To Improve E-beam T-gate Yield by Pre-Cleaning Process

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Abstract

Bi-layer photo resistance of PMMA/PMAA is a well studied configuration for forming an E-beam T-gate for GaAs semiconductor process. While the PMMA/PMMA resist system is capable of patterning narrow gate lengths, it can be difficult to get sufficiently retrograde profiles to avoid the formation of metal stringer defects during the gate formation process. In order to reduce the occurrence of stringer formation during gate metallization, a new lift-off process flow has been developed using a spray-type isopropanol (IPA) cleaning step followed by an acetone (ACE) soak step. This new lift-off process flow removed any stringers formed during gate metallization without reducing yield due to pinch-off defects.

INTRODUCTION

Successful gate metallization is strongly dependent on the initial resist profile in conjunction with the post metallization cleaning (lift-off) processes. In the case where the resist profiles are nearly vertical it is common to get stringer formation. These stringers are areas where the gate metal has formed a connection between the metalized gate and the surrounding resist. Stringers are highly undesirable and are often seen in the final transistor performance as higher leakage currents and/or lower breakdown voltages. If stringers are formed during metallization, they can be removed by high pressure spray during the lift-off process. Unfortunately this high pressure spray is also prone to damaging the newly formed 0.15um gate. In this work, a new two-step lift off process is developed using an initial physical spray step to eliminate stringers followed by a second soaking step to complete the metal lift-off.

PROCESS DEVELOPMENT

PMMA/PMAA is often utilized as an e-beam resist system for gate formation [1] [2]. However, using this configuration it can be difficult to achieve a resist profile that is sufficiently retrograde for metal lift-off processes. Figure 1 shows a SEM cross section of a typical PMMA/PMAA resist profile. This profile will lead to the formation of metal stringers during metal lift-off. Figure 2 illustrates the mechanism of the metal stringer formation. During the evaporated metal deposition step, metal is able to coat the sidewall of the resist structure and bridges the gap to the gate structure. Traditional lift-off processing uses a acetone soak (non-spray) to remove the resist. This soak is ineffective at removing the metal stringers. The SEM in Figure 3 shows an example of stringer formation using PMMA/PMAA with an acetone soak lift-off.

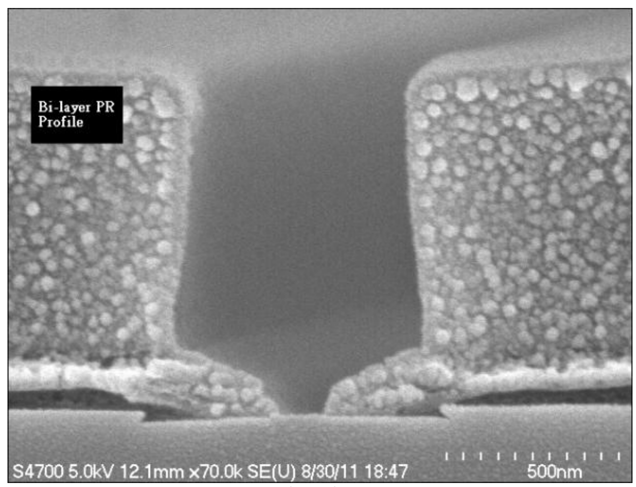


Figure 1, The bi-layer resistance profile of e-beam lithography technology.

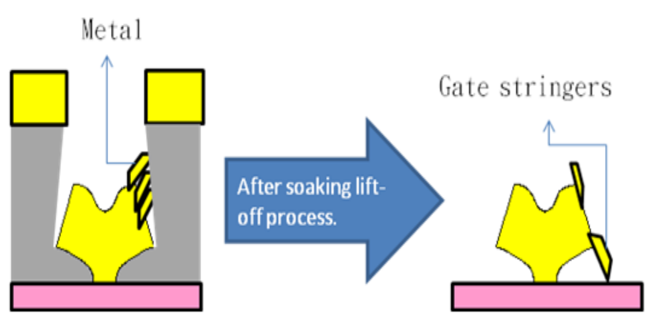


Figure 2, The mechanism of metal stringer.

The focus of this study was to develop a new cleaning sequence to physically remove any stringers without damaging the newly formed gate. High pressure spray processes are sufficient to remove stringers, but often causes physical damage to unprotected T-gates at their weakest point (e.g. at the substrate interface or the neck). In order to overcome the limitations of physical spray based processes, a new hybrid process was developed. Figure 4 shows a schematic of the new process flow. The new approach uses a high pressure spray to remove the stringers with a solvent (IPA) that is selective to the underlying resist. In this way, the energy from the spray removes the stringers while leaving the supporting resist structure largely intact to support the fragile gate. Once the stringers are removed, the remaining resist is dissolved using a traditional wet ACE soak process. Since the IPA will not dissolve the PMMA/PMAA resist, the T-gate's weakest part including the foot print and gate neck are well protected.

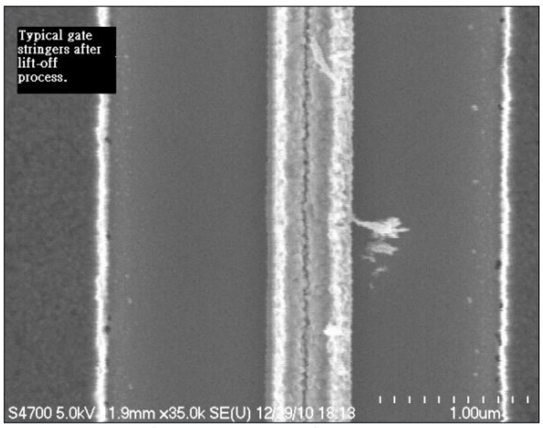


Figure 3, The photo of stringers on top of gate, and between gate and semiconductor

Wafers fabricated using the new process flow showed a significant reduction in stringer formation. Figure 5 shows a typical top down SEM micrograph of the new process (compare to the SEM in Figure 3).

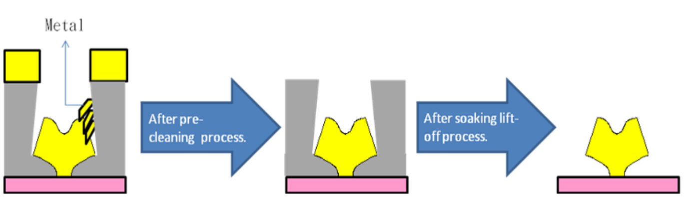


Figure 4, The concept of IPA spray type clean plus ACE soaking type clean

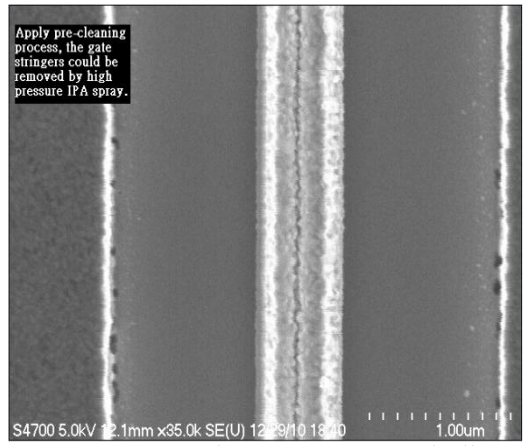
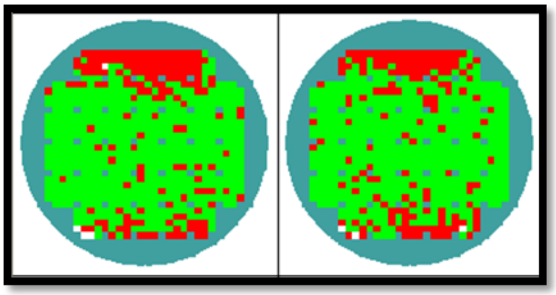


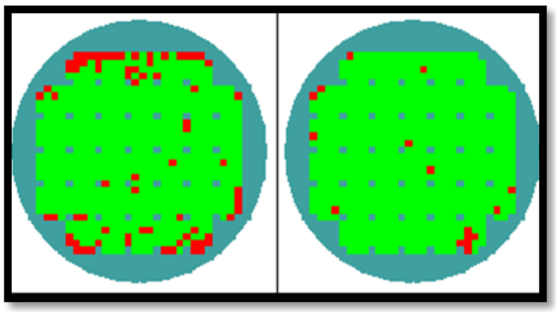
Figure 5, The SEM picture of the gate by using new lift-off process

RESULTS AND DISCUSSION

Though the SEM analysis showed that the new process was performing well, it was important to examine the process impact on device performance. In order to perform electrical tests, a test circuit was designed to evaluate gate leakage current and breakdown break down voltages. Figure 6 compares the electrical test results between wafers using an acetone soak process and the new two-step clean process. Figure 6(a) shows the sorting map of the wafers processed by standard pure ACE soaking type lift-off process. Note the dc yield loss at the edge of the wafers. This pattern is typical for metal stringer due to the angular dependence of the evaporation source. Gates in the center of the wafer receive normal incidence deposition, whereas gates at the edge of the wafer are deposited slightly off axis. In contrast, Figure 6(b) shows a significant reduction in failed die using the new IPA spray / ACE soak, especially at the wafer edges. The angle dependence of the evaporation is identical the wafers shown in Figure 6(a).



(a)



(b)

Figure 6, (a) The yield mapping of wafer processed by traditional lift-off process. (b) The yield mapping of wafer processed by new lift-off process.

CONCLUSION

Bi-layer photo resistance of PMMA/PMAA Gate metal lift-offs processes suffer significant gate leakage issues due to the presence of gate metal stringers. This report summarizes the result of using a high pressure spray IPA cleaning followed by an ACE soaking process on e-beam t-gate metal lift-offs processes. The improved lift-off process effectively removes the stringers while protecting the gate during the spraying process. SEM inspection results showed that the IPA pre-cleaning process effectively reduced gate stringers. This sequence resulted in a lower risk of the pinch-off yield loss. The new clean sequence exhibited superior DC, leakage and pinch off performance when compared to an acetone soak process.

ACKNOWLEDGEMENTS

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[2] Huatang Chen, Andrew Ketterson, et al, “Improved T-Gate Yield Using E-Beam Trilayer Resist Process”,GaAs Mantech Conf. April 2011.

Acronyms

PMMA: Poly(methyl methacrylate)
PMAA: Poly(methacrylic acid)
IPA: Isopropanol
ACE: Acetone