Innovative Metal Lift-off Process Using Dry Carbon Dioxide

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Abstract

The Eco-Snow 'dry' carbon dioxide process is investigated as a replacement for conventional solvent and de-ionized water spray techniques for metal lift-off process steps. Results show wafer yield improved as a result of reduced electrical degradation and particle density. We also observe reduced contact resistance between the interconnect metal and ohmic metal layers of greater than 20%.

INTRODUCTION

The rapid increase in demand for high speed GaAs based devices has resulted in a change of philosophy for device manufacturers. Traditionally made in small fabs on older generation tooling, manufacturers are now investing in larger fabs, new tools, and techniques to benefit from the mass production methods that characterise the more mature Silicon industry. The shift to 6" wafers is one such indicator of this drive to reduce costs by improving productivity.

This paper reports on work aimed at developing a manufacturable, high throughput lift-off process, using an innovative dry carbon dioxide (CO_2) process in place of a de-ionized (DI) water spray. Costs of ownership, throughput, and yield improvement were the three key focus points during the tests.

In traditional GaAs device manufacture, interconnect formation uses evaporated or sputtered metal deposited over patterned resist. The bulk of resist and metal are then removed by a wet solvent lift-off process, followed by a high pressure DI water or solvent spray process to remove residual metal.

However, there are some problems with this process. The bulk removal of photoresist and metal can be incomplete due to variations in lithography, resist profile and thickness and metal deposition type and thickness. Often residual metal artifacts remain on the edge of the device pattern, which can cause electrical shorting and reduce device yields. Further, in terms of device performance, the high pressure DI water spray or solvent spray step can cause staining and corrosion leading to additional device degradation. The dry, non-contact CO_2 process addresses both of these issues eliminating metal residues and corrosion.

ECO-SNOW DRY CO_2 TECHNOLOGY

The Eco-Snow technology utilizes a directional stream of solid CO_2 particles and gas and is currently used for a variety of process applications including post-chemical-mechanical polishing (CMP) cleaning, etch residue removal, and precision particle removal. Expanding pressurized liquid CO_2 through a specially designed nozzle creates the aerosol spray. As the liquid carbon dioxide is sprayed through the nozzle it cools rapidly creating the directional stream of CO_2 gas and solid CO_2 (dry ice) particles.

Each process application requires an optimized set of CO_2 particle characteristics including the CO_2 particles' size, density, and velocity to ensure complete removal of residues and contamination from the surface without device damage or erosion. The dry CO_2 technology relies primarily on a physical mechanism for the removal of residues and contamination. The solid CO_2 particles physically impact the surface of the wafer where through collisions they transfer momentum to the contaminants, knocking them free of the surface. The contaminants then become entrained in the gas stream and are transported away from the wafer surface.[1]

SOLVENT LIFT-OFF PROCESS

Solvent (typically NMP or acetone) based metal lift-off processes are commonly employed for a number of metal layers including ohmic metal, gate metal, and interconnect metal. The lift-off process consists of two steps. The first is an extended (20-30 minutes) immersion of the wafer in organic solvents to soften and dissolve the photoresist. The organic solvent penetrates through microscopic pores in the metal layer and via the exposed edge of the photoresist. Once the photoresist has been softened and dissolved the metal is free to float away from the device surface. The bulk of the metal is removed in this manner with the exception of metal strings that bridge the edge of the photoresist profile to the devices. These metal residues are commonly called stringers, flags, or veils. A typical metal stringer is shown in Figure 1. A second solvent step consisting of an organic solvent or DI water spray is required to remove these metal residues.

There are several disadvantages to this two-step solvent-based metal lift-off process. First, DI water and solvent sprays can operate as a carrier moving contamination from one spot to another on the wafer. Spin drying the wafer assists in removing solvent films and contamination; however, heavy metal debris, can end up dragging across the surface of the wafer increasing the potential for damage to multiple devices. Any remaining and re-deposited stringers can result in electrical shorts across devices causing losses in device yields. Second, prolonged exposure to organic solvents and DI water sprays can cause stains, corrosion, and etching that result in degraded device performance and increases in contact resistance.[2, 3]

ECO-SNOW DRY LIFT-OFF PROCESS

An Eco-Snow *WaferClean* System, Model ACS1600 as shown in Figure 2 was utilized for removal of the residual metal remaining after a conventional organic solvent immersion lift-off process. As shown in Figures 3a and 4a residual metal stringers remain on the surface of the wafers prior to the dry CO_2 process. These experiments were performed on GaAs wafers populated with MESFET devices. The ACS1600 has automated cassette-to-cassette handling and an environmentally controlled Class 1 chamber, in which the wafers were processed.

The Eco-Snow process was evaluated for metal residue removal, as an alternative to the solvent or DI water spray because it leaves no residue, is non-corrosive, improves process control, and does not require a spin dry process step, or waste disposal. The optimised process parameters incorporated an aggressive spray exposure consisting of relatively high velocity and high-density CO_2 particles. The typical process time for a 4" wafer was 2 minutes. The nozzle velocity was 2" per second with a 45° angle of incidence. During the process CO_2 snow particles break up the metal "stringers" into very small pieces that are carried away in a high velocity stream of CO_2 gas. As shown in Figures 3b and 4b, the dry CO_2 process achieved 100% removal of the stringers and metal residues without being subjected to extra handling or corrosive solvents.

ECO-SNOW DRY PROCESS REDUCES CONTACT RESISTANCE

The conventional solvent lift-off process exposes the devices for extended periods of time to solvents and DI water. This can result in degradation of the electrical characteristics of the devices. This degradation typically manifests itself as an increase in contact resistance due to corrosion and residues left behind by the solvent and DI water sprays. Many solvents are reused over a period of time and have dissolved photoresist and particles in the solution. After a solvent or DI water process, there can be films left on the device that increase the contact resistance of the Ohmic metal layer. This additional resistance degrades the performance of the device and can cause immediate and latent device failures.

Replacing the solvent and DI water sprays with a dry CO_2 process eliminates the potential for residues to be left behind. Because CO_2 is dry and chemically inert it does not lead to corrosion of the various device materials even after extended exposures.

As a result, electrical degradation and particle density were reduced resulting in improved device performance and yield. The dry CO_2 lift-off process reduced the contact resistance between the local interconnect metal layer and the ohmic metal layer by over 20% as shown in Figure 5.

CONCLUSION

The Eco-Snow dry CO_2 process effectively removes residual metal contamination generated from the solvent lift-off process step resulting in increased yields. It also eliminates solvent residues and corrosion resulting in reduced contact resistance, improved device life and performance and improved process control. The Eco-Snow dry CO_2 technology is currently being evaluated for a number of additional process steps because of the 'dry', fast, and environmentally compatible advantages over conventional cleaning processes.

One such innovative application of the Eco-Snow process is as a full metal lift-off process step. The dry CO_2 process selectively lifts off the metal layer from the photoresist completely exposing the photoresist. The photoresist is then completely removed by using a relatively quick solvent dip. This significantly shortens the exposure time to solvents thereby dramatically reducing the quantities of solvent consumed and the amount of hazardous solvents requiring disposal.

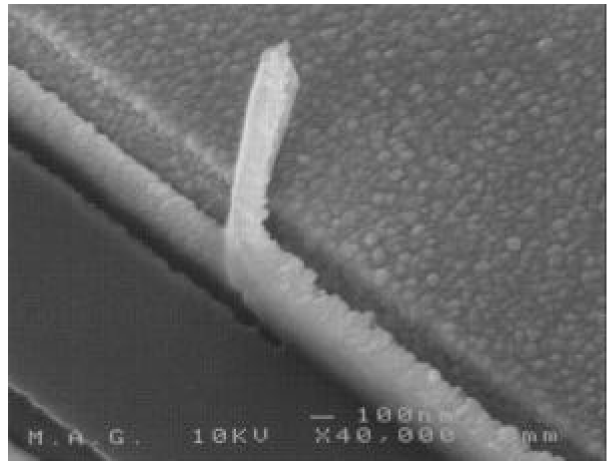

Figure 1. SEM image showing typical metal stringer after solvent lift-off process.

Figure 2. The Eco-Snow *WaferClean* System, Model ACS1600 used for metal lift-off process steps.

ACKNOWLEDGEMENTS

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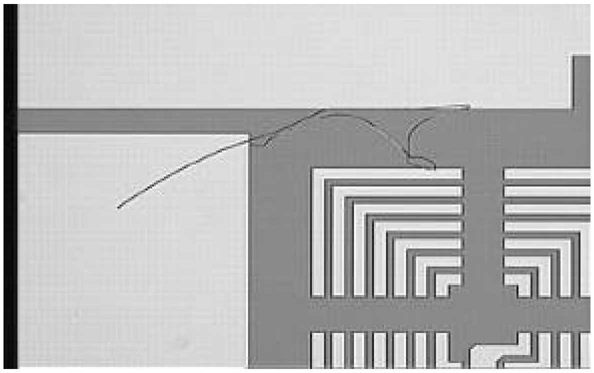

Figure 3a. Metal feature is shown after an organic photoresist solvent lift-off step. The feature displays residual metal "stringers" attached to the perimeter of the metal.

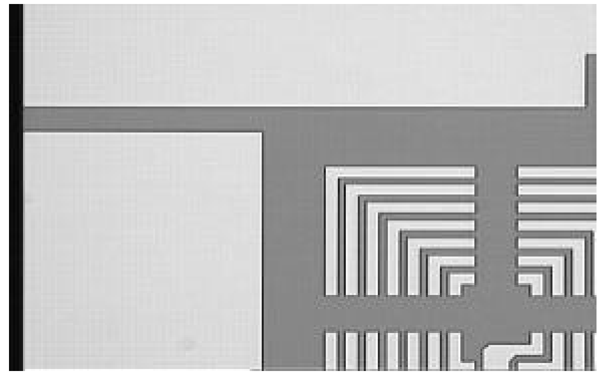

Figure 3b. Metal feature after being processed on the Eco-Snow dry CO_2 *WaferClean* System, Model ACS1600. Note the stringer feature is removed with the metal and surrounding areas free of debris and stains.

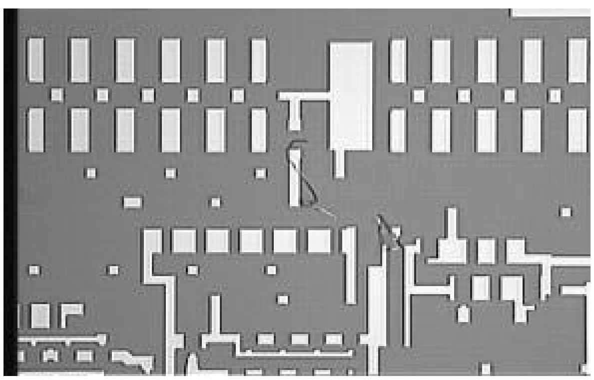

Figure 4a. Metal features are shown after an organic photoresist solvent lift-off step. Features displays residual metal "stringers" attached to the perimeter of the metal.

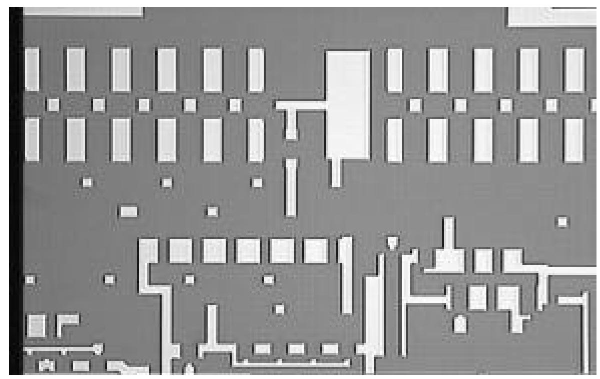

Figure 4b. Metal features after being processed on the Eco-Snow dry CO_2 *WaferClean* System, Model ACS1600. Note the stringer features are removed with the metal and surrounding areas free of debris and stains.

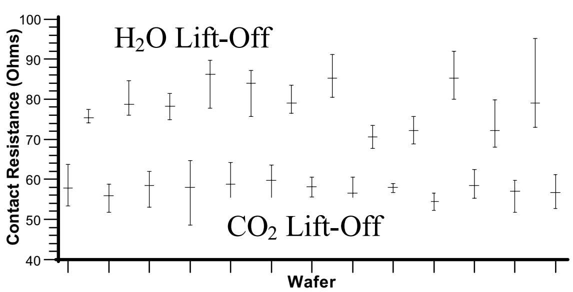

Figure 5. DC parametric test data showing improved contact between the interconnect layer and the ohmic metal layer. An HP Parametric Tester was used to perform the measurements.