Development of Thin Film Photolithography Process: Patterning Printed Circuit Boards (PCBs) and Copper Electroplating

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Abstract:

A successful process of thin film photolithography using commercially available dry film sensitized copper clads (approximately 770 µm) was developed. Processing steps do not require extreme temperatures (higher than 40°C and lower than 100 °C) and final product is ready to use in 30 minutes. Necessary steps of the photolithography process include exposure to UV light, developing of exposed photoresist, etching of unwanted conductive substrate, and final photoresist strip to leave a final product. Average copper thickness is measured to be 30 µm. The average thickness of the photoresist was 30 µm as well. Experimenting in controlling the copper thickness by etching after final strip and by etching for controlled time periods after developing was also tested. Our best results are achieved by etching after final strip because surface smoothness is an essential parameter. Etching for controlled periods of time was also effective but left undesired surface imperfections on the base level of the conductive substrate. We present the Scanning Electron Microscopy (SEM) results for the process. We have experimented to control the rate of deposition by controlling the voltage and current of the power supply. When limiting the current to 20 mA, we find that the rate of deposition is approximately 1 µm per minute. These processes will lead us to develop more complicated micro structures with higher resolution down to 10 µm for different thicknesses in the near future. Our target potential applications include characterization of electrical properties of advanced materials such as piezoelectrics or ferroelectrets for energy harvesters, microfluidic applications to study polymer crystallization in liquids and bacteria hydrodynamics under certain flow rates.

I. Introduction:

Photolithography is one of the key processing steps in electronics today. The purpose of the process of photolithography and microfabrication is to create structures on the micron scale or even smaller[1]. The process has been optimized to produce these smaller and smaller structures since it was invented, providing today's technology to become smaller, faster, and more reliable. The technology also provided technological breakthroughs such as transistors and most Integrated Circuits (IC's) today[1]. Photolithography is also known as the building blocks to sensors and actuators in Micro Electro Mechanical Systems (MEMS)[2], including fabrication and characterization of accelerometers[3] and advanced materials such as ferroelectrets and piezoelectrics for energy harvesters[4],. The process of photolithography is extremely flexible when designing geometric patterns; any pattern can be achieved depending on the technology available down to the nanometer scale. Some interesting advanced structures that can be created from photolithography are gears, cantilever beams, and actuators, as shown in figure 1a and 1b. Also there has been great focus on three-dimensional microstructures for various microsystems[5].

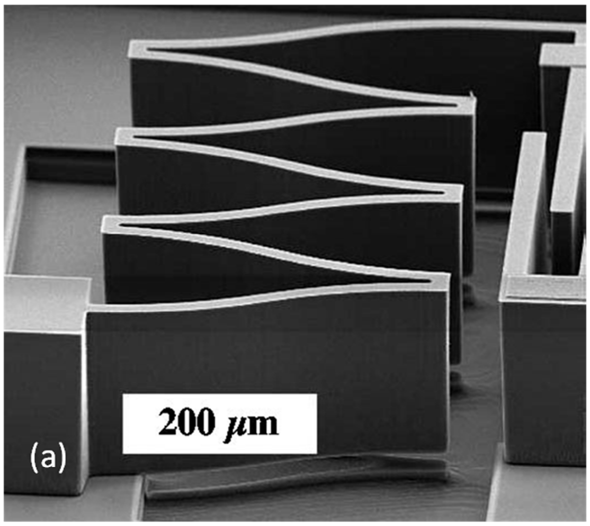

Figure 1a. Microflexure created by vertical etching through a wafer with Deep Reactive-ion Etching (DRIE) [6].

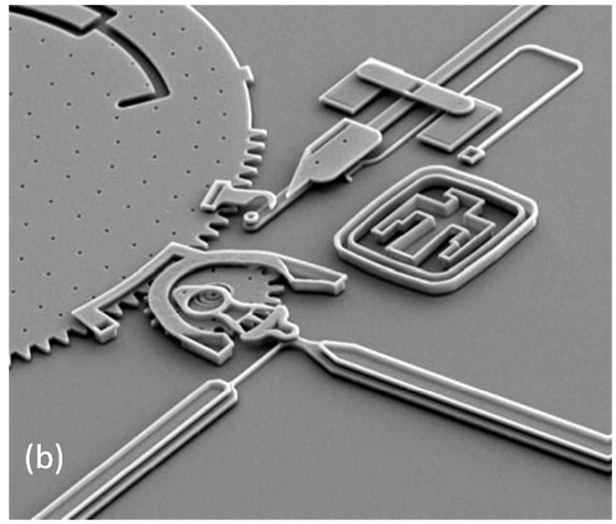

Figure 1b. MEMS with rotary bearing surfaces and interlocking gears (Sandia National Laboratories) [7].

Thin film photolithography process starts with a substrate in which you want to imprint a circuit on to. There are many different categories for each photolithography step and each has their own advantages and disadvantages[8]. These categories include ways of etching, photoresist coating, and UV exposure. Some of these processes can be more expensive or less precise, which will be explained in more detail a little further on. A simple process flow of photolithography is shown in figure 2. The substrate is covered with a thin film layer depending on what the circuit needs to be make from and a photoresist layer[2]. The thin film may be deposited onto the substrate and the photoresist will need to be spun or sprayed on top of the thin film for even coating[9]. The designed mask is place on top of the photoresist, and then exposed using UV light. This photochemical reaction hardens the photoresist at the points that were exposed. The substrate is agitated in presence of developer to remove undesired photoresist, leaving behind the pattern or design of the mask. To remove the uncovered thin film the substrate is placed in an etchant bath, now leaving only the desired structure and the substrate. A final strip is necessary to remove any photo resist left, to produce the final product.

Understanding thin film photolithography is crucial in the development of a microfabrication facility. Microfabrication is the basis to most IC; therefore it is necessary to know the equipment and chemicals important to the microfabrication process[10]. Developing this process will help in creating more advanced MEMS structures, such as cantilever beams, mechanical sensors, energy harvesting platforms, and accelerometers[11]. Once the process is developed and optimized, less expensive ways to create these systems will be possible[12]. The miniaturization of these electrical circuits and systems has changed our everyday lives, and has widely impacted the technology we use today.

In experimenting with this process and the development a thin film photolithography process was possible, using commercial dry film photoresist copper clads. This process will be further explained step by step further on. Performing certain steps to understand how they affect our results, some improved our results and others hindered them. This includes different masks, time in developer and etchant, agitation of the solutions, and temperature. From the different trials we discovered that the process only requires a moderate temperature (lower than 100 °C) and a finished product in about 30 minutes. Another process that was experimented with is thin film electrodeposition of copper. Performing alterations to the procedure to better understand the effects of each step, including current, voltage, and time in the solution. This developed process will be later explained and also shown in figure 2. These processes will greatly improve our ability in creating in house PCBs and implementing them in our potential applications from above.

II. Photolithography Procedure

Thin film deposition is the first step in wet etches in photolithography. The process involves producing a coating, usually metallic, on a surface by supplying electrical current. To deposit a metallic substance onto a substrate, the substrate must be conductive or have a conductive layer spudder coated on to the substrate. Deposition of a metallic substance is achieved by putting a negative charge on the substrate to be coated and the metallic substance to be positively charged creating an anode. Both the cathode and anode are then dipped in a salt of the metal to be deposited. Since the metallic ions in the solution are positively charged they are attracted to the cathode object (substrate).

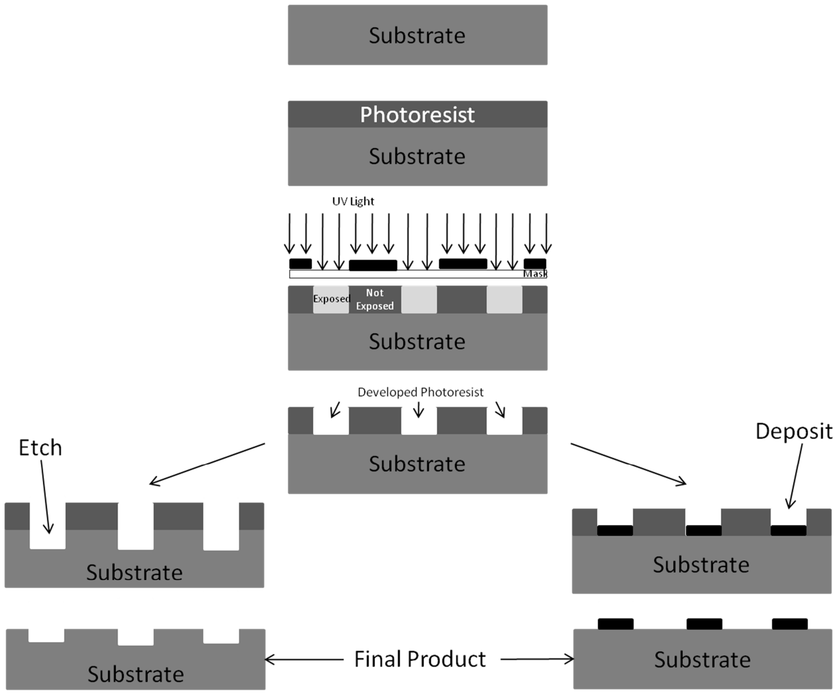

Figure 1: Basic steps of photolithography.

There are more types of deposition than just electroplating which is explained above and shown in figure 2. Some other methods include Chemical Vapor Deposition (CVD) and Physical Vapor Deposition (PVD), each have their own sub categories or methods of depositing thin films. CVD is the process of exposing a substrate to a chemical reaction to deposit a thin film layer to the surface. This process is rarely used in the deposition of copper and other materials that can be easily deposited by electroplating, because the process is not cost effective.

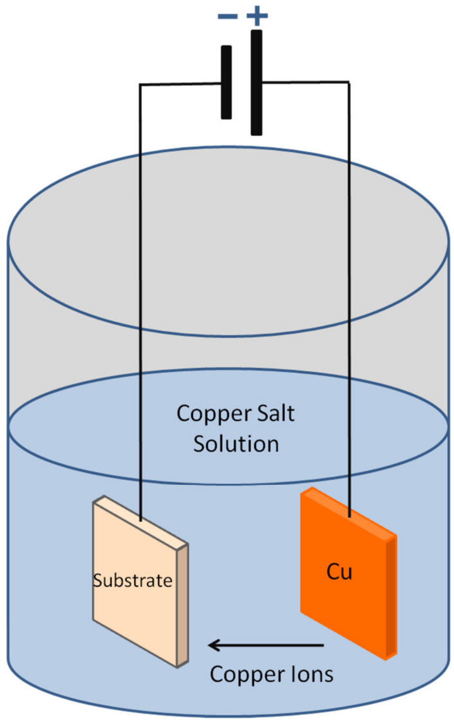

Figure 2: Basic setup of electroplating Copper.

Photoresist coating techniques plays a major role in wet etches in photolithography. There are several different coating methods and each specific to certain applications. Some photoresist coating options are spray coating, spin coating, roller coating and dip coating. Multiple factors that have to be considered in chasing application type, which include film thickness, coating time, size, substrate texture and cost. Spray coating has the highest risk in poor resist covering, although can be practically inexpensive and can work with all sized and shaped substrates. Spin coating utilizes centripetal forces to spread the resist across the substrate. The process holds a high yield in a flat surface covering but it almost ineffective in three dimensional structures.

UV Exposure is one of the most crucial steps in Photolithography. Just like the other processes there are multiple ways of exposing the photoresist to UV light. The most simplistic way is by using a mask and a UV light emitter. The mask is a clear piece of thin piece of plastic or class, with a printed pattern on it. The substrate is set on top of the mask, only allowing the certain design to be exposed to the UV light. Even though this process is so simple it leaves a wide margin for error in various areas. Another way would be to use a mask aligner which pin points exact places to be exposed. Although this process is very precise, it is a very expensive piece of equipment.

Developing is a chemical agent that removes the un-disable photoresist, leaving behind the printed pattern of your mask depending on if it was for negative or positive resist. After the substrate has been exposed, there are two distinct types of resist, negative once exposed hardens and positive weakens the resist for the developer.

Etching is the process of removing the thin film layer of the substrate in the areas that are not protected by photoresist. This process utilizes a chemical agent, either in a plasma or liquid form. Plasma etching or dry etch is a more precise way of etching and tends to be anisotropic, this means avoiding major undercutting that can occur during this step. Although wet etching tends to be more isotropic it is extremely less expensive than dry etching and it is also very crucial to MEM systems.

III. Experimental Results

The process of thin film photolithography using commercially available dry film sensitized copper clads was developed. For the best results the process followed these steps in a black room. There was some trouble with exposing the photoresist while cutting the PCBs. The process includes putting the PCB on top of the mask in the UV exposer (Figure 3a). Then after making sure is no air bubbles in the mask and there is a tight fit, exposure of the sample for five minutes is the next step. This will produce the hardened design of the photoresist, the sample is developed in a developer solution at 43°C for 35 seconds to remove the unexposed photoresist. This took a couple of attempts to find the right time because too much or too little was developed. The sample is now ready to be chemically etched, it is placed in a etcher solution at 55°C for sixteen minutes to remove undesired thin film layer (Figure 3a). The etching also took multiple tries to figure out the correct duration of time. The sample was left in the etchant for too long and the etchant began to dissolve the walls of the sample. This wasn't visible by the naked eye but was apparent under the SEM. The final step is to strip the exposed photoresist on top of un-etched thin film layer in developer solution at 47°C agitated for six minutes. The average copper thickness produced is measured to be 30 μm. The average thickness of the photoresist was 30 μm as well. The copper thickness was also experimented by etching after final strip and by etching for controlled time periods after developing.

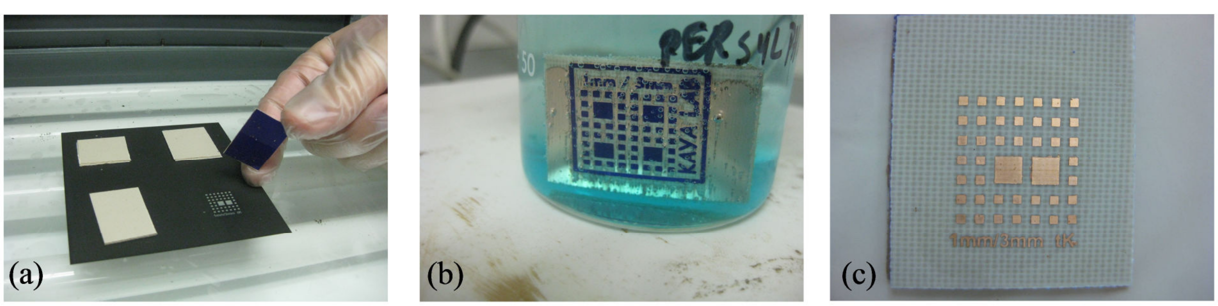

Figure 3: a) UV exposure b) Chemical etch c) Final Product

The final products were taken to a Scanning Electron Microscopy (SEM). The products were analyzed for many different variables including precision and quality. The Figure below is a photograph of a sample from its cross section view, where the sample was cut to expose the thickness of the thin film layer.

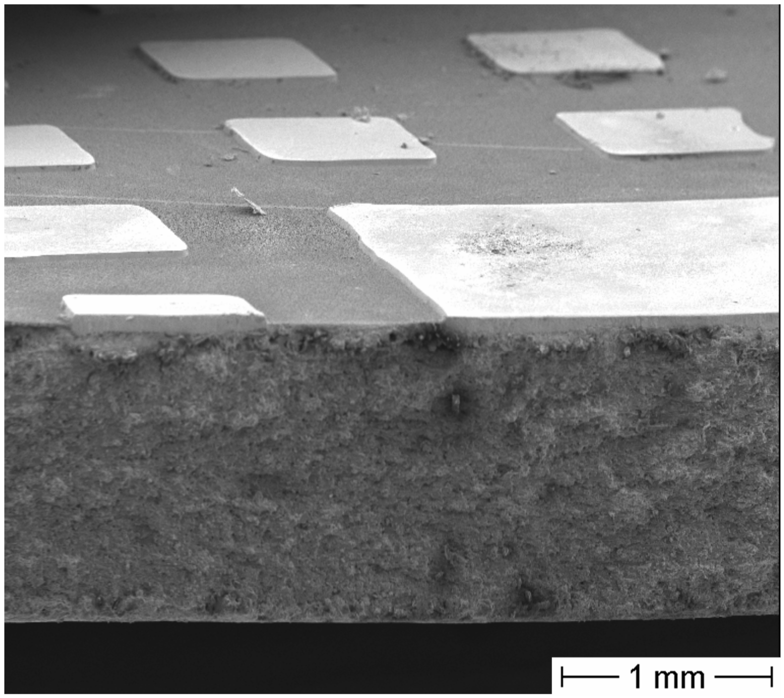

Figure 4: SEM of final Product

The electrodeposition process was experimented with to control the rate in which a thin film layer of copper is deposited by controlling the voltage and current of the power supply. When limiting the current to 20 mA, the rate of deposition found was approximately 1 μm per minute. There was trouble with trying to deposit this layer any faster because it becomes very inconsistent, this will create dimples and a very rough layer. The deposition of copper was achieved by putting a negative charge on the substrate to be coated and the copper source positively charged (Figure 5). They were dipped in a salt solution of copper sulfate. The samples were more uniform after shorter time of deposition, after longer periods of the samples would create rises and holes.

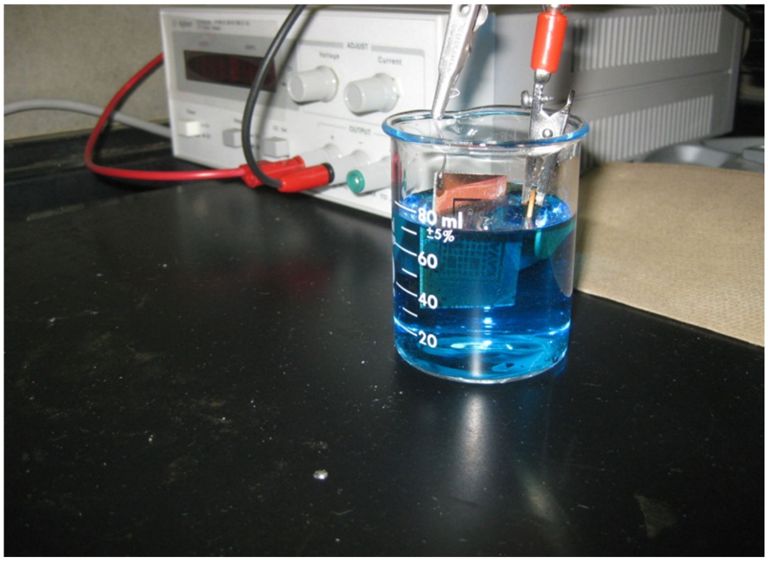

Figure 5: Electrodeposition system

IV. Applications:

Photolithography has a very wide spectrum; it can be used in many different applications. It is used in almost every IC today and in making MEM systems. Since the process is so versatile, it is able to produce very complex structures, devices, and systems on a micro scale. Another application that relies on photolithography is microfluidics, which deals with the precise control and manipulation of fluids. Microfluidic channels to control the fluids are produce from photolithography.

Applying this process to future work will help in building pcbs for certain applications such as piezoelectrics or ferroelectrets for energy harvesters and producing tri-axis accelerometers.

V. Conclusion:

Photolithography is the beginning step in most electronics today. It is a chemical treatment process that removes undesired areas of a thin film to produce certain patterns. This process is extremely flexible and can be implemented in many fields and applications. The main purpose is to create structures on the micrometer-scale or even smaller, which can be very difficult with other fabrication techniques. Some structures produced from photolithography include geometric patterns such as gears, cantilever beams, and actuators, which are crucial in many Micro Electro Mechanical Systems sensors. Photolithography has also leaded to technological breakthroughs such as the transistor and integrated circuits.

Our development of a thin film photolithography process was successfully accomplished using dry film sensitized copper clads. The fabrication process is very simple, straightforward, and repeatable. It includes UV exposure of the photoresist copper clads, developing the unexposed photoresist, wet chemically etching the exposed copper, then a final strip of the photoresist to make the final product. It has a processing time of less than 30 minutes and is completed at low temperatures. The resolution we were able to create is on the order of 500 μm and an average thickness of the photoresist was 30 μm as well.

VII. Acknowledgments:

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