Revitalization of Single Layer Lift-off For Finer Resolution and Challenging Topography

Randy Redd, David Maurer, L. Scott Klingbeil
Motorola Semiconductor Product Sector
Compound Semiconductor One; CS-1
2100 E. Elliot Road, Mail Drop EL-609 Tempe, AZ 85284
Phone (480) 413-5969, FAX (480) 413-5748, Email: R15203@email.sps.mot.com

ABSTRACT

The necessity for metal lift-off processes in the compound semiconductor industry is very acute because of the need to pattern non-reactive metals such as gold. As the gallium arsenide industry matures from the niche markets of the past to competing with the mainstream semiconductor industry, reducing manufacturing costs becomes increasingly important to ensure continued growth. Moreover, newer technologies have pushed the typical requirements for lift-off into a realm difficult to achieve with many existing methods. Presented, is the development work of a single layer and single exposure lift-off process capable of resolving sub 1.0µ lines and withstanding a silicon nitride dry etch process prior to metal evaporation. Daily process control has been demonstrated with a variation of ± 0.032µ on 1.2µ nominal features. This lift-off technique relies upon a single layer of photo resist with no added costs for additional dielectric deposition and etch processes or applications of photosensitive polyamide layers. In addition to being relatively low cost, the improved performance has enabled development of new technologies with fine line requirements and challenging topographies.

INTRODUCTION

For the purpose of comparison, metal lift-off methods can be separated into either single-layer or multi-layer methods. Historically, multi-layer techniques have had higher costs of ownership, because of additional dielectric depositions and subsequent etches or expensive polyamide treatments. There are also process and manufacturability issues associated with the traditional single-layer methods such as, process stability of the reverse tone photoresists, increased capital expense of the electron beam exposure methods or potential health hazards of the HMDS and chlorobenzene surface treatment methods.

Upon completing an evaluation of various lift-off methods, it was determined that none of the existing methods would meet the requirements of CS-1. Therefore, with the assistance of AZ Clariant, a new Single Layer Lift-off (SLL) process was developed. The SLL method utilizes a developer (TMAH) to produce an inhibition layer at the surface of a single layer of photoresist. Since the surface inhibition layer has a lower solubility in the developer than the bulk of the photoresist film, an overhang in the resist is produced when the exposed pattern is developed. This overhang ensures that the evaporated metal, deposited on the patterned resist, is discontinuous thereby enabling proper metal lift-off.

The process selected by CS-1 needed to meet as many of the following criteria as possible, 1) Compatibility with existing CS-1 equipment and chemistries, 2) Good process control, 3) Low cost, 4) Minimal additional cycle time as compared to a standard photo process, and 5) Sub micron resolution.

SINGLE LAYER LIFT-OFF PROCESS

Process Description

1. Coat AZ®6210 photoresist with extended spin time of 90 sec.
2. Soak in TMAH (0.261N)
3. Soft Bake 70°C
4. Expose Canon i1
5. Post Exposure Bake @135°C
6. Develop in TMAH (0.261N)

The initial process flow using this resist was; coat, soft bake, TMAH soak, expose, PEB and develop. SEM photos show the resist profile generated by this process is adequate to ensure clean metal lift-off, see Figure 1.

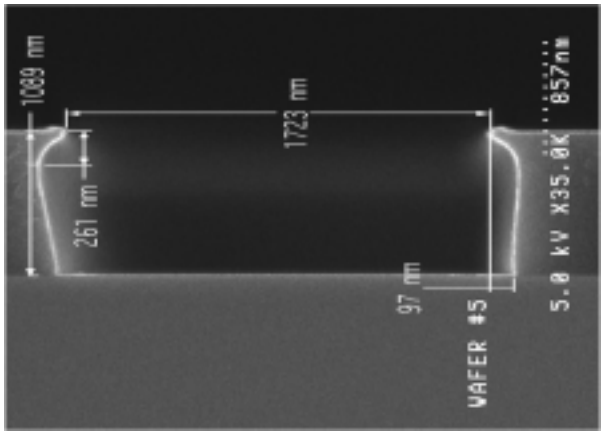

Figure 1. Photoresist profile of coat-soft bake- soak process.

An additional criterion for the SLL process was for the resist overhang or lip to withstand 400Å HFSiN plasma etch. The HFSiN film serves as a surface protection layer for enhancement mode epitaxial devices. The thickness of the photoresist lip using the coat-soft bake-soak process was deemed to be too thin to guarantee a robust process window, because of the resist erosion during the plasma etch step.

Therefore, additional experimentation was done to increase the thickness of the photoresist lip. It was discovered that the thickness of the lip could be increased by changing the order of the soak and soft bake steps and increasing the resist drying time, as is shown in the process description. The SEM X-sections show both the thickness and overhang of the lip were dramatically increased using the soak / bake sequence, see Figure 2.

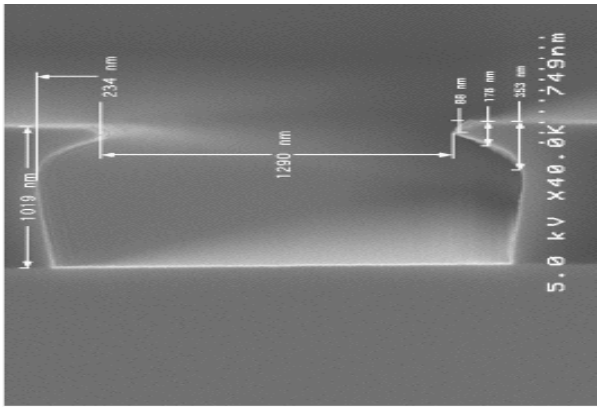

Figure 2. Photoresist profile of coat-soak-soft bake process.

As part of changing the sequence of the soak and bake it was also necessary to increase the resist drying time to 90sec to minimize the resist loss during the soak step. An additional benefit of increasing the drying time of the photoresist was an increase in the free volume of the resist film. During the coating step microscopic pinholes are created when the solvent vacates its position in the resist film during the spin drying of the photoresist. The porosity caused by this drying effect is know as the "Free Volume"[1] of the photoresist. By increasing the free volume of the resist film, the TMAH was able to penetrate further into the film creating a thicker inhibition layer.

Inhibition Layer Formation

There are two mechanisms, which create the inhibition layer in the AZ®6210 photoresist. In the first mechanism, the developer soak generates basic TMA+ phenolates on the surface of the photoresist. These caustic sites on the resist surface catalyze azocoupling, which creates an azodye[2]. The azodye greatly reduces the solubility of the surface of the photoresist creating the inhibition layer. Experimental data has shown this reaction rate to be temperature sensitive, therefore selection of the proper soft bake and PEB temperatures are critical to optimum performance of the process.

Since AZ®6210 is a non-fractionated-resin resist, it also takes advantage of the non-uniformity of the molecular weight of the resin to create the inhibition layer. "Gas chromatographs show that the average molecular weight of non-fractionated photoresist on the surface of the film increases following the TMAH soak"[3]. This increase in average molecular weight also reduces the solubility at the surface of the photoresist. It is this difference in solubility, between the surface of the photoresist and the bulk of the film, which creates the re-entrant photoresist profile necessary for proper metal lift-off.

Process Performance

Process control and minimum feature size were both very important in the development and selection criteria of any new lift-off process introduced into CS-1. SEM analysis of the resist profiles following metal deposition, confirm adequate discontinuity of the evaporated metal film to ensure clean metal lift-off, even at sub micron geometries, see figures 3 and 4.

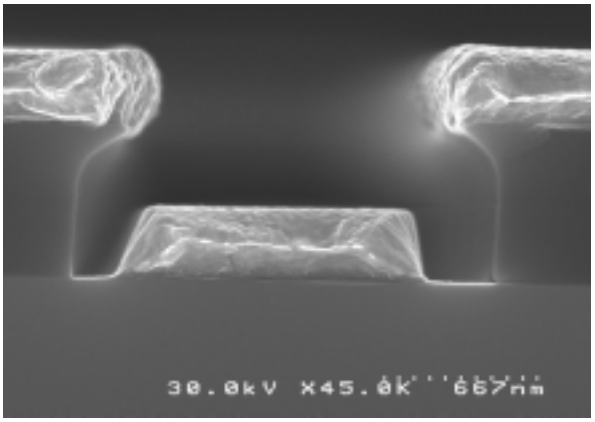

Figure 3. Photoresist profile following metal evaporation.

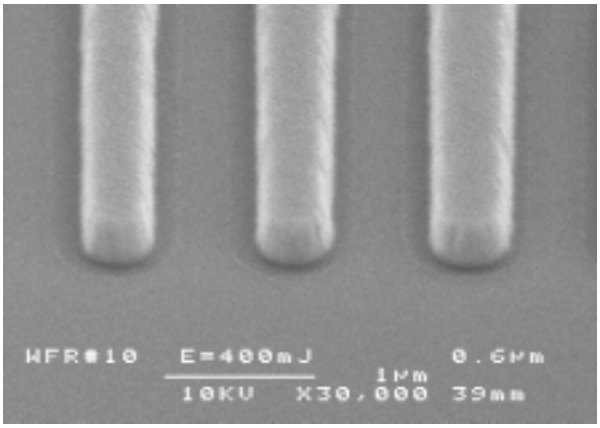

Figure 4. Equal line-space 0.6µ metal lines following lift-off.

The second essential performance requirement of any process introduced into a high volume-manufacturing environment is process control and stability. In order to determine the stability and control of this process, wafers were measured on a KLA 8100 SEM over a period of several months. Each wafer was measured at 17 sites across the wafer and the standard deviation of these measurements were plotted over time, see figure 5. The data clearly indicates the variation within a wafer to be acceptable with an average wafer variation of 0.032µ, measuring a 1.2µ nominal feature**.** The data further illustrates capable process control with a

wafer variation Cp of 1.39, calculated from the nominal ± 10%.

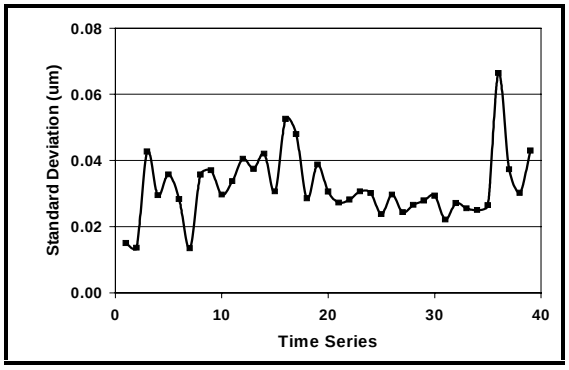

Figure 5. Standard deviation of 1.2µ nominal photo feature for 150 mm wafers (Apr to Nov. 2000)

The final aspect of process performance that was investigated, was the versatility of the method for use over a wide range of topographies. Wafers with topographies as high as 4.0µ were evaluated using the SLL method. For this application AZ®4330,a non-fractionated, photoresist coated to a thickness of 3.5µ was used. With only changes in the exposure energy and develop time, photoresist profiles necessary to provide adequate discontinuity in the evaporated metal film were achieved, see figure 6.

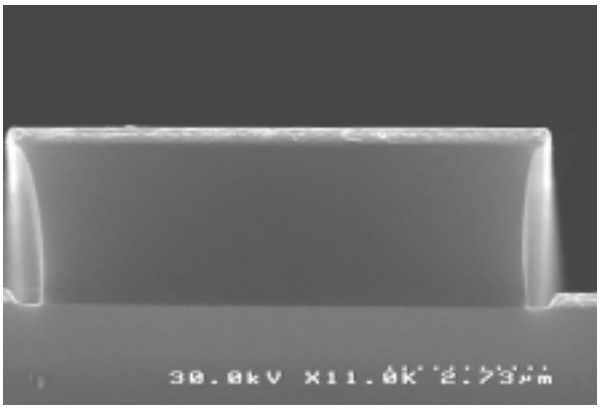

Figure 6. Photoresist profile following metal evaporation for large topography lift-off .

CONCLUSION

It is evident from the data presented the SLL process has met the initial process selection criteria for new process introduction into a low cost, high volume manufacturing environment. The only chemicals used in the lift-off process are photoresist and (0.261N) TMAH, both of which are compatible with our standard lithographic processes. Additionally TMAH was already in use and plumbed to our existing coat/develop tracks. The process exhibited excellent process control, both within a wafer and from wafer to wafer, over an extended period of time. Since the SLL process could be run on our existing lithographic equipment no additional capital costs were required. The only costs associated with this lift-off process are the chemicals associated with any standard photo-imaging layer. The additional cycle time consisted of the incremental time to soak a wafer in TMAH during the coat process, and this was minimal since our tracks have both coat and develop capability in a single recipe flow. Finally the requirement of sub micron resolution and process stability were met with demonstrated resolution of 0.6µ on a consistent basis and excellent process control and stability at our nominal dimensions.

ACKLOWLEDGEMENTS

The authors would like to acknowledge and thank Mr Mark Spak of AZ Clariant for his help in the process development and for his technical contributions. We would like to also thank Eppi Irwin, Denise Barrientos, and Tan-Chen Lee of PMCL for analytical and SEM support, and Billy Martinez of CS-1 for sample preparation.

REFERENCES

[1] L. Pain, C. Le Cornec, C. Rosilio, P.J. Paniez, "Free volume variations during exposure and PEB of DUV positive resist: Effect on dissolution properties", SPIE Vol. 2724, (1994)

[2] R. Redd, M. Spak, J. Sagan, O. Lehar, R. Dammel, , "Lithographic Process For High-Resolution Metal Lift-Off", SPIE Vol. 3678, (1999)

[3] Mitsuhiro Furuta, Shingo Asaumi, Akira Yokota, "Mechanism of dissolution inhibition of novolak-diazoquinone resist", SPIE proceeding