An Evaporation Lift off Process with Unidirectional Conformal Coverage

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Abstract

Typical evaporation processes begin in the 10E-7 Torr range. In this high vacuum regime, the evaporation process has line-of-sight characteristics due to the long mean free path. An evaporator designed for a lift off process employs a wafer dome with a spherical radius that matches the source location. Coupled with a photolithography process that generates a retrograde angle or an undercut profile, the combination enables clean metal lift off. However, the same line-of-sight property that facilitates metal lift off results in non-conformal step coverage. With conventional evaporation methods, conformal step coverage causes difficulty with liftoff. In this work we will discuss a technique Raytheon RFC recently developed that offers a unidirectional step coverage advantage over a standard lift off evaporator. By using an oscillation wafer motion, the evaporant flux can reach the feature normally shadowed by the film growth thereby improving step coverage. This method is suited for applications where conformal coverage in one direction is desirable.

INTRODUCTION

Metallization in compound semiconductor device fabrication is by and large evaporation followed by a lift off process to remove the unwanted metals. E-beam evaporation is a simple and effective metallization process. Because the process typically begins under high vacuum, the coating has line-of-sight property owing to the long mean free path. An image reversal photo process that generates a retrograde angle or a bi-layer process that produces an overhang profile will cause a discontinuity in the metal film coverage making clean lift off feasible. Insufficient retrograde angle will produce a thin uninterrupted layer of metal on the photoresist. After liftoff, the excess metal will become defects such as stringers, wings or flaps.

Unfortunately, the very quality that benefits a lift off process is not optimum for step coverage. Figure 1 shows an example of step coverage of one metal layer over another metal layer separated by a dielectric film.

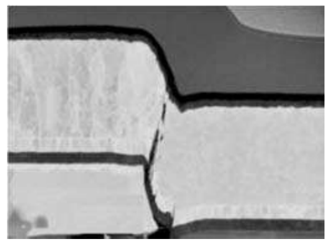

Figure 1. Examples of metal topology over a step.

In an evaporator designed for lift off processing, the evaporant flux is set at normal incidence to the wafer. The sloped sidewall receives a portion of the flux determined by cosine θ. Not only does the vertical surface see a lower deposition rate, more importantly, the film has lower density due to the flux angle and lower energies of the arriving atoms. Consequently, the film on sloped and vertical surfaces generally assume a Zone 1 film structure as shown in Figure 2.

A common solution to improve step coverage is to increase film thickness. Another approach is to increase the mobility of the arriving metal atoms through heat, thereby promoting film growth. However, the temperatures required to effectively enhance film growth (at $T_S/T_M > 0.2$) is above the glass transition temperature (T_g) of most photoresist types. Therefore, this approach is not compatible with a lift off process.

Ion beam assisted evaporation has been tried to improve step coverage. Atomic peening can densify Zone 1 micro-structure and move the film into Zone T. But the energetic ion bombardment is known to crosslink the photoresist and creating photoresist residue problem and stripping difficulties [4].

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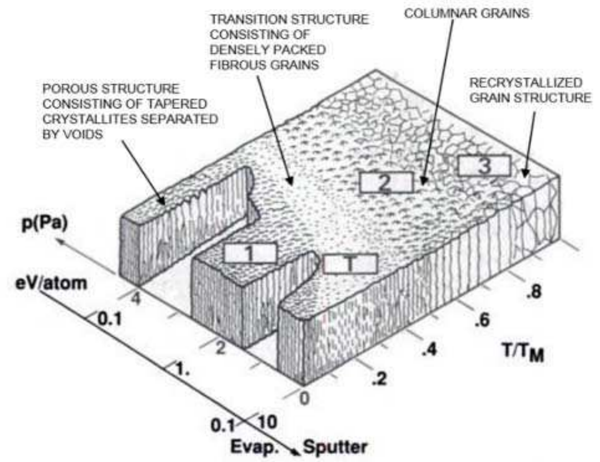

Figure 2. Zone diagram with permission to reprint from JVST

Experiment

The fundamental solution is to vary the flux direction away from normal incidence periodically to reach the shadowed region. Moving the flux can allow the atoms to fill in between the islands during film growth. Since our objective is to achieve conformal coverage in one direction (X) only, we introduced oscillation wafer motion in the Y direction. After a level of design effort was complete, a prototype was fabricated that can hold a 4" wafer in an oscillation motion. See Figure 3.

Figure 3. Single wafer oscillation wafer holder

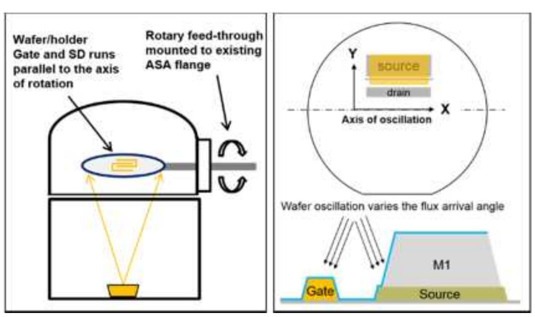

Figure 4. Illustration of the oscillation wafer motion and flux angle

The mechanism consisted of a wafer holder, a shaft and a coupler that connected to the rotary feed-through. The substrate holder had the wafer flat and exclusion machined in. A ¼" shaft passed through the center of the holder with 0.060" clearance above the wafer; see Figure 3. No wafer retainer was needed since the shaft would prevent the wafer from falling out. Two set screws secured the shaft to the wafer holder. We machined an ASA flange to which a rotary ferro-fluidic feed-through could be mounted. A modified geared motor taken from an old track system provided the power. The motor is mounted outside of the vacuum system and drives the wafer fixture via the rotary feed-through. The gear drive's rotary motion was transferred to oscillation motion through an arm and mechanical linkages. The amplitude of the motion was controlled by the throw of the arms. Frequency was controlled by the motor RPM, which was controlled by the power supply voltage.

A Temescal VES2550 evaporator was chosen for this study since the entire oscillation mechanism could be inserted through the view port, which was conveniently located in the top chamber cover. The wafer holder placed the wafer at the center of the chamber directly above the source. We removed the shaper mask since batch uniformity was not a concern for a single wafer. The tooling factors were adjusted for the new wafer location.

A batch of short loop wafers were processed having the same topology of a device wafer. Oscillation began during the soak step. The frequency was kept at about 1 Hz with an amplitude of 1". This translated into 30 degrees of oscillation.

After deposition, the wafer received a lift off process in NMP. The unwanted metal lifted off normally without any issues. No issue with metal liftoff in either X or Y direction was evident.

Results

Figure 5a is a FIB / SEM image of a standard evaporated metal going over another metal with a 70 degrees side-wall angle. The metal thickness on the sidewall is about 1/3 of the total thickness on the horizontal surface.

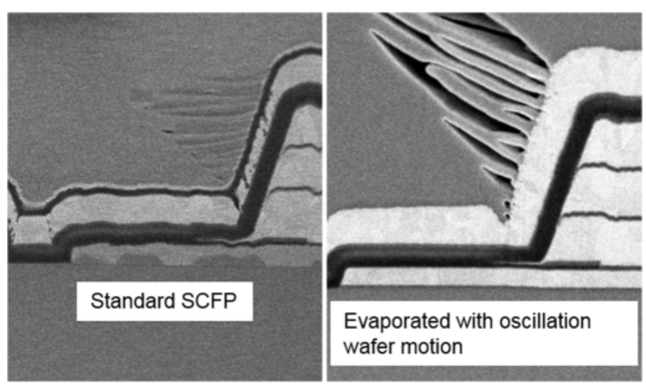

Figure 5a and b. Standard SCFP compared to oscillation motion

A FIB/SEM image of the same metal that ran using the oscillation fixture is shown in figure 5b. Improved step coverage is clearly observed. The absence of micro-fractures and the grains in the FIB images suggest that the film is Zone T.

The results confirmed that changing the incidence angle can improve step coverage by allowing the evaporant flux to reach the shadowed region. There exists an optimum oscillation setting for this technique to be effective. Small oscillation angle will not be effective. However, too large of an oscillation angle will create adverse shadowing effects. If the oscillation amplitude is further increased, flaps or stringers may start to develop on each end of the metal. By considering the topology, an optimal amplitude can be established for improved step coverage without causing detrimental effects of flaps or CD control.

Other parameters such as frequency, dwell time, and resist profile need to be considered to achieve maximum effectiveness.

From our initial results, we concluded that if the oscillation angle was increased beyond 30 degrees, no further gains in step coverage could be achieved but some shadowing would begin to develop. We determined that the optimal angle should be reduced to about 20 degrees. This amplitude will allow the flux to fill the ledge while not too large to cause detrimental shadowing from structures with sufficient height.

CONCLUSIONS

We have demonstrated the feasibility of one dimensional conformal step coverage in an evaporation lift off process. Compared to the standard E-beam evaporator with a rotational lift off dome, the oscillation wafer motion offers an improved step coverage. By varying the evaporant angle, film coverage on sloped and vertical surfaces is improved because the evaporant can fill in between the islands during film growth. Because of the changing flux angle, the deposition has a wider "foot". CD control will therefore require optimizing the photoresist profile and biasing the mask.

The deposition on the sloped sidewall is thicker than the control sample. More significantly, the film growth has better quality. Although a single wafer fixture is used in this study, the oscillation wafer motion mechanism can be integrated in a production size batch evaporator with a few added mechanical parts.

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