Oxygen Plasma Photoresist Strip in High Volume HBT Production

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Keywords: HBT, resist strip, oxygen plasma

Abstract

A dry resist strip process using oxygen plasma is reported to strip resist layers after He^{++} ion-implantation and dielectric SiN etch. The new dry strip process implemented has the following advantages over a wet NMP strip: (1) dry strip tools have good process control with end point monitoring, (2) elimination of environmentally harmful chemicals, (3) tremendous cost savings, and (4) process time reduction.

INTRODUCTION

Resist strip is a critical process used repeatedly during the manufacture of GaAs HBT power amplifiers. Traditionally, wet solvent strip process has been used for compound semiconductor manufacture. Several challenges are encountered when using a wet strip process. First, the process must continually provide a clean surface after strip while meeting throughput demands. Second, the process cost must continuously be optimized and reduced since wet strips consume large quantities of costly organic solvents, such as NMP and EKC. And finally, stringent environmental regulations must be met. Due to these challenges, the replacement of current wet resist strips by other strip technologies is preferred. In this paper, a dry resist strip process using oxygen plasma is reported to strip resist layers after He^{++} ion-implantation and dielectric SiN etch at Skywork's high volume HBT Fab. Process characterization shows that dry resist strip has several advantages over NMP wet resist strip process.

PROCESS CHARACTERIZATION

(1) Oxygen Plasma Characterization

An oxygen plasma strips resist through the combustion of organic resist by reactive oxygen species produced in the RF discharge. The gaseous products are carbon oxides and water vapor, which are subsequently pumped out of the tool. The wafer temperature is the most critical parameter for the resist strip. Figure 1 shows the bi-linear Arrhenius plots of ash rate dependence on temperature for a downstream plasma asher.

As seen in Figure 1, there are two process regimes. Regime 1 represents a high temperature ash process with activation energy (Ea) of 0.08 eV. In this regime, the ash rate is diffusion limited and is proportional to the concentration of active oxygen species formed in the plasma.[1] The temperature dependence is relatively weak. In addition, the ash rate dependence on the RF power is secondary when the RF exceeds a threshold value. This regime is ideal for the resist strip process and represents the conditions used for Skyworks' dry resist strip. Regime 2 is a low temperature process having Ea of 0.31 eV. In this regime temperature affects the ash rate exponentially. This condition is usually used for organic residue clean or for the removal of carbonized resist formed during ion implantation.[2]

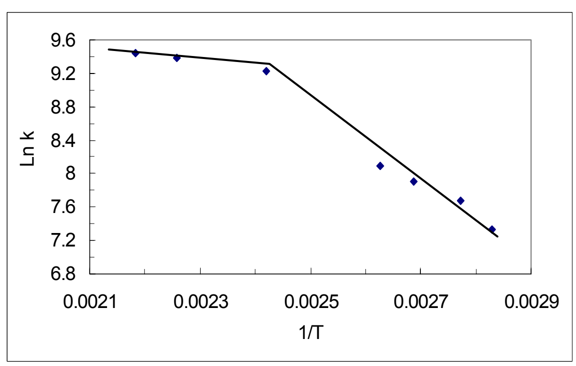
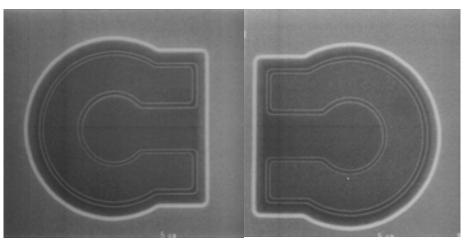


Figure 1: Dependence of ash rate (k) on the wafer temperature

(2) Resist Strip After Ion-Implantation

It is well known that photoresist gets carbonized during ion-implantation, and forms a hard crust on the outside of the resist layer. This hardened resist is rigid, and almost impermeable to solvents and gases. It usually has to be removed by a low temperature plasma ash before solvent strip. When using a dry resist strip, the low temperature ash remains unchanged, and is simply followed by high temperature dry resist strip. The low temperature ash removes the hard resist crust and avoids its further hardening in the high temperature dry resist strip. The SEM photos shown in Figure 2 illustrate that the dry strip is clean and comparable to the wet strip.

Our investigations also show that the photoresist chemical formulation is extremely critical to the dry resist strip. Resist residues are always observed for some photoresists even after repeated dry strip process runs.



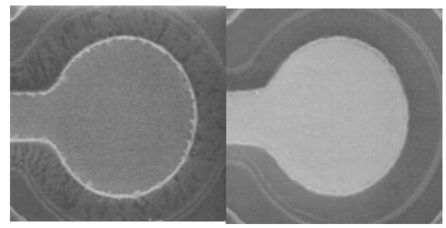
(a) (b)

Figure 2: SEM images for resist strip after ion-implantation: (a) NMP wet resist strip, and (b) dry resist strip

(3) Resist Strip After Dielectric (SiN) Etch

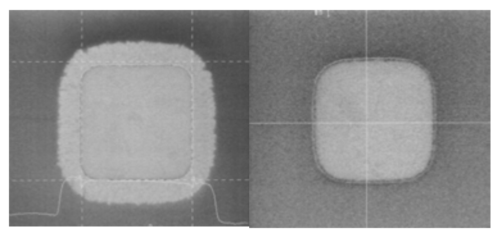
In general wet resist strip processes following the SiN etch have three steps: solvent resist strip, oxygen plasma ash and acid/base clean. The dry strip flow has only two steps: dry strip and wet clean. Several resist layers for SiN etch have been successfully converted to the dry strip process. There are two predominant reasons that the dry resist strip is applicable to HBT fabrication at this stage: (1) most of the devices are protected from plasma damage by the SiN layers, and (2) the SiN layer is stable and remains intact when exposed to the high temperature oxygen plasma. It is reported that PECVD deposited MIM SiN shows even better electrical stability after being treated with a N_2O based oxygen plasma. [3]

It is well known that the chemistry of the dielectric etch plays an important role in the wet resist strip process. This has also been clearly observed in the dry resist strip process. Fig. 3 shows that the wafers are almost clean after contact via (CV) dry strip. Adding a weak NH_4OH solution dip gives completely clean results. Fig. 4, however illustrates that more polymers can be seen around the etched openings after a different nitride (NV) dry resist strip. Hence, a strong acid has to be used to remove polymer residues.



(a) (b)

Figure 3: SEM images after CV resist strip: (a) dry resist strip, and (b) dry resist strip coupled with NH_4OH clean



(a) (b)

Figure 4: SEM images after NV dry resist strip: (a) after dry strip, and (b) dry strip coupled with acid clean

(4) Other Characterizations

Since this is the first time Skyworks has used dry resist strips in high volume GaAs HBT production, many tests have been performed to qualify the dry resist strip process. Statistical analysis shows that all major electrical parameters remain unchanged. Autoclave humidity tests illustrate that there are no signs of nitride delamination. Furthermore, the electrical characteristics are also unchanged after the autoclave test. Figure 5 shows contact via resistance distribution for the wet and dry stripped wafers. Since a higher resistance is not observed, it demonstrates again that the dry strip process provides a clean wafer surface.

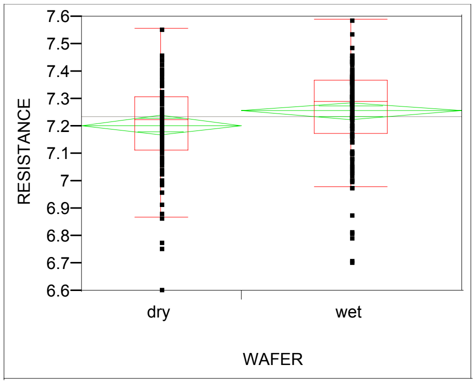


Figure 5: Contact via resistance comparison of dry strip vs. wet strip

CONCLUSIONS

Oxygen plasma dry resist strip has successfully replaced NMP wet strip to remove resist after ion implantation and SiN etch in high volume GaAs manufacturing. All characterization experiments show that dry resist strip process produces high quality products with superior process stability and repeatability. It has the following advantages over the conventional NMP resist strip: (1) huge processing cost reduction – chemical costs as well as wet strip tool maintenance, (2) resist strip time reduced by 50%, (3) dry strip has better process control, and (4) process is environmentally friendly.

ACKNOWLEDGEMENTS

Authors appreciate the constructive discussions with Jiro Yota, Jim Penney, Qiuliang Luo, Shiban Tiku, Tom Grayson and Ravi Ramanathan. Thanks are also given to Jose Arreaga and Murali Rao for the autoclave and leakage tests.

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ACRONYMS

SiN: Silicon Nitride
HBT: Hetero-junction Bipolar Transistor
NMP: N-methyl-2-pyrrolidone