polymerize SU-8 resist during the post exposure bake process. The photoacid opens the epoxide rings of the SU-8 resist and serves as a catalyst for the cross-linking reaction [29]. Therefore, by projecting UV light through emulsion mask onto the coated resist, the features on emulsion mask are transferred onto the SU-8 resist forming a latent image. The wavelengths of UV light of the exposure system range from extreme UV (10-14 nm) to deep UV (150-300 nm) to near UV (350-500 nm). In near UV, i-line (365 nm) and g-line (435 nm) of broadband mercury lamp are commonly used.

Exposure of coated photoresist through emulsion mask can be performed by three methods: (1) contact lithography, (2) proximity lithography and (3) projection lithography as shown in figure 5. By contact lithography, the emulsion mask is pressed against the resist-coated substrate to achieve a reasonably high resolution to around the wavelength of the radiation [21]. But, contact lithography induces formation of emulsion mask defects. In proximity lithography, emulsion mask defect that results from contact is reduced by keeping the emulsion mask a set distance above the substrate. However, the resolution limit is increased due to diffraction spreading [25]. Projection lithography derives from its name from the fact that the image of the emulsion mask is projected through high-resolution lens onto the resist-coated substrate. According to Mack (2007), the projection lithography outperforms contact and proximity lithography as high defect densities and poor resolution issues are avoided.



(a) (b) (c)

Figure 5. Types of photolithography in exposure system: (a) Contact lithography, (b) Proximity lithography, (c) Projection lithography

2.3.5 Post Exposure Bake

Madou suggested that precise control of post exposure bake (PEB) improves linewidth control by enhancing adhesion, minimizing scumming, improving contrast and resist profile and lessen the standing wave effect in regular positive resist. Baking at 100 ˚C to 130 ˚C renders the diffusion of photoactive compound and hence the standing wave ridges are smoothened [21]. V. Pinto et. al. (2014) stated that post exposure bake (PEB) increases the degree of cross-linking in the SU-8 irradiated areas, making it resistant to the solvent’s action during subsequent development process [30]. However, elevated temperature has damaging effect on the resist with similar concerns as during the prebake process.

2.3.6 Development

The resist film is developed after exposure and post exposure bake to convert the latent image into a relief image which will act as a mask for subsequent subtractive and additive steps [25]. Selective dissolving of resist takes place depending on the photoresist tone during the development of exposed resist. The resist-coated substrate is usually immersed in a beaker filled with the developer and constant agitation during development are provided to continuously feed fresh developer to the resist pattern. According to Martinez-duarte et. al. (2011), agitation can be conducted manually or performed with a rotator and thermal energy can be applied to the developer bath to assist developing process [29]. Sonicator bath can be an option of mechanical agitation. Other alternative includes magnetic agitation [30].

2.4 Physical Vapor Deposition

Physical vapor deposition (PVD) process is a thin film deposition technique in which material is vaporized from a solid or liquid source in the atomic or molecular form and transported through a vacuum or low pressure gaseous environment onto the substrate where it condenses from vapor phase. PVD processes are typically used for thin film deposition of elements and alloys as well as compounds ranging from a few nanometers to thousands of nanometers [31]. PVD processing comprises evaporation, sputter deposition, arc vapor deposition and ion plating.

2.4.1 Thermal Evaporation

In thermal evaporation, the material is transported from a thermal vaporization source through the space with little or no collision with gas molecules and deposited onto the substrate. Thermal energy is transmitted to atoms of material to raise their temperature to a point that allow efficient evaporation or sublime [32]. Generally, thermally heated source is used to generate thermal energy for vaporizing material whereas the substrates are mounted at a considerable distance away from the thermally heated source. According to [31], resistive heating is the most widely used method to vaporize material at temperature below 1500 ˚C whereas for temperature above 1500 ˚C, focused e-beams are commonly used. For resistive heating method, electrically conductive containers in the form of basket, boat or crucible which typically made of tungsten (W), tantalum (Ta), molybdenum (MO), graphite (C) and boron nitride (BN) are commonly employed. Figure 6 shows some resistive heating source configurations.

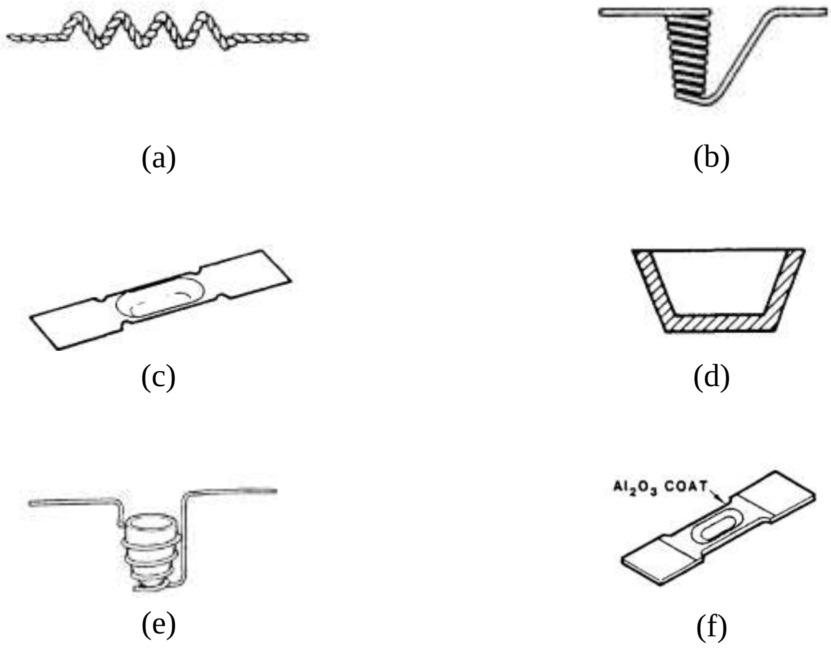


Figure 6. Resistive heating source configurations: (a) Spiral, (b) Wire basket, (c) Boat, (d) Crucible, (e) Crucible with basket and (f) Coated boat
(Source: Mattox)

For the deposition of alloys, each constituent has different vapor pressure and deposition rates and thus the stoichiometry of the resulting deposited film would be different from that of the source alloy materials [33]. Studies have been focused on thin film which consists of compositions such as Fe, Ni, Cr, Al and Co due to the potential applications in micro-electronics and magnetic sensor technology. Various alloys includes Ni-Cr alloy [34], Al-Cu alloy [35], Cu-Ni-Co alloy[36] have been deposited as thin film by evaporation method. Hafner et. al. proved that Al-Cu thin films could be deposited by single source evaporation of Al-Cu alloy due to the similar evaporation temperatures of Al and Cu which are 821 ˚C and 857 ˚C. However, based on the author’s knowledge, no comprehensive work was dedicated to deposition of Fe-Cr-Al alloy on alumina substrate.

2.6 Lift-off

Lift-off method is a commonly used technique to expose a pattern into a sacrificial layer which is usually made of photoresist. A metallic or dielectric thin film is first deposited over the entire area of the sacrificial layer in which this layer would be removed subsequently during lift-off process to leave only patterned film. Previous works have been focused on three basic methods that lift-off technique could be used, which includes the single layer method [37]–[39], multilayer method [40]–[43] and surface-modification method [44], [45].

Suitable stripper is used to lift-off undesired metals which was deposited on photoresist pattern by dissolving the resist [41]. During lift-off process, undercut region of resist is permeated and dissolved by the solvent [42]. Solvent such as N-methylpyrrolidone or acetone bath fitted with ultrasonic agitation were used to strip lift-off resist after PVD as in [38], [42].

CHAPTER 3 RESEARCH METHODOLOGY

3.0 Introduction

This chapter discusses the research methodology that was used in the present work. The flow chart as shown in figure 7 summarizes the overall methodology.

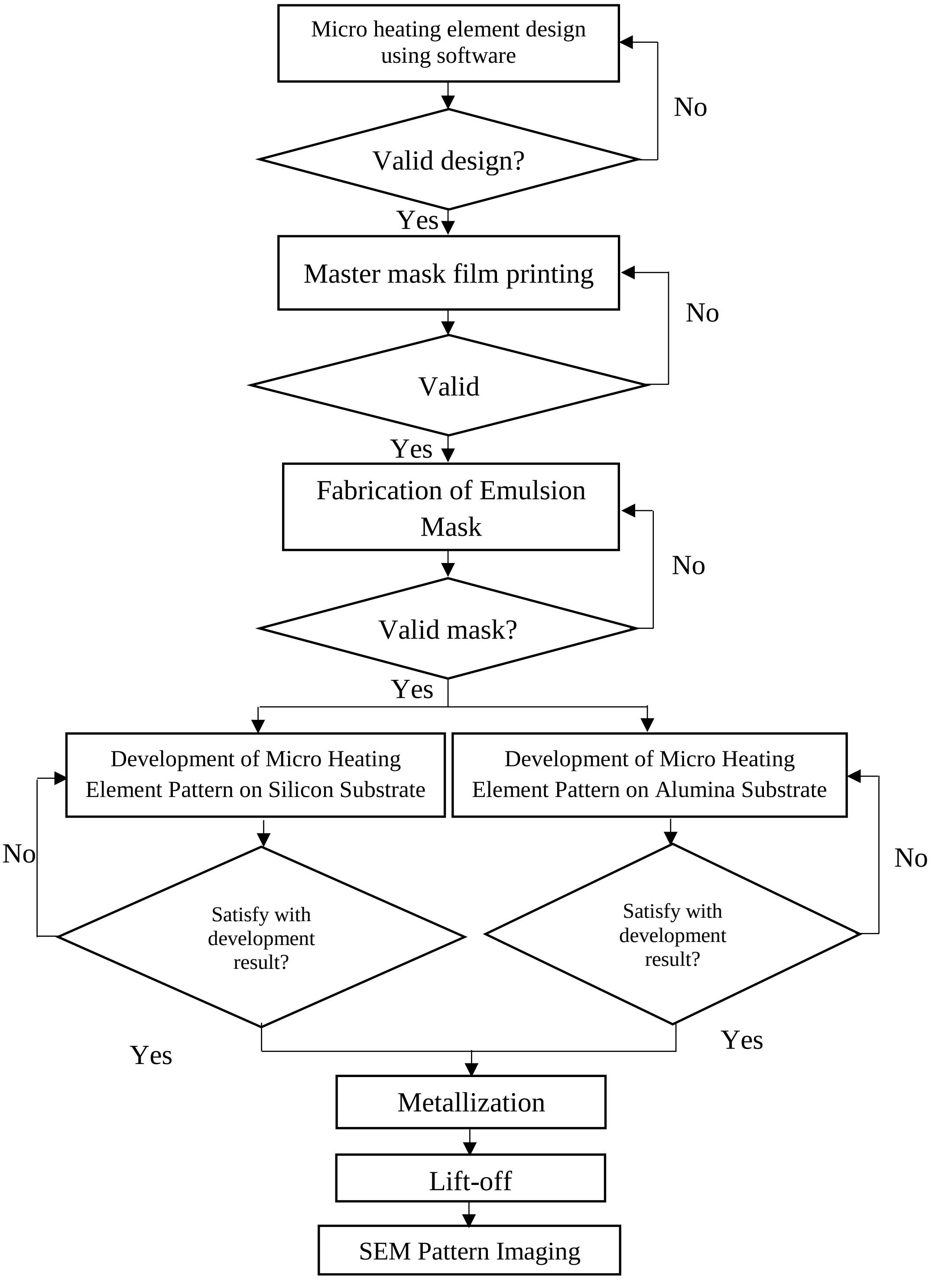


Figure 7. Overview of methodology

3.1 Materials

3.1.1 Substrates

Two types of substrates were used for depositing micro heating element in this work. Alumina substrate was used as primary substrate for micro heating element to exploit its advantages for micro heater whereas silicon substrate as a conventional and commonly used substrate, was deposited with micro heating element to compare the results.

3.1.1.1 Alumina Substrate

As-sintered alumina was used as substrate for the micro heating element in this study. Alumina powder was poured into the mold. The powder was stirred gently with spatula to ensure the powder fill the mold evenly. Then, the alumina powder was pressed at 30 MPa by motor-powered hydraulic press. The compressed powder was removed from the mold gently. Then, the compressed powder was fired at temperature 1600 ˚C for four hours. The alumina substrates were left to completely cool before removing from the furnace. Figure 8 shows as-sintered alumina substrates.

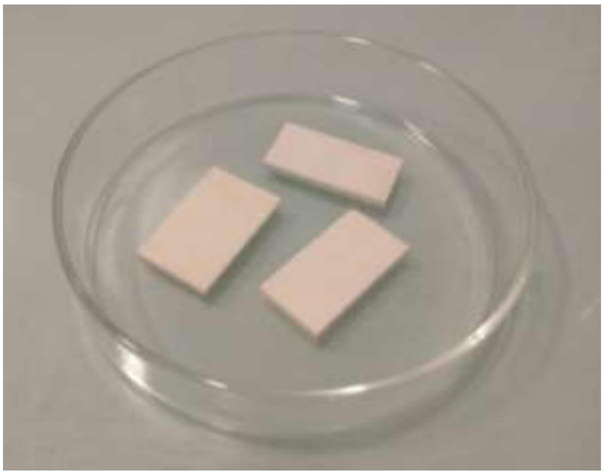


Figure 8. As-sintered alumina substrates

3.1.1.2 Silicon Substrate

8-inch in diameter and 0.5 mm thickness non-device, non-doping silicon wafer was used as another type of substrate for developing micro heating element. The wafer, with its polished surface facing upward was placed on a flat soft gridded cutting mat. The surface was drawn with 25 mm x 15 mm rectangular shape covering the entire silicon wafer. By using carbide-tipped scriber and clean ruler, the polished surface of wafer was cleaved gently. After cleaving, the chips produced were removed by rubber duct blower. The cleaved wafer was gently pressed to break into pieces according to drawn shape.

3.1.2 Photoresist

A commercially available SU–8 10 negative tone photoresist (MicroChem) was used as the lift-off resist for transferring the pattern of micro heating element from emulsion mask onto the substrate. A broadband UV exposure system (350-450 nm) is recommended by the manufacturer when this negative photoresist is used for the UV exposure process. The exposed resist layer will be developed with MicroChem's SU-8 developer solution.

3.1.3 Iron-chromium-aluminium (Fe-Cr-Al) Alloy Wire

Iron-chromium-aluminium (Fe-Cr-Al alloy) with its trade name Kanthal A1 wire as shown in figure 9 was used as source material for the thermal evaporation process.

(a) (b)

Figure 9. Kanthal A1 wire is used as source material: (a) Kanthal A1 wire (Vapor Tech), (b) Kanthal A1 in wire form

3.2 Methodology

There are three principal stages of process to develop the micro heating element. The geometry structure of micro heating element is first patterned onto substrate by optical lithography. In the second stage, the substrate is metallized by thermal evaporation method. At third stage, the micro heating element is obtained after the resist mask is stripped. The fundamental process of fabricating the micro heater by emulsion mask is illustrated in figure 10.

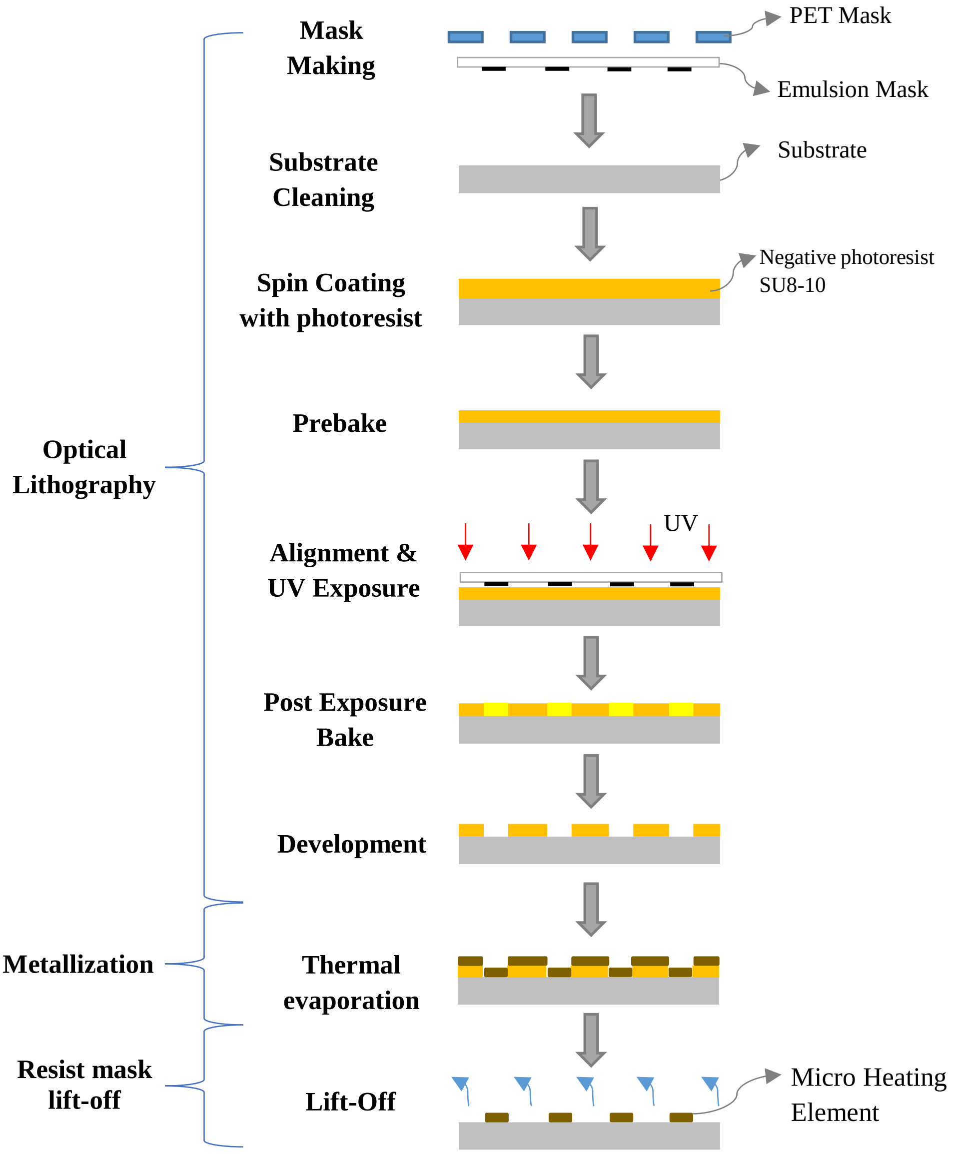


Figure 10. Process flow of depositing micro heating element on substrate

3.2.1 Patterning of micro heating element on substrate

This section discusses the process of transferring micro heating element pattern from CAD design onto the substrate by using optical lithography method.

3.2.1.1 Preparation of master mask film design

The geometric pattern of micro heating element for emulsion mask was designed using CAD design software. CorelDraw was used to design the geometric pattern of micro heater due to its user-friendly features that eases the creation of geometric shape. The design of micro heating element geometric pattern is scaled up to

5 times of the desired size as the emulsion mask that are fabricated using simple mask fabrication machine MM605 (Nanometric Technology Inc.) projects the pattern in 1/5 scale. Meander shape was adopted as the design of the micro heating element to obtain uniform distribution heating over the substrate. A total of 5 designs for micro heating element were sketched with width of 60 µm and pitches of 120 µm, 140 µm and 160 µm as shown in table 3. Illustration of pitch, width of line and distance between consecutive lines is shown in figure 11. Each design was sketched to maximize the coverage on the surface of 25 mm x 15 mm substrate to achieve a uniform heating effect over the whole surface of substrate and to avoid delamination of heating element due to different thermal expansion coefficient of substrate and heating element metal. Optical proximity correction (OPC) which comprises 10 µm x10 µm mousebit and 20 µm x 20 µm serif as shown in figure 12, was included into Design A and Design D. Full designs are attached in figure 39 – 43 at Appendices section.

$$\text{Pitch, } p = \begin{array}{c}\text{Width of heating}\\ \text{element line, } w\end{array} + \begin{array}{c}\text{Distance between}\\ \text{consecutive line, } d\end{array}$$

Equation 1. Calculation of pitch for heating element design

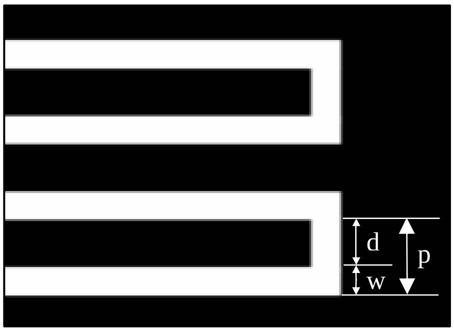


Figure 11. Illustration labelling with pitch, width of line and distance between consecutive lines

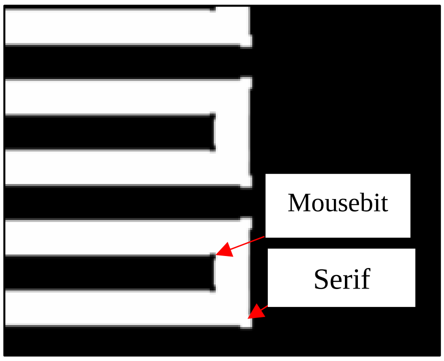
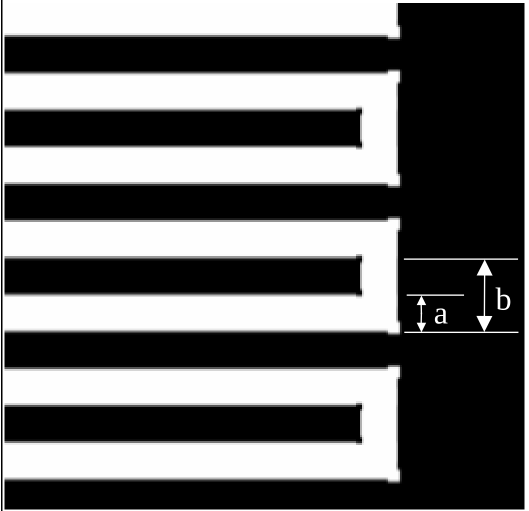
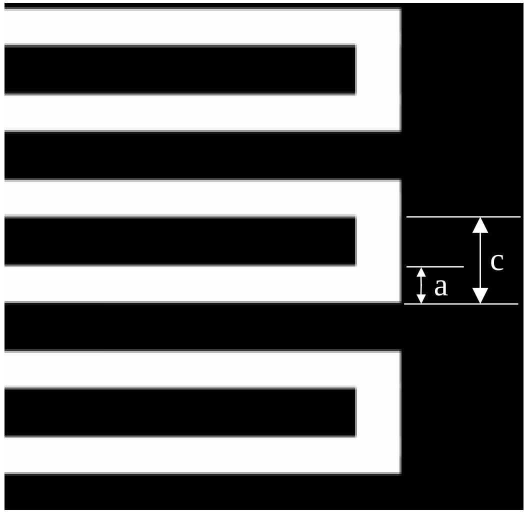
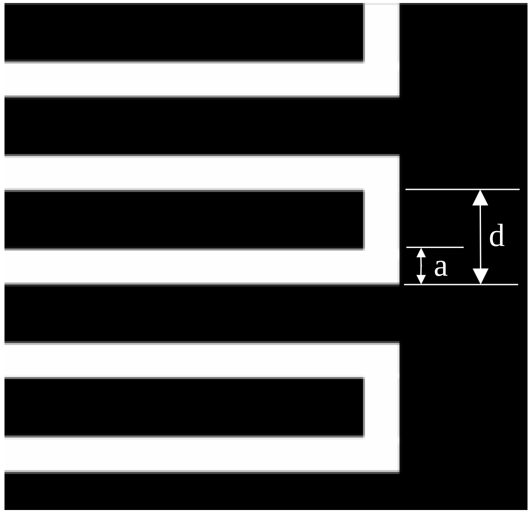


Figure 12. Heating element with mousebit and serif

Table 3. Illustrations showing the design of micro heating element with respective dimensions

Illustration	 (a) Design with 120 µm pitch	 (b) Design with 140 µm pitch	 (c) Design with 160 µm pitch
Dimensions	a = 60 µm, b = 120 µm, c = 140 µm, d = 160 µm		
Design	Design A and Design D	Design B	Design C and Design E
Remarks	Optical proximity Correction (OPC) at every U-turning edge was included. The OPC consists of mousebit 10 µm x10 µm and serif 20 µm x 20 µm		

The design was printed on A4-sized polyester (PET) film by imagesetter. The printed film is known as master mask film and it can be used to fabricate emulsion mask repeatedly.

3.2.1.2 Emulsion mask development

The development of emulsion mask was conducted in a dark room. The master mask film was placed in the center of the lightbox as shown in figure 13 of the Simple Mask Fabrication Mask MM605 (Nanometric Technology Inc.) which equipped with five 15W FL15ENW fluorescent lamps (Matsushita Electric Co.). The image on master mask film was projected in 1/5 scale to a High Precision Photo Plate (Konica Minolta, Inc.) by using a MM605 as illustrated in figure 14. The photo plate (also known as emulsion mask) is a glass plate coated with photosensitive agent composed of silver halides, gelatin and other additives. The emulsion mask was placed on the mask holder with the silver halides coated surface facing towards the lightbox. The exposure process is carried out with exposure time of 8 seconds.

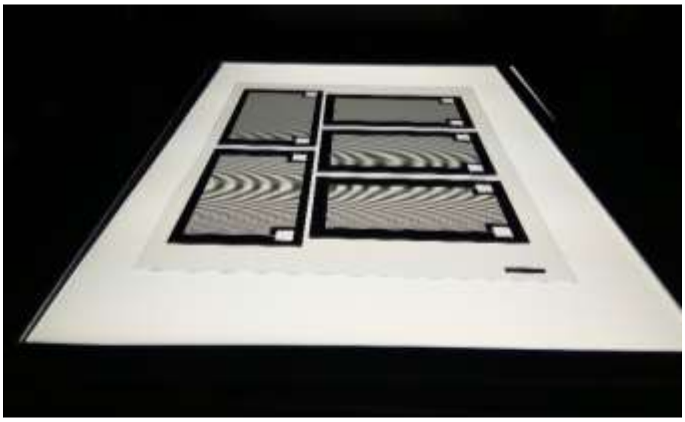
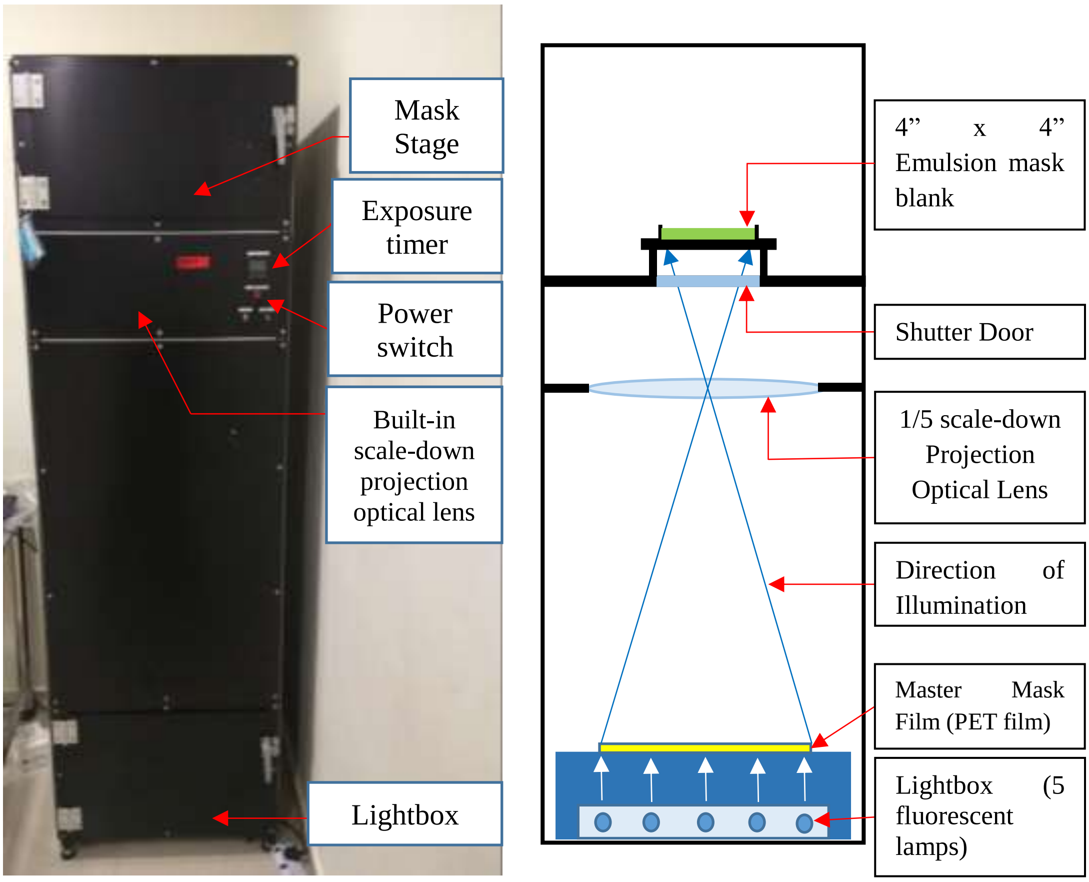


Figure 13. Master mask film was placed at the center of lightbox

Prior to exposure process, an emulsion mask developer, distilled water and fixer were prepared. The emulsion mask developer was prepared by mixing one part of high-resolution plate developer CDH-100 (Konica Minolta, Inc.) to four parts of distilled water. The exposed emulsion mask was immersed into the emulsion mask developer and stirred continuously for 2 minutes. Then, the mask was stirred in distilled water for 2 minutes to stop the reaction of developer, followed by continuously stirring in fixer CFL-881 (Konica Minolta, Inc.) for 10 minutes. The continuous stirring of emulsion mask in the emulsion mask developer creates a uniform development.



(a) (b)

Figure 14. Illustration of (a) Simple Mask Fabrication Machine MM605 and (b) Working mechanism of MM605

During the developing process, the latent image is converted into high optical density metallic silver. Stirring in fixer solution creates light-resistant permanent image which acts as a good optical filter on the emulsion mask. After cleaning under tap water stream for 5 minutes and dried, a light field emulsion mask was created. The development process was summarized in table 4. The master mask film and the light field emulsion mask is compared in figure 15 (a) and (b).

Table 4. Emulsion mask development process

Step	Materials	Time (minute)	Remarks
1	High-resolution plate developer CDH-100 mixture	2	Mixture of ONE CDH-100 to FOUR Distilled water
2	Distilled water	2	
3	Fixer Agent CFL-881 (Konica Minolta, Inc.)	10	
4	Tap water	5	Emulsion mask is rinsed under tap water stream