AC 2011-1595: EXPERIMENTAL MODULES INTRODUCING MICRO-FABRICATION UTILIZING A MULTIDISCIPLINARY APPROACH

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Experimental Modules Introducing Microfabrication Utilizing A Multidisciplinary Approach

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Abstract

A comprehensive, multidisciplinary approach to introducing the concepts of microfabrication to the undergraduate student body is being developed. The approach relies on multidisciplinary expertise in electrical engineering, mechanical engineering, chemistry, and physics and utilizes a pipeline approach to introduce concepts in microfabrication at the freshman, sophomore, and junior levels followed by a comprehensive capstone course in microfabrication at the senior level. In this paper, we describe the specific microfabrication modules being developed and their method of implementation.

Introduction

Microfabrication, the processes for fabricating structures at length scales below several microns, is critical to many branches of science and engineering. It is heavily used to fabricate electron devices, integrated circuits, accelerometers, lasers, and miniature microphones and is becoming more prevalent in the biological sciences. Since microfabrication is such a broad and multidisciplinary activity, the conventional approach of presenting this topic in a single course in one department seems inappropriate. Many approaches have been presented to develop appropriate educational material in microelectronics [1-4]. Here, we describe our efforts to introduce microfabrication technology in a comprehensive, cross-curricular way through lectures, demonstrations and experiments from freshman through junior classes across four disciplines (Electrical and Mechanical Engineering, Chemistry, and Physics). In particular, we describe the capstone multidisciplinary fabrication experiments that we have designed.

Junior level courses from four departments will integrate microfabrication experimental modules into the existing syllabi. These modules will expose students to the concept of a clean room, the concept of microfabrication, and attract and interest them in the microfabrication side of their discipline. In the senior year, students in these disciplines have an opportunity to take a multidisciplinary microfabrication capstone course that serves as a complete introduction to clean room theory and practice.

The modules the students will construct in the senior level capstone course include fabricating a thin film transistor, fabricating an organic light emitting device (OLED) and fabricating a microfluidic device. The transistor module will expose students to the important design parameters of a transistor and how they are characterized. The OLED module will introduce the technology and language of displays as well as measurements of the device efficiency in converting power to visible color. Finally, the microfluidic module will demonstrate routing of fluidics on the micrometer channel scale – this is a common application in biomedical fields. Every student will be exposed to all of these fields, leading to a broad, deep, and detailed educational experience. An example of the transistor fabrication project is illustrated in Figure 1.

Transistor Fabrication Experimental Module

In this module the students fabricate a thin film transistor (TFT). A TFT is a type of field–effect transistor made by depositing thin layers of a semiconductor, a dielectric and metallic contacts. This differs from traditional transistors that use the substrate as the semiconductor material. The TFT chosen for the class experiment has four layers. The "gate" is a chromium layer that is the first film deposited. The dielectric, silicon nitride, is the next layer. The semiconductor layer, zinc oxide, is the third film. The molybdenum source/drain layer is the last to be deposited. Figure 1 shows a diagram of the transistor.

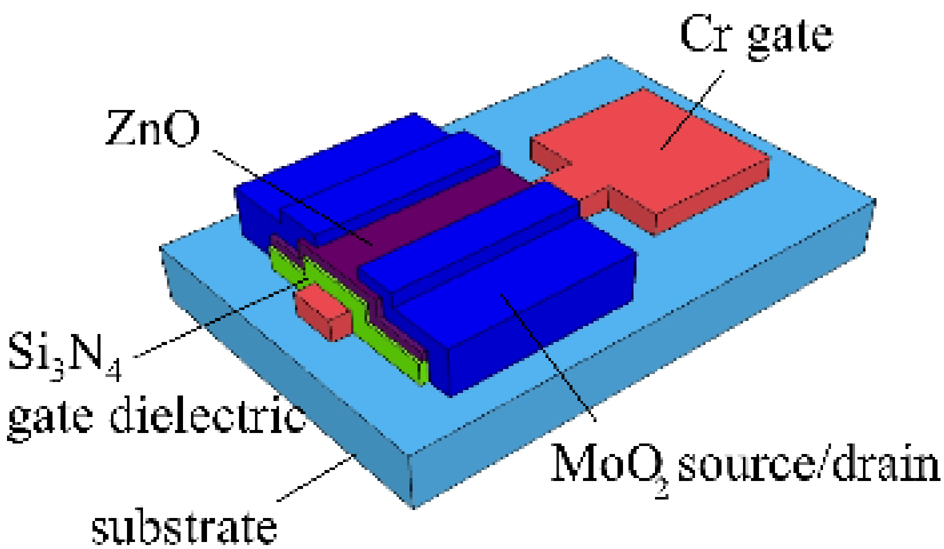

Figure 1. Thin Film Transistor

The TFT module exposes students to the techniques of evaporation, sputtering, plasma enhanced chemical vapor deposition (PECVD), wet etching, reactive ion etch (RIE), photolithography and rapid thermal processing (RTP). While these topics are covered in class lectures, there is no substitute for the experience gained from the lab exercises. The photolithography is performed on a contact aligner using positive photoresist. The completed TFT structures are shown in Figure 2.

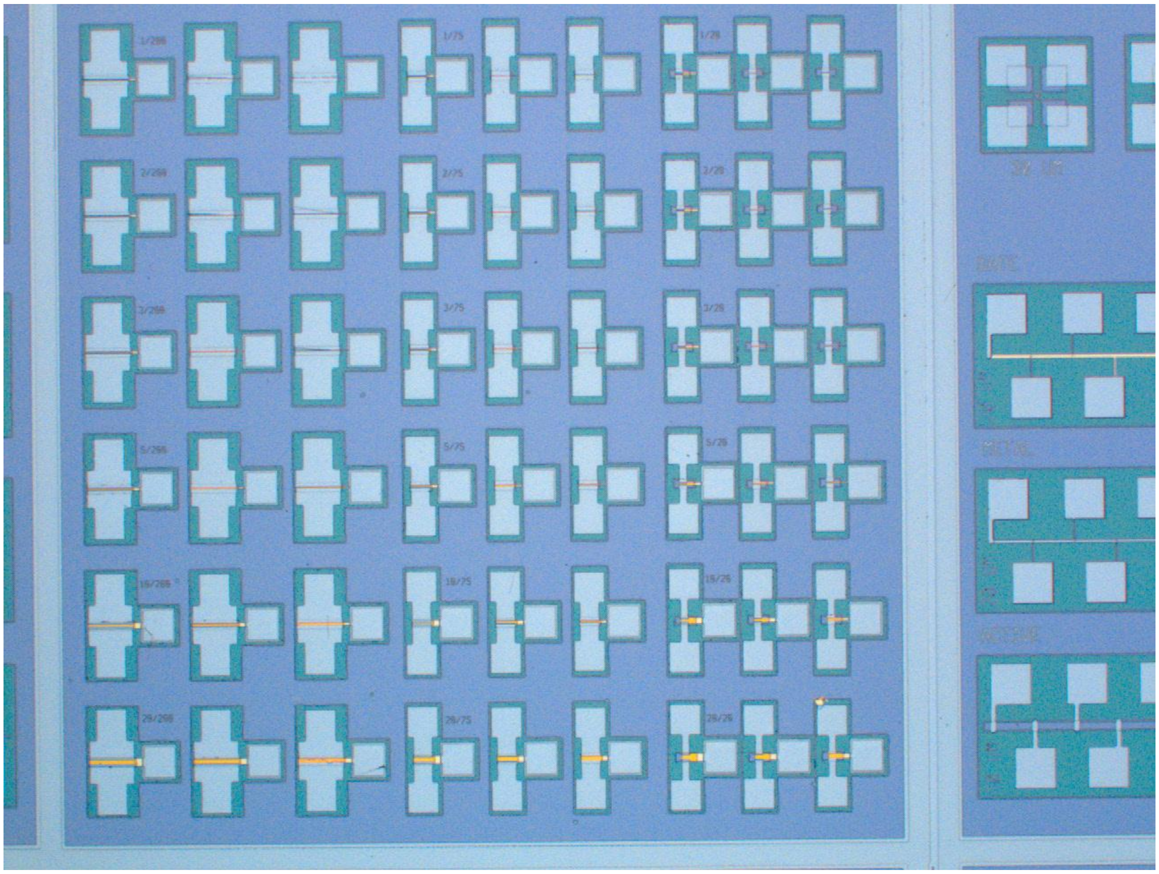

Figure 2. Thin film transistors created by students.

Organic Light Emitting Device (OLED) Module

In this module students fabricate an organic light emitting device (OLED). An OLED is a light emitting diode in which the emissive material is a film of organic compounds. The OLED module exposes students to the techniques of evaporation, wet etching, spin coating, photolithography and the use of a “shadow mask”. The photolithography is performed on a contact aligner using positive photoresist. The completed OLED structures are shown in Figure 3.

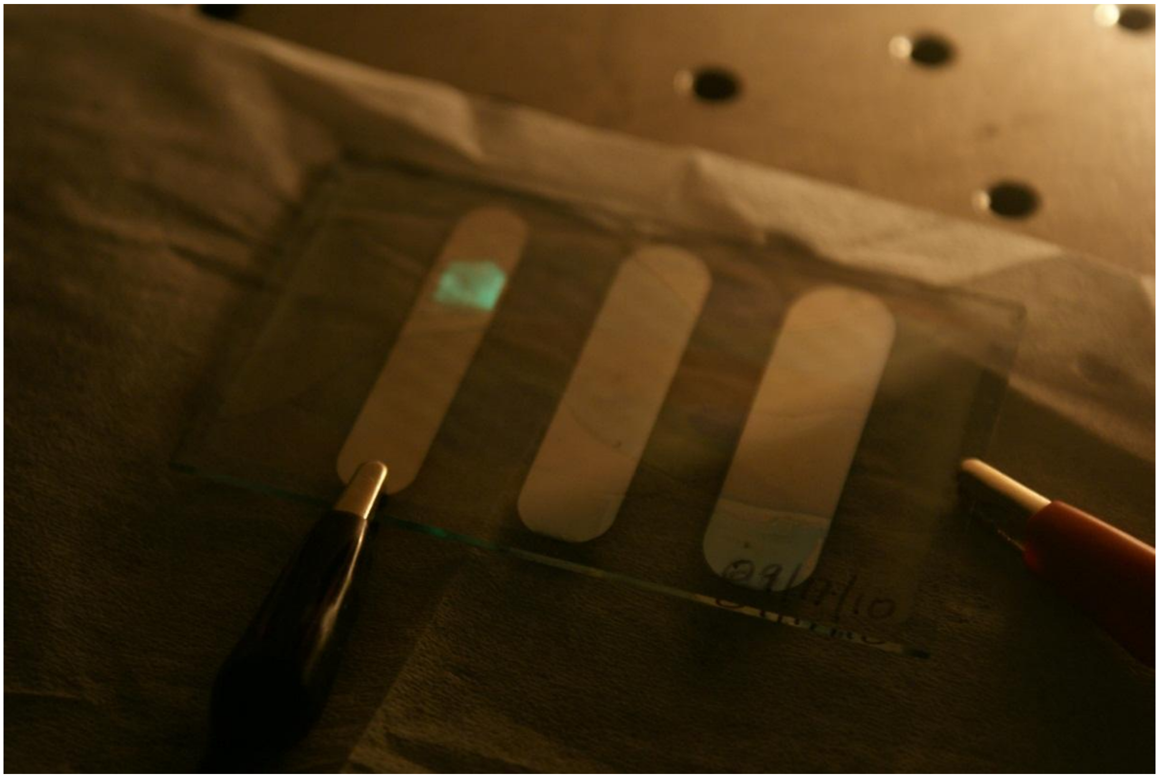

Figure 3. Completed OLED.

Microfluidic Device Module

Students fabricate a microfluidic device in this module. This module introduces students to all aspects of photolithography, rapid prototyping of masters with SU8, replica of masters and plasma oxidation. Microfluidic devices in recent years have been widely exploited in a diverse range of chemical and biological applications for material synthesis, device assembly and bioanalysis. The fabrication process is relatively straightforward and this makes it an ideal module for the students to get familiar with micro-fabrication [5]. The substrate used for this experiment is a 4" silicon wafer. The master for the device is first created from a negative resist on the surface of the wafer. The microfluidic device is then molded in poly(dimethylsiloxane) (PDMS). After molding the PDMS device and its glass cover are exposed to low-power oxygen plasma either in a plasma asher, RIE or PECVD and plasma-oxidized, then bonded together. A SEM of the channels is shown in Figure 4.[6]

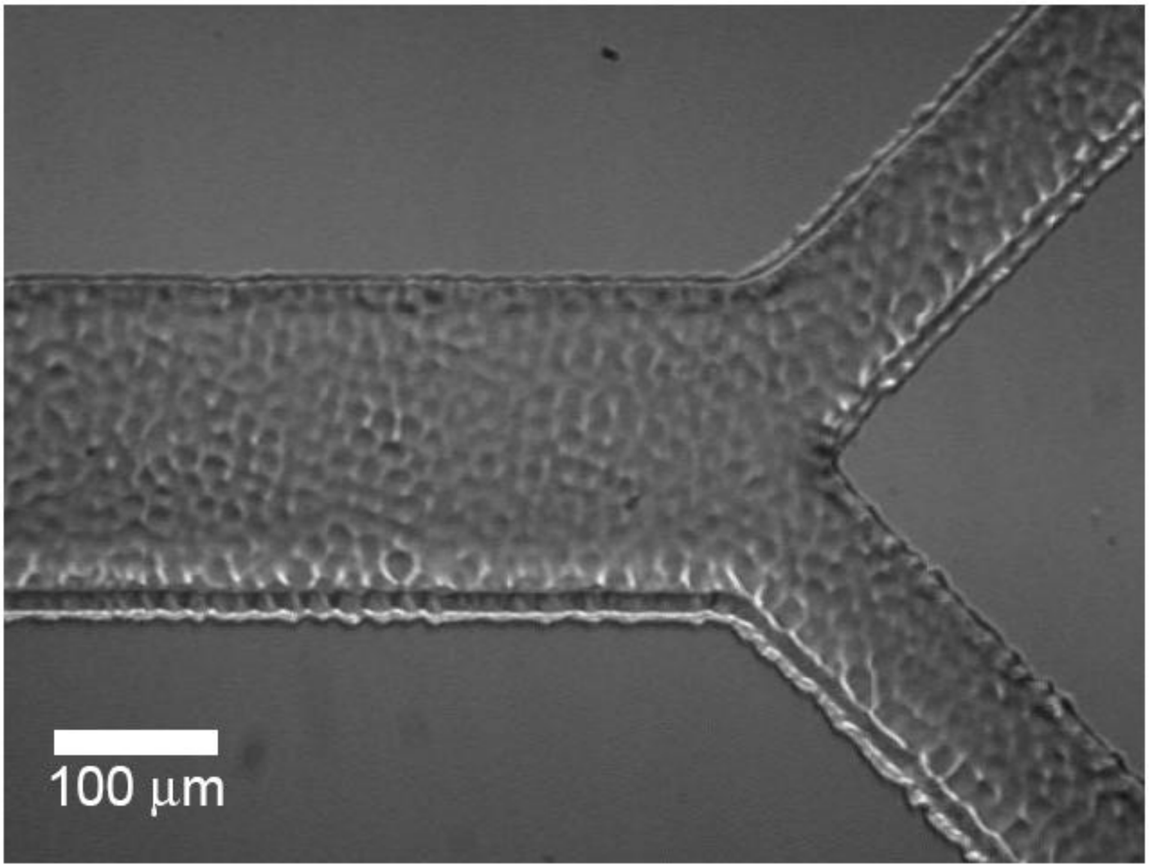

Figure 4. SEM of Microfluidic Device[6]

Capstone Course Logistics

Laboratory safety is the chief concern when introducing undergraduates to techniques in microfabrication. The chemicals used for processing are hazardous and injury can result from improper handling. Accidental exposure to the wet chemicals used in processing presents the greatest risk. While automated equipment in the lab may utilize hazardous chemicals, exposure is minimized through the use of equipment safety interlocks. The automated equipment is expensive and, at times, delicate. Equipment misuse and damage is a concern.

Proper training in lab safety and equipment use is the only realistic method to minimize the risks described above. Proper training, typical of that required of research program cleanroom users, requires a considerable time commitment. Training an entire class to become proficient in equipment operation is impractical. To overcome this issue, graduate student teaching assistants (TAs) were trained prior to the first class offering. Only the trained TAs were allowed to handle the hazardous materials and operate the equipment. Two TAs were selected and trained over the course of a semester prior to the offering of the capstone course. All capstone course students were provided an extensive safety orientation prior to cleanroom access.

The enrollment of the capstone course was capped at 18 students. There were three, 2.5 hour lab sessions offered, with enrollment in each session capped at 6 students. In a given lab session, the 6 students were divided into two groups and assigned a TA for the course. The groups were kept small to enable maximum student participation in an environment strongly controlled by the TA.

Not all fabrication steps in each module were preformed during the lab session due to the excessive time required for certain processes. These steps were performed by the TAs outside of the scheduled lab times. Since photolithography is central to microfabrication, all of the photolithography steps were done in the lab.

Process Flows

The process flow for creation of the microfluidic device is shown in Figure 5. The creation of the master is done during the lab session. This step introduces all aspects of photolithography to the students. A silicon wafer is used for the substrate. Negative photoresist (SU-8) is spun onto the surface of the wafer. The SU-8 is baked, exposed and developed. After cleaning, creation of the master is complete.

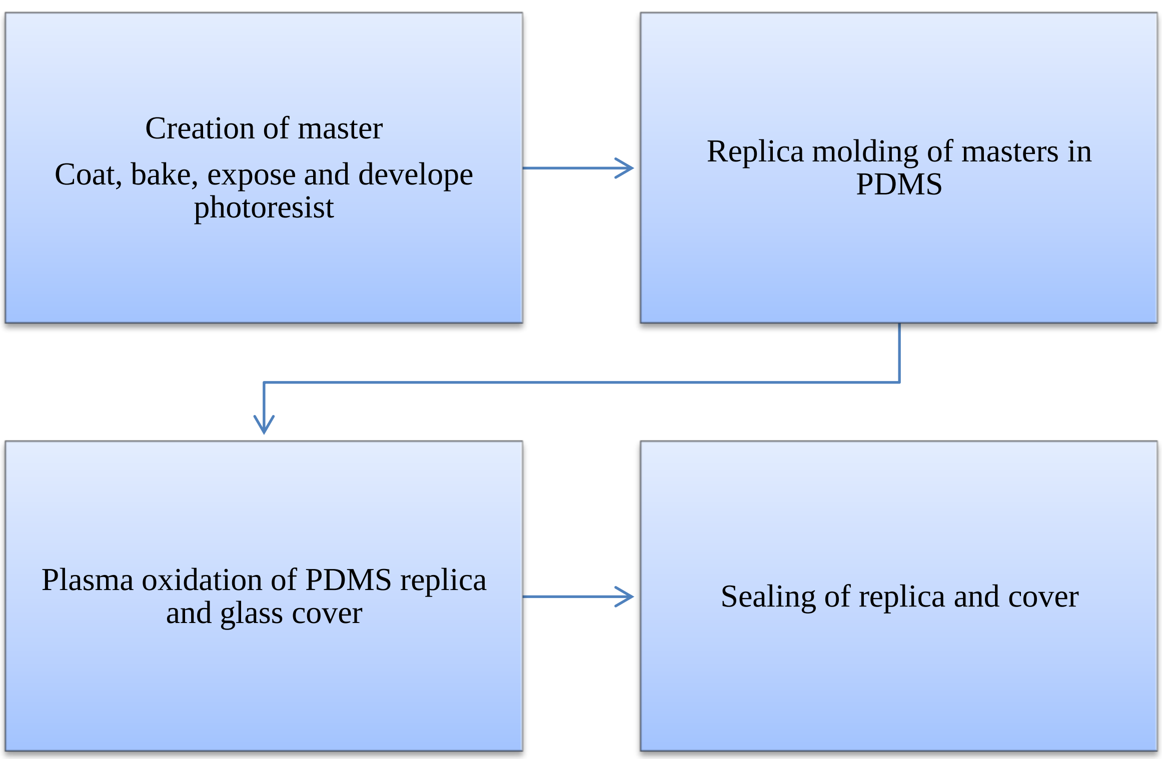

Figure 5 Process Flow for Microfluidic Device [5,6]

The master is placed into a form and the form is put on a hotplate. PDMS is poured over the wafer and allowed to cure. After curing, the PDMS casting is removed from the master. The

PDMS casting and a glass cover are plasma-treated in an O2 plasma in the RIE. The cover and the casting are brought into contact and are sealed together.

The process flow for creation of the OLED is shown in Figure 6. The substrate used for this experiment is a 2 inch by 3 inch glass slide that is purchased with a coating of indium tin oxide (ITO). The first step in the experiment is to pattern the ITO.

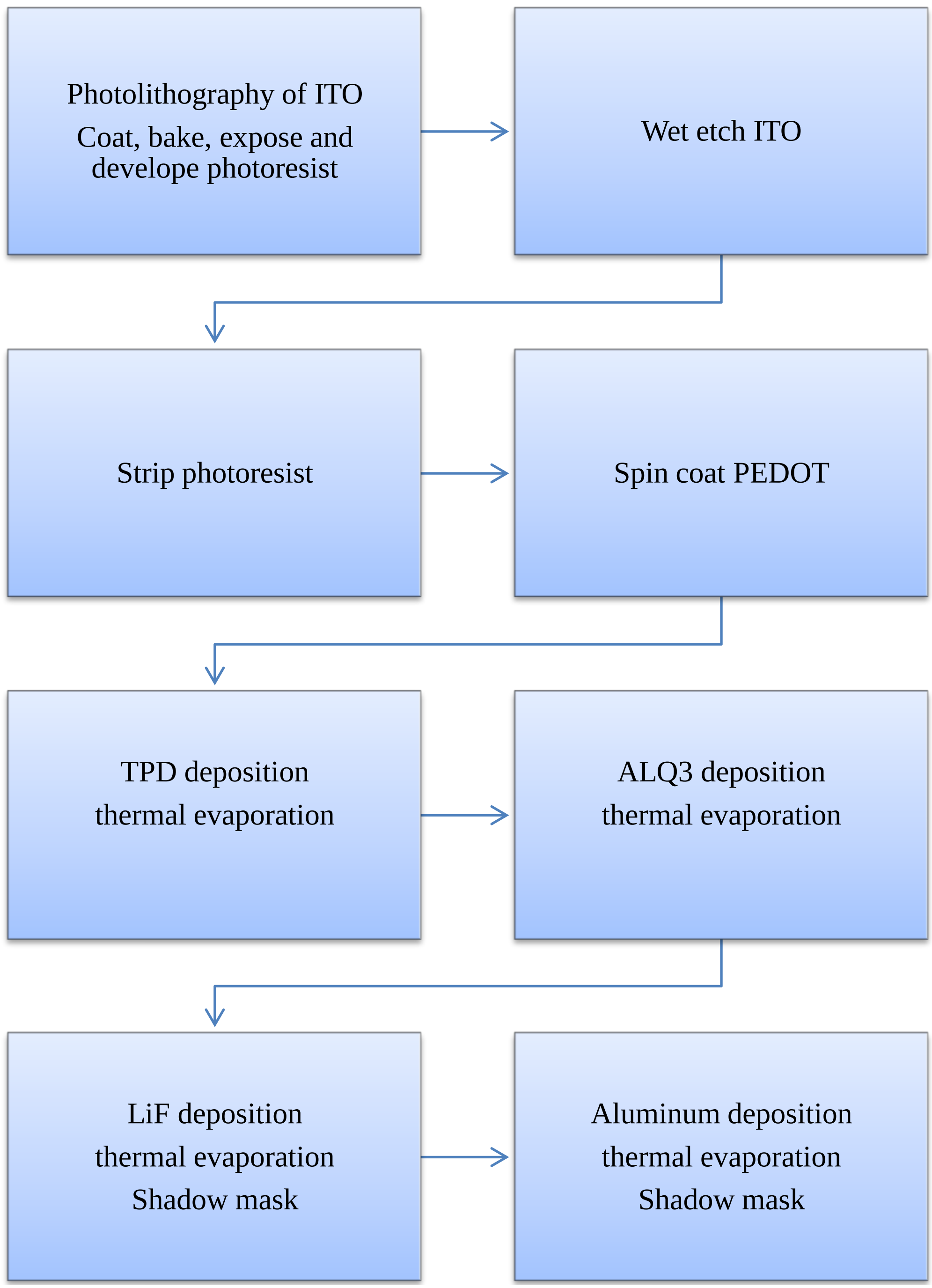

Figure 6. Process Flow for creation of OLED's

The slide is coated with positive photoresist in a resist spinner. After the bake, the photoresist is exposed in the contact aligner and then developed. The ITO is then etched in a combination of acids. After removing the photoresist, the surface is coated with PEDOT in a spin coater. Only the ITO layer is patterned via photolithography. The patterns in the other layers are all created with a “shadow mask’. The remaining films are deposited via thermal evaporation. The LiF and aluminum films are deposited using a shadow mask. The shadow mask is a plate of aluminum with the needed pattern cut into it. Deposition on the surface occurs where the pattern has been cut into the mask.

The process flow for creation of the TFT is shown in Figure 7. The substrate used for the experiment is a 4” silicon wafer with 1 micrometer of silicon dioxide on the surface. The substrates were purchased with the silicon dioxide pre-grown on surface. The silicon dioxide is necessary to prevent the gate and source/drain from shorting to each other. Purchasing the substrate with the silicon dioxide on the surface eliminates the need for a large and expensive oxidation furnace. Another non-conductive substrate could have been used. The first step is deposition of chromium via e-beam evaporation. This step is done before the students arrive. A short orientation of the evaporator is given before moving onto patterning the layer. The chromium is patterned with photolithography using positive resist and wet etching. After removal of the photoresist, silicon nitride, followed by zinc oxide are deposited onto the wafer. Both of these steps are performed during the lab. These films are then patterned using photolithography as before. This layer must be precisely aligned to the “gate” layer. Proper alignment of the wafer to the mask is demonstrated. Molybdenum is then deposited on the wafer prior to the next lab session. Using photolithography as in the prior two steps followed by etching in the RIE, the source / drain structures are then patterned in the molybdenum. Finally, the molybdenum is oxidized in the RTP. The TFT process takes 4 lab sessions with two steps performed by the TA’s outside of lab.

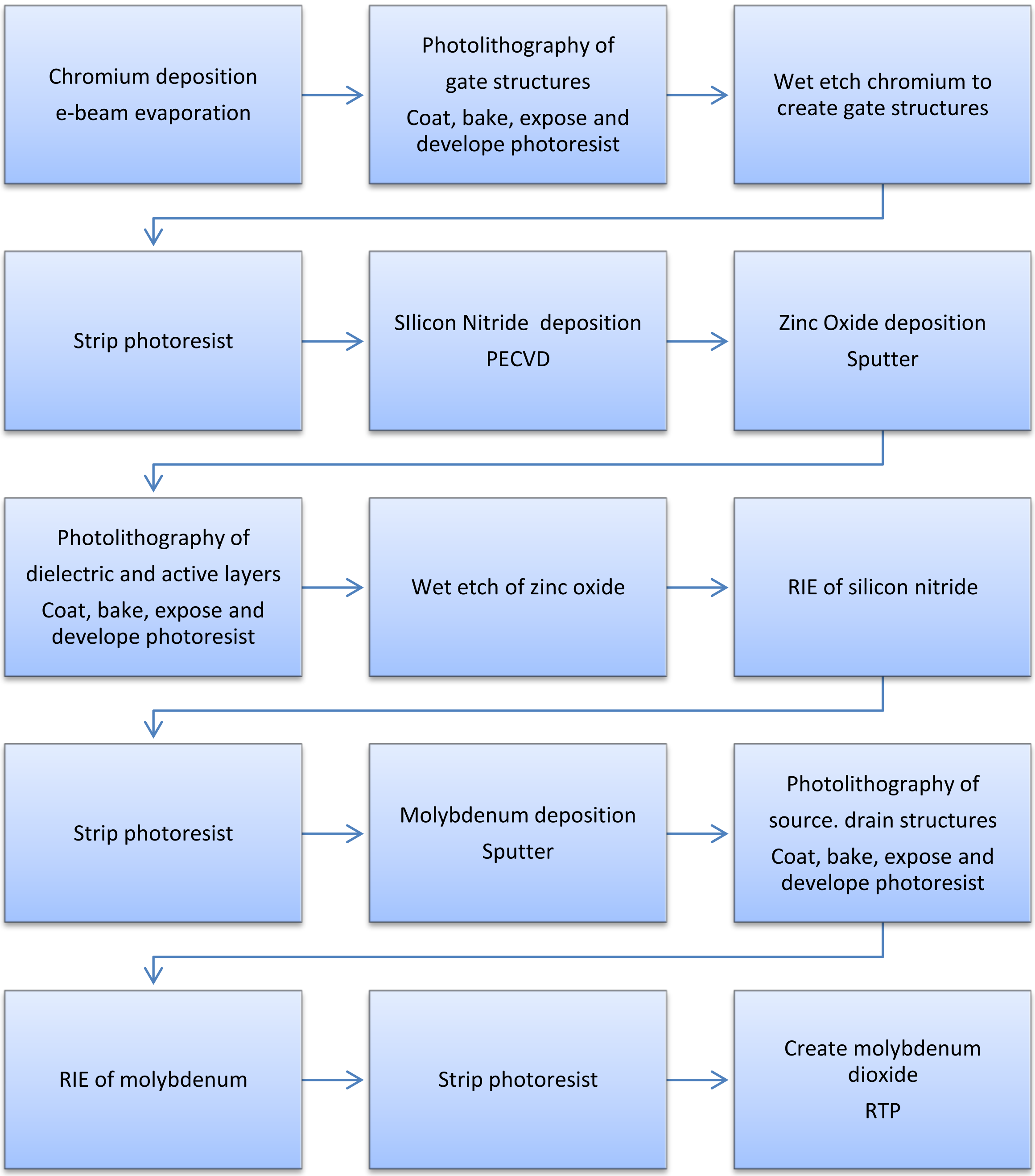

Figure 7. Process Flow for creation of TFT's.

Conclusion

Microfabrication, is a broad and multidisciplinary activity with applications in chemistry physics, and engineering. A senior level course has been developed where students from these disciplines are introduced to microfabrication practice. This papers presents three laboratory modules that have been developed for this class. The modules presented in this paper result in the student creating organic light emitting devices, microfluidic channels, and thinfilm transistors.

All of these experiments have been tested, and lab procedures have been developed for running of the course. The TAs have been selected and thoroughly trained on the equipment and on the safety procedures. We look forward to the inaugural running of the course.

Acknowledgment

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