Effects of Electron Radiation Generated during E-beam Evaporation on a Photoresist Liftoff Process

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Abstract

In compound semiconductor manufacturing, metallized wafers are put through a wet strip process in N-methyl pyrrolidone (NMP) to dissolve the photoresist, liftoff the unwanted metals, and to form the electrical circuit. There is a wide selection of photoresist suitable for liftoff process. However, most of the available resist can be cross linked if exposed to excessive heat or when bombarded by electrons with sufficient energies. Cross linked resist will not dissolve completely in the normal wet strip chemicals and a residue will result. Although the resist residue can usually be completely removed with more aggressive wet and dry strip processes, the additional rework steps negatively impact the production flow and ship schedule. One theory that explains the residue issue after metal deposition is energetic electron radiation cross linking the photoresist during the E-beam evaporation process. We have conducted a series of experiments to understand the source of the electrons and to quantify the level of secondary electron emission during the deposition process. Results of our work confirmed that backscattered and secondary electron emission is dependent on the evaporation material type. Further, there is strong evidence that suggests impurities in the source material directly influence electron emission. Based on the results of the investigation work, we have taken measures to prevent the problem from reoccurring.

INTRODUCTION

Many new resists have been developed in recent years designed for liftoff metallization process. Chemically amplified resist (CAR) achieves the re-entrant profile due to the nature of the exposure and acid diffusion kinetics. Other approaches like post exposure bake image reversal process can attain similar results. Most of these resists share a common characteristic - given enough thermal or radiation energy, the polymer will cross link rendering it resistant to strip chemicals. In the case of the bi-layer resist process, electrons can cause resist blistering in the PMMA layer [1]. There have been other reports of unintentional exposure of PMMA and PMGI during the E-beam deposition process in the compound semiconductor community.

Previous work had linked high levels of energetic electron emission in the evaporation process generated by the electron beam hitting the Pt melt. We have found that other than the source material difference, impurity type and level can greatly influence electron radiation.

In our Metal 1 process we had noticed resist residue after our normal liftoff processes, which included a NMP soak followed by an oxygen plasma descum step.

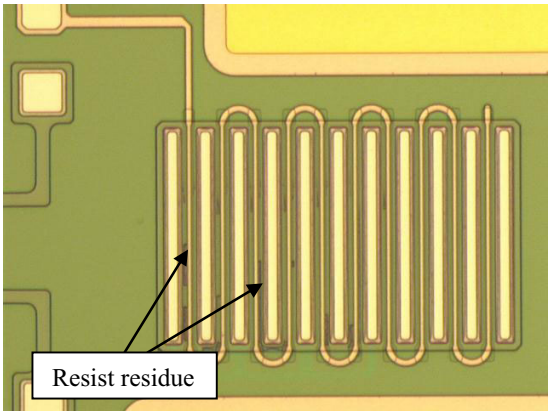

Figure 1 Resist residue in the S/D electrodes

Resist residue remained on the source / drain electrodes in the form of a stringer along the "foot" of the metallized area but none was observed in the field. See figure 1. Focused ion beam (FIB) and scanning electron microscopy (SEM) inspection revealed that the residue was part of the resist profile in the source/drain electrodes of the FET and was not re-deposited from the NMP bath. See figure 2, 3.

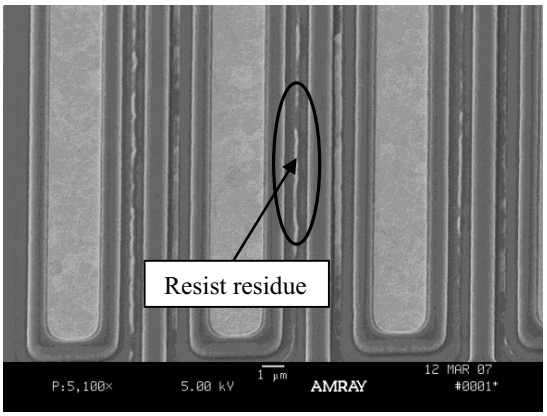

Figure 2 Top view SEM image of resist residue

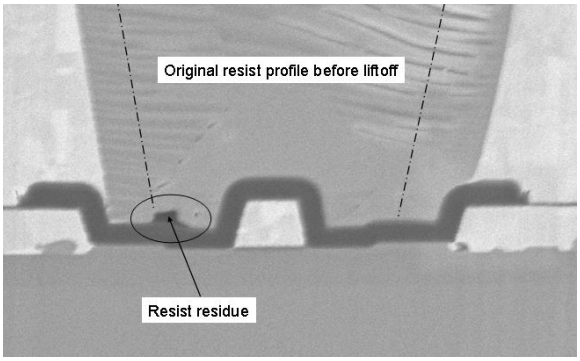

Figure 3 FIB SEM image showing residue was part of the resist.

Lower deposition rates were tried along with varying ramp and thermal soak cycles and different evaporators. None of the attempts proved effective and the problem persisted. The theory of thermal cross linking of the resist was initially considered. Substrate temperature was taken using heat sensitive labels, which confirmed the wafers did not see temperature above 80°C; much lower than the glass transition temperature (Tg), which is about 160°C according to the photoresist manufacturer. Furthermore, if heat was the root cause, one would expect the resist under the metal to be heavily cross linked due to the latent heat of condensation of the large thermal mass of the entire M1 stack. The fact that the resist residue only occurred at the foot contradicted the thermal theory. We concluded that cross linking due to radiation during the evaporation was most likely.

EXPERIMENTAL PROCEDURE

To investigate the source of the radiation, we conducted a series of experiments designed to compare the amount of energetic free electrons during the evaporation process. A Faraday cup is commonly used to precisely measure electron flux (charge) although its application is limited to a rather small area. By fabricating an electrode to fit inside the chamber of our evaporator, we can compare energetic electrons generated from the beam hitting different materials. The copper electrode plate is isolated from ground by ceramic standoffs. A copper wire connects the electrode to a Keithley 2420 source measure unit (SMU) where the signal is logged in a data file. Since the set up is not calibrated against any certified standard, the measured potential can not be interpreted as the actual amount of charge or current.

A Temescal FC2700 evaporator with a 15KW power supply was used for this experiment. We created a recipe with a standard 30 second ramp up to 45% soak 1 power and a 15 second ramp to 50% soak 2 power. The dwell time was 30 seconds for both soak cycles. Our primary Metal1 tool has 6 pockets, 5 of which are Au. We ran different Au melts using the recipe while logging the voltage collected at the electrode.

RESULTS AND DISCUSSION

With the 10KV high voltage turned on and the emitter in idle, the electrode was 0V with respect to ground. As soon as there was beam emission current while the power ramped up and the beam started to appear on the Au melt, the SMU measured -1.5V. The voltage remained somewhat constant as the power continued to ramp up to 45% of maximum. When the Au melt began to turn molten, the voltage dropped abruptly to -0.5V. Further increase in power to 50% caused the electrode voltage to fall off to -0.4V. As the power ramped down the melt began to solidify. The electrode voltage returned to about -1.4V. While the Au melt was in a molten state, the plate voltage was not affected by varying beam power.

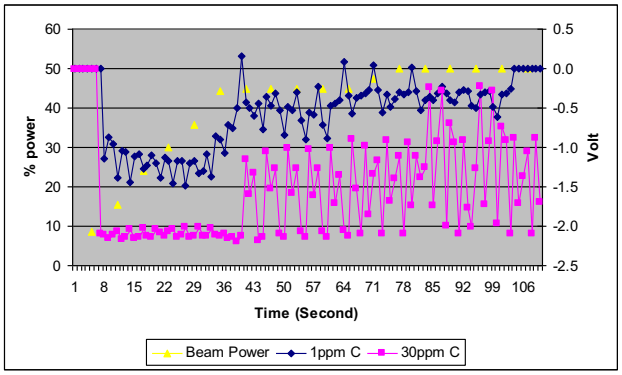

Chart 1 Data log of two Au melts with beam sweep.

The melt recipe employed a circular beam sweep pattern of 2Hz and the sampling rate of the data log was 1 second. The circular sweeping motion of the beam correlated with the spikes in Chart 1. The beam focus changed as the beam went around the melt, sweeping different part of the surface. With each pass over the melt, the beam focus tightened and diffused while passing over areas with high C causing the electron radiation to vary. When the experiment was repeated with a static beam, the voltage did not fluctuate and it followed the same trend. See Chart2.

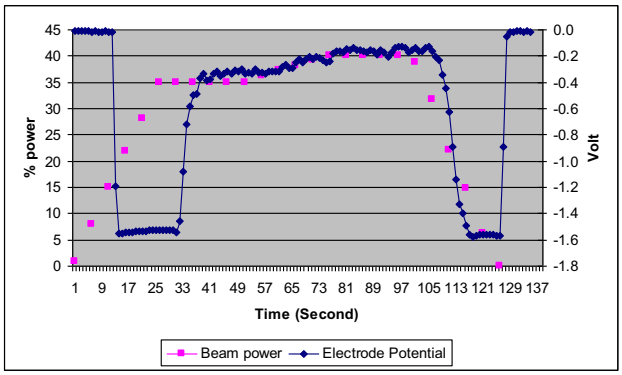

Chart 2 Electrode potential in relation to power. Static beam.

The experiment was repeated using a Au melt with about 30ppm of C on the surface. When the beam hit the source, the electrode potential to ground was two times higher at -2.2V. It took more power and a longer time to turn the melt molten. Throughout the ramp and soak cycle, it followed the same trend although the entire curve shifted more negative, indicating more electrons were collected by the electrode. See Chart 1. When the melt did turn molten, the voltage dropped but it stayed at an overall higher negative voltage. A melt with more than about 30ppm of C on the surface will not turn molten completely with even 90 percent beam power of 15KW.

Although both Au sources appeared to be clean and shiny optically, SEM inspection of the high C source revealed specks of carbon particles on the surface. A Au melt made from a low C content material (< 1PPM) has no visible C particle in SEM inspection. Figure 5 is an EDX survey of the general area shown in Figure 4. A strong C signal indicated contaminant on the source. C can be incorporated during the drawing and swaging process of the Au slug manufacturing where oil is used as a lubricant. Poor clean room practice and improper handling techniques while replenishing the charge can also introduce C to the melt.

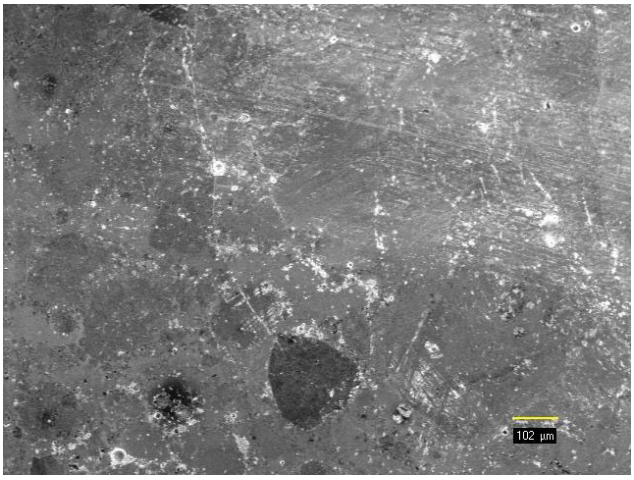

Figure 4 100X SEM image of Au source with 0.05 Atomic% C.

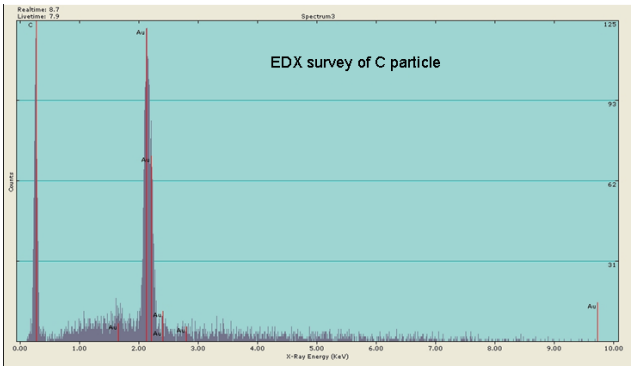

Figure 5 EDX survey of the contaminated area showed a significant C peak

Figure 6 100X SEM image of a clean Au source

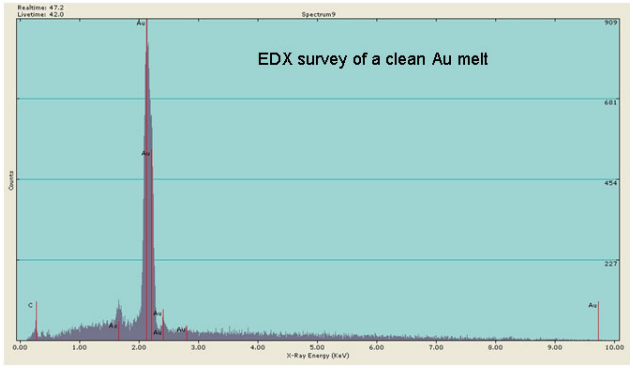

Figure 7 EDX survey of a clean Au melt made from low C content material.

Our experiment showed that electron radiation peaked when an electron beam hit a cold, solid melt. When the melt turned into a molten state, electron emission dropped and stayed constant regardless of beam power. Since secondary electrons usually do not hold a lot of energy, they are unlikely to be the main contributor that caused the resist cross linking. Electron reflection from the source is believed to be elastic [4]. Back scattered electrons retained much of the 10KV acceleration potential and are more likely to be causing the resist to cross link.

Using the electrode potential as a reference, we had determined -0.4V as the baseline voltage for a good clean Au melt. Subsequent runs after rejecting the bad melts registering higher than -0.8V were all free of the resist residue.

THEORY

C in the Au source floats to the surface forming a "skin". When the electron beam encounters the C, some of the electrons are scattered, therefore not efficiently transferring the energies to melt the Au source. Accelerated by 10KV, the back scattered electrons still retained a lot of energy. When the back scattered electrons reach the wafer in sufficient number, the photoresist becomes cross linked. The exact reason why the C particles tend to scatter the electron beam is not fully understood. Based on the results of the experiments, we know a material in solid phase generates a lot more free electrons than when it is in liquid phase. We can then theorize that because of its very high melting point, C particles remain in solid form and effectively block the electron beam from melting the Au.

Since C is linked to the Au spitting problem during evaporation, this principle will be applicable to monitor the condition of Au source as a preventive measure. More work is planned to study how the amount of Au spitting relates to the electrode voltage and C level in the material.

CONCLUSION

When the electron beam hits a solid source it generates a lot of energetic electrons. When the source is molten the emission level drops. We can theorize that this phenomenon is due to the transfer mechanism of kinetic energy to thermal energy. Electron backscattering from a solid source can be treated as an elastic collision. High concentration of C on the surface of the Au source tends to reflect electrons rendering the electron beam ineffective in melting the Au. The back scattered electrons and the secondary electrons generated caused the photoresist to cross link during deposition.

Since the photoresist sidewall is exposed during the entire deposition process, it will be cross linked the most. The resist under large metallized features will be shielded from further bombardment once the first several hundred Angstroms of metal is deposited.

Different metals generate different levels of electron emission and characteristics. A Ti melt, for example, generated about half the voltage compared to a clean Au melt in our study.

The resist residue problem can be eliminated by careful handling of the materials, and by removing the contaminants from the source. Since the implementation of measures to minimize C contamination of Au melts, and by rejecting Au source with higher than -0.8V emission, the resist residue problem has not returned.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Y. C. Pao, K H.Tran, C. Shih, N. Hardy, Solution to the E-beam Gate Resist Blistering Problem of 0.15 micron PHEMTs CS Mantech Conference 1999.

[2] L. G. Feinstein, M.J. Bill, H.P. Reduction of nodules in electron-gun-evaporated Au films, Journal of Vacuum Science and Technology. Vol.12, no.3 May/June 1975.

[3] G. Han, M. Khan, Y. Fang, F. Cerrina, Comprehensive model of electron energy deposition. Journal of Vacuum Science and Technology. B 20(6) Nov./Dec. 2002.

[4] Scanning Electron Microscopy, Applications to material and device science, P. R. Thornton.

ACRONYMS

pHEMT: Pseudomorphic High Electron Mobility Transistor

NMP: N-Methyl Pyrrolidone