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Single-Step Lift-off Process with Toluene and Shipley 1813 Type photoresist

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Abstract: *"Lift-off" is a simple, easy method for making metallic patterns on a substrate, especially for metals such as platinum and nickel which are difficult to be etched by conventional methods that involve wet chemical or dry reactive ion etching. The mechanism of the toluene single-step lift-off process is defined. The toluene penetrates to some depth into the resist film during the soaking cycle, extracting residual casting solvent and low-molecular-weight resin species. The toluene is subsequently removed by a rinse cycle. The penetrated layer of resist develops at a slower rate than the underlying bulk resist, producing the lift-off structure. Variances in the structure of the photoresist lift-off image are the result of complex interactions among exposure, toluene soaking, development, and post-application baking conditions. Effects produced by these variables can be controlled by monitoring the linewidth, overhang, and height of the lift-off resist structure using a scanning electron microscope (SEM). So, the purpose of this paper is to provide the details of the lift-off process using toluene to create the patterns with the highest accuracy. After each test, cross section of the patterned dry film side wall is observed under a microscope to check if a profile is obtained.*

Keywords: *Lift-Off, Photoresist, Photolithography, Metal, Toluene.*

INTRODUCTION

Metal patterning using a photoresist is one of the key processing technologies in integrated circuit fabrication (Kanikella, 2007). For applications which are not easily patterned by conventional lithography and etching techniques, the lift-off method has been widely used as a simple and easy method for patterning materials as films. The photoresist lift-off process was introduced to semiconductor manufacturing as an improvement in metal pitch for high-density arrays. Lift-off processes accomplish this improvement by eliminating the etch bias component of subtractive etching (Collins and Halsted, 1982). A metal film is deposited by physical vapor deposition (PVD) (Chew et al., 2009), such as sputtering or evaporation on a previously patterned sacrificial material, such as a photoresist. In order to get metal selectively on certain regions of the wafer, a lift-off process can be used. A pattern is defined on a substrate using photoresist. A film, usually metallic, is blanket-deposited all over the substrate, covering the photoresist and areas in which the photoresist has been cleared. During the lift off, the sacrificial layer under the film is removed with a solvent, removing the film on the sacrificial layer, leaving only the metal layer which was deposited directly on the substrate. Metal lift-off can be performed using positive as well as negative photoresists. Historically, there are three basic ways in which lift-off could be performed: the single layer method, the multi-layer method, and the surface modified method. The single-layer method, usually using a negative photoresist, is the simplest and involves only one lithography step. The multi-layer method has process complications due to additional polyimide depositions and subsequent etching steps. In the surface-modified method, the top surface of the photoresist is chemically modified by soaking it in toluene solution so that it will develop at a slower rate than the underlying photoresist (Lee and Yoon, 2005). So in this work, the details of the lift-off process with toluene and Shipley 1813 type photoresist is reported.

Lift-off structure

The general Lift-off process is: First a pattern is defined on a substrate using photoresist (Zhang, 2006). The sample is first patterned using standard lithographic techniques such that photoresist covers regions where metal is not desired. A film, usually metallic, is deposited all over the substrate, covering the photoresist and areas in which the photoresist has been cleared. The metal thus contacts the substrate only in regions where it is required. During the actual lifting-off, the photoresist under the film is removed with solvent, taking the film with it, and leaving only the film which was deposited directly on the substrate. The schematic diagram of the lift-off process is shown in Fig. 1.

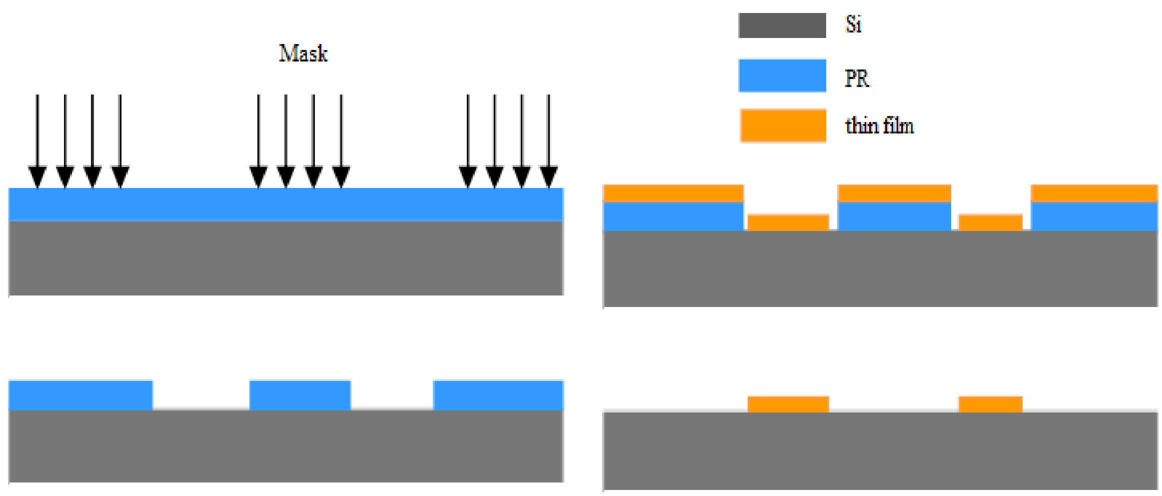

Figure 1. Lift-off process

Standard photolithography processing

Only one mask step and the standard photolithography procedure is involved (Masoumi et al., 2017). The main disadvantage of this method is that the film is deposited on the sidewall of the photoresist, and adheres to the substrate even after the resist removal. This sidewall may be peeled off in subsequent processing, resulting in particulates and shorts, or it may flop over and interfere with etches or depositions that follow. Post-develop bake is recommended before film deposition based on the condition that bake time and temperature are well controlled. Lift-off can be accomplished by immersing in acetone. The length of time for lift-off will depend on the film quality (generally, the higher the film quality, the more impermeable it is and the longer it will take to lift-off.) The sidewalls from deposited film can be removed using a gentle swipe of a clean-room swab or a directed stream of acetone from a squeeze bottle. Keep the substrate immersed in acetone until all the film has been lifted-off and there are no traces of film particulates (Masoumi et al., 2016) -- once particles dry on the substrate, they are difficult to remove. Due to the fact that the metallization, with the conventional lift-off process, has problems such as: No gap Creation in the electrodes, as shown in Fig. 2, the lift-off process is performed with an optimization using toluene.

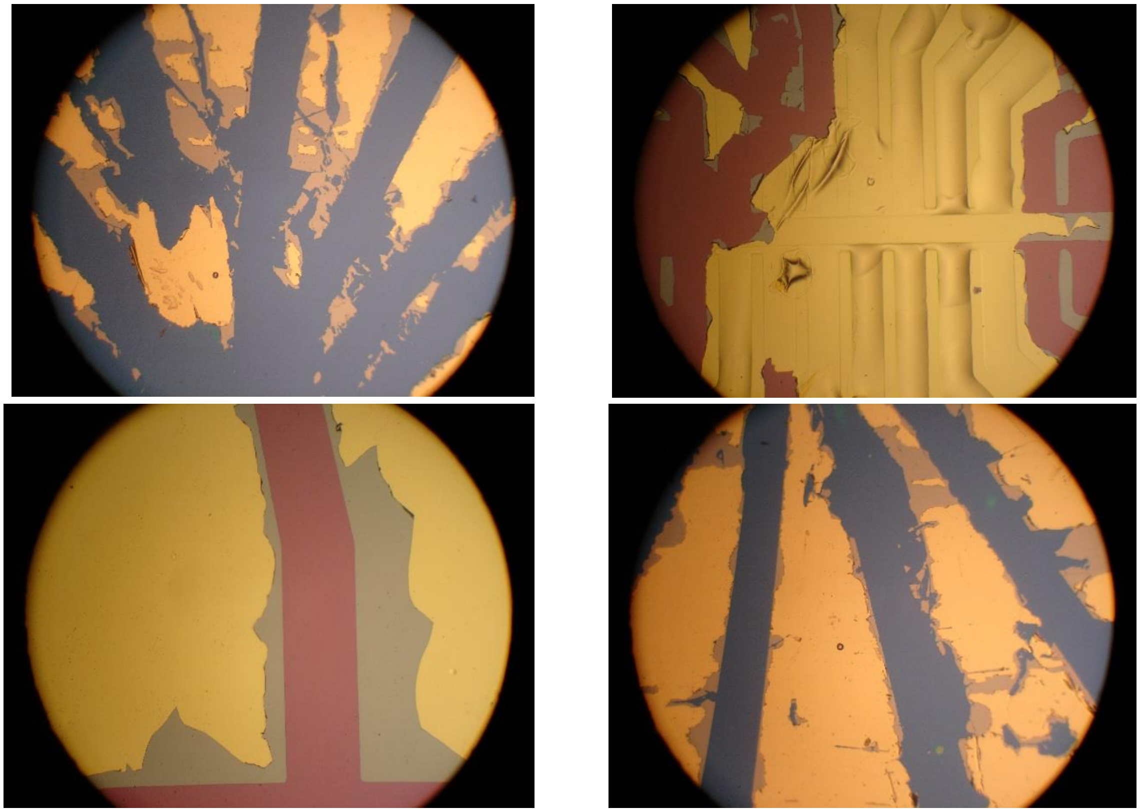

Figure 2. Samples that not have any gap in the electrodes with conventional lift-off process.

Required conditions for the deposited film

1. During film deposition, temperatures cannot be high enough to burn the photoresist.
2. Adhesion of the deposited film on the substrate is very good.
3. The film can be easily wetted by the solvent.
4. The film is thin enough and/or grainy enough to allow solvent to seep underneath.
5. The film is not elastic and is thin and/or brittle enough to tear along adhesion lines.
6. The film quality is not absolutely critical. Photoresist will outgas very slightly in vacuum systems, which may adversely affect the quality of the deposited film.

An important feature of lift processes is that the side wall profile of the photoresist must be vertical or with an overhang. This causes a break in the deposited metal film and ensures easy lift-off. After normal lithography the side walls are sloping and in order to get an overhang profile the lithographic process is altered slightly. A toluene (formerly chlorobenzene) soak step is included after the UV exposure but before development. The toluene hardens the top layers of the photo resist making them harder to develop away. In general, the exposure time and the development time need to be changed from the optimal conditions to account for the alteration of the resist properties due to the toluene soak. The flow chart for a lift-off process is included here.

Sequence of lift-off process with toluene

1- Clean the sample using the standard procedure.
2- Spin the photoresist on the wafer (Shipley 1813) with 3000 rpm for 45 Sec.
3- Bake the sample for 1 minute at 115 ° C.
4- Exposure for 42 seconds (should not be developed at this stage).

Remember to use a dark field mask- the desired features are transparent and the background is dark. Do not develop the photoresist at this stage.

5- Immerse the sample in a beaker containing toluene for 42 Sec.
6- Blow dry the sample with N2. Do not rinse the sample in DI H2O after the toluene soak.
7- Now develop the photoresist using DI 2:1 developer using the standard procedure.

Never Post bake a sample that is intended for lift-off. Rinse and dry.

8- Evaporate the desired thickness of metal in the vacuum evaporation setup.
9- Strip off the photoresist.

Place the sample in a beaker containing acetone for about 15-20 minutes. The acetone should strip off the photoresist thus removing the undesired metal. In case some metal does not come off, you may have to squirt some acetone over these regions to dislodge the metal. Dip the sample in Isopropyl alcohol for 2 minutes to remove the acetone.

10- Rinse in DI H2O for 1 minute & blow dry with N2.

In this way, the problem of the lift-off process (Masoumi et al., 2018) was solved by using a solution of toluene by forming edges in the photoresist. The SEM images of this stage are shown in fig 3.

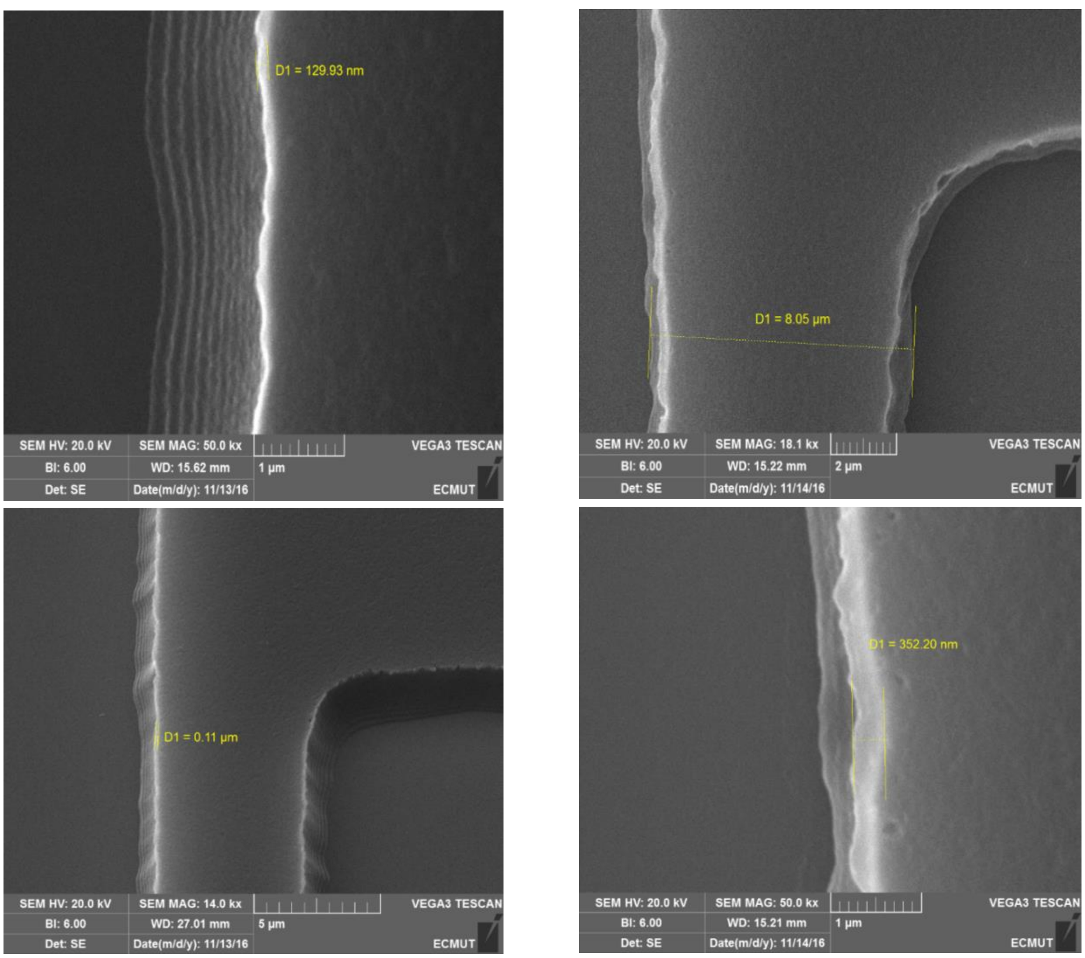

Figure 3. The SEM images of the photoresist in a toluene solution. Upper row, 1 minute and lower row 2 minutes in a toluene solution with an acceptable edge thickness for the lithotripsy with acetone solution and ultrasonic waves.

Comparison Between Positive and Negative Photoresists

Comparison between positive and negative photoresists are shown in table 1.

Table 1. Comparison between positive and negative PR.

property	Positive Photoresist	Negative Photoresist
Resolution	High	Low
Developer	Temperature sensitive (-)	Temperature non-sensitive (+)
Mask Type	Dark-Field Mask: lower-defect	Clear-Field Mask: higher-defect
Rinse	In Water (+)	In solvent (-)
Cost	More Expensive	Cheaper
Exposure Speed		3-4 times faster
Adhesion		Better
Backing	In air (+)	In Nitrogen
Profile	Undercut (+)	Overcut (-)
Lift-off	In Acetone	In solvent (Methyl Ethyl Ketone) (-)

- Negative resist lift-off process has fewer steps than the positive resist lift-off, and is therefore more cost- and time-effective.
- Negative photoresist will produce ragged metal edge, the results coming from positive photoresist is good.
- Negative resists were popular in the early history of integrated circuit processing, but positive resist gradually became more widely used since they offer better process controllability for small geometry features.

Conclusion

A new process has been proposed and tested for obtaining undercut profiles suitable for lift-off metallization with uv exposure systems and Shipley 1813 photoresists. A negative profile of the dry film is critical to form a discontinuous layer of deposited metal for effective metal lift off. When the results of the preceding studies of the toluene interaction with the components of resist films are combined, the mechanism of the toluene lift-off effect becomes evident. Toluene diffuses into the resist film, swelling it and forming a gel to the depth of the diffusion (Halverson, MacIntyre and Motsiff, 1982). Loss of resist thickness during the toluene soak is used instead of penetration, as measured on SEM photographs, to monitor the soaking process. The process has been tested with Shipley 1813 photoresist and a toluene soak, followed by development in 1:2 Shipley 1813 developer-water. Two process variations include the use of a toluene presoak (instead of chlorobenzene) and soaking in toluene before (rather than after) uv exposure. A manufacturing process should be optimized towards low exposures, deeper penetration (Collins and Halsted, 1982), and high baking temperatures, thus providing a process that is less sensitive to development time. After development, resist profiles with overhangs suitable for lift-off metallization are obtained. It appears that removal of solvent and low-molecular-weight resin from the resist may be responsible for the observed differential development rates. In addition, the soak time and temperature behavior indicate a diffusion-type process. The process showed promise to produce reliable and well-controlled undercut profile that is ideal for thin film deposition process, especially for off-normal directional ion beam deposition.

References

1. Chew M., Ho S. W., Su N., Liao E., Rao V. S., Premachandran C., et al., (2009). "Development of negative profile of dry film resist for metal lift off process," in 2009 11th Electronics Packaging Technology Conference, pp. 884-888.

2. Collins G. G. and Halsted C. W., (1982) "Process control of the chlorobenzene single-step liftoff process with a diazo-type resist," IBM Journal of Research and Development, vol. 26, pp. 596-604, 1982.
3. Halverson R., MacIntyre M., and Motsiff W., (1982). "The mechanism of single-step liftoff with chlorobenzene in a diazo-type resist," IBM Journal of Research and Development, vol. 26, pp. 590-595.
4. Kanikella P. R., (2007). "Process development and applications of a dry film photoresist,".
5. Lee H. S. and Yoon J. B., (2005). "A simple and effective lift-off with positive photoresist," Journal of Micromechanics and Microengineering, vol. 15, p. 2136.
6. Masoumi S., Hajghassem H., Erfanian A., and Molaei Rad A., (2016). "Design and manufacture of TNT explosives detector sensors based on CNTFET," Sensor Review, vol. 36, pp. 414-420.
7. Masoumi S., Hajghassem H., Erfanian A., and Molaei Rad A., (2017). "Design and fabrication of field effect transistor based on graphene as an explosive detector."
8. Masoumi S., Hajghassem H., Erfanian A., and Molaei Rad A., (2018). "Design and manufacture of TNT explosives detector sensors based on GFET," Sensor Review, vol. 38, pp. 181-193.
9. Zhang N., (2006). "Literature research report for lift-off method," BME 390A term project, accessed at http://www. vanderbilt. edu/viibre/documents/Zhang—lift-off. doc.