Passivation Stress versus Top Metal Profiles by 3D Finite Element Modeling

Xiaokang Huang, Liping Zhu*, Bang Nguyen, Van Tran, Harold Isom

TriQuint Semiconductor, Inc., 500 W Renner Road, Richardson, TX 75080
* TriQuint Semiconductor, Inc., 2300 NE Brookwood Parkway, Hillsboro, OR 97124

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Abstract

Passivation hermiticity is always a concern in integration circuit fabrication and application. Passivation stress is one of the key factors for the passivation integrity. In this paper, passivation stress is investigated as a function of top metal profiles with a 3-Dimentional Finite Element Modeling (3D FEM). A new structure is proposed for reducing the passivation stress at the corner of a top metal foot to prevent a potential passivation crack. A sloped metal with a curved foot profile is demonstrated. The pros and corns of the new structure are discussed at the end.

INTRODUCTION

Passivation hermicity is always a concern for semiconductor IC in both Si and compound semiconductor devices. Cracks are one of the passivation defects which is specifically important for compound semiconductors due to the materials used for inter metal dielectric layers such as bisbenzocyclobutene (BCB) in compound semiconductors. Figure 1 shows an example of a passivation crack at the corner of the top metal foot. Many investigations have been conducted by FEM simulation [1], [2] or experiments [3], [4]. In this paper, the passivation stress is investigated as a function of the top metal profile and passivation thickness with a 3-Dimentional Finite Element Modeling (3D FEM). Based on the results of the simulation, a sloped top metal with a curving foot profile is designed and fabricated. The pros and corns of the new structure are discussed.

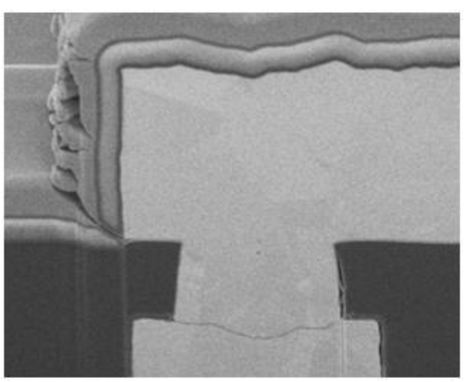

FIGURE 1 PASSIVATION CRACK AT THE CORNER OF THE TOP METAL FOOT

Figure 2 (a) shows the basic interconnect structure which contains two metals and two interconnect layers with SiN as the passivation. Both the top metal (M2) and the underlying metal (M1) are plated Au connected through vias (VIA1 and VIA2). The inter-layer dielectric films are bisbenzocyclobutene (BCB). For simplicity, SiN between BCBs and TiW under each Au are not shown in Figure 2. The dimensions of metals and dielectric layers are not scaled here.

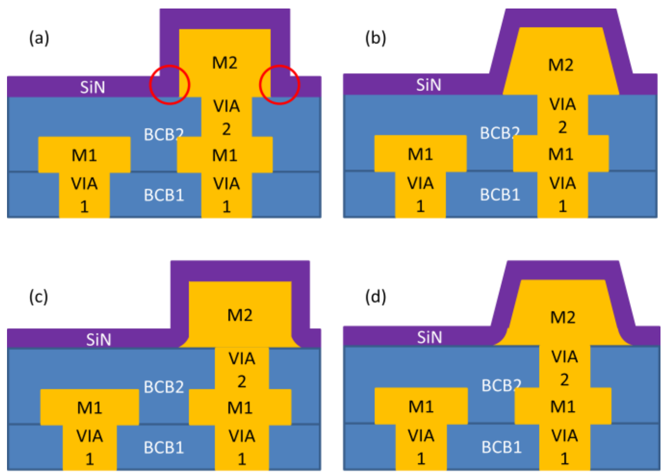

FIGURE 2 DIFFERENT TOP METAL PROFILES PROPOSED FOR SIN STRESS REDUCTION AND PASSIVATION CRACK ELIMINATION. (A) RIGHT ANGLE; (B) SLOPED ANGLE; (C) RIGHT ANGLE WITH CURVING FOOT; (D) SLOPED ANGLE WITH CURVING FOOT

The two red circles are the locations where the stress is the highest which induces the SiN passivation cracks. There are different ways to eliminate the cracks, such as optimization of SiN thickness and stress. However, in certain cases, there are limitations of what SiN thickness and stress can be changed. Therefore seeking a different way for resolving the SiN crack issue is very important.

Since the crack is right at the corner of M2 due to the straight angle of the profile, another way of reducing the stress at the corner is to modify the corner profile by smoothing the straight angle. Figure 2 (b) shows a M2 with a slope angle. Figure 2 (c) is a M2 with a curving foot at the corner. Figure 2 (d) is a combination of both a slope profile and a curving foot at the corner.

10 b

In the next few sections, we used 3D FEM for the evaluation of the impact of the three different M2 profiles to the SiN passivation cracks. Since there is a correlation of SiN crack and thickness established with experiments [4], we also simulated the correlation of SiN stress and thickness for both purposes of verifying the model and parameters used in the simulation and determining the SiN crack threshold for M2 profile evaluation.

SIMULATION MODEL

The software used in the simulation is Ansys. The Finite Element Analysis (FEA) model was used to conduct sensitivity analysis of design form factor effects, such as metal thickness, metal side wall angle and corner filet on PSN stress which is a metric used to assess risk of PSN crack and provide solutions for optimal process. A slice of FEA model was constructed by using hex brick elements and constrained in normal surfaces of front and back, bottom, and two sides with the top free. The selection of proper mesh size is very important for achieving valid simulation results. By comparing the simulation results among different mesh sizes, one fourth (1/4) of standard SiN thickness was used for the mesh size for the most of the structure in the simulation as shown in Figure 3 (a). At the area near the surface of SiN passivation, a fine mesh is used as shown in Figure 3 (b).

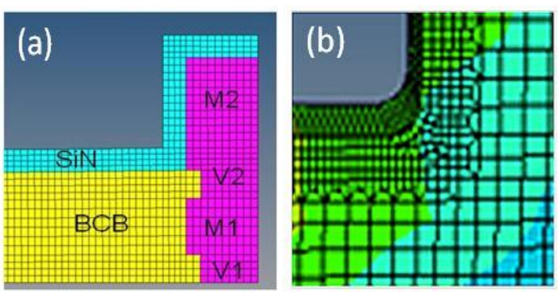

FIGURE 3 MESH STRUCTURES (A) IN A STRAIGHT ANGLE METAL PROFILE WITH NORMAL MESH AND (B) IN A CURVING FOOT METAL PROFILE WITH FINE MESH NEAR SIN SURFACE

The thermal load from 320C to 23C was imposed to simulate deposition and cool down process. Material properties used in the simulation are given in the Table 1. ρ is the material density. *v* is the Poisson's ratio. *E* is the elastic modulus. CTE is the coefficient of temperature expansion. The data are from www.MetWeb.com. The strength of SiN has a value between 800 to 2100MPa, which depends on the film deposition.

According to the First Principal Stress Theory, we compared the maximum stress value in the SiN film to the strength of SiN. Once the maximum stress value was larger than the strength of SiN, then cracks would occur. The strength of SiN or the crack threshold in our case is determined by comparing the simulation results to the experiment data [4].

TABLE I

MATERIAL PROPERTIES USED IN THE SIMULATION (WWW.METWEB.COM)

	ρ Mg/mm³	*E* GPa	*v*	*CTE* ppm/C	*Strength* MPa
Au	$19.32x10^{-9}$	77.2	0.42	14.1	120
BCB	$0.95X10^{-9}$	2.7	0.34	42	80 ~ 90
SiN	$3.2X10^{-9}$	260	0.25	2.8	800 ~2,100

SIMULATION RESULTS

First, we simulated the SiN stress at the M2 corner with a right angle slope as a function of SiN thickness shown in Figure 4. The highest SiN stress is at the corner of M2, where the crack observed in our experiment. The highest stress in SiN passivation decreases with the thickness of SiN. This is consistent with the experimental observations in Ref. [4]. At a certain point where the maximum stress is lower than the strength of SiN, the crack will not happen. By comparing with the results in Ref. [4], the stress threshold of the SiN crack shown in Figure 4 (d) is determined as a reference for M2 profile evaluation in this paper.

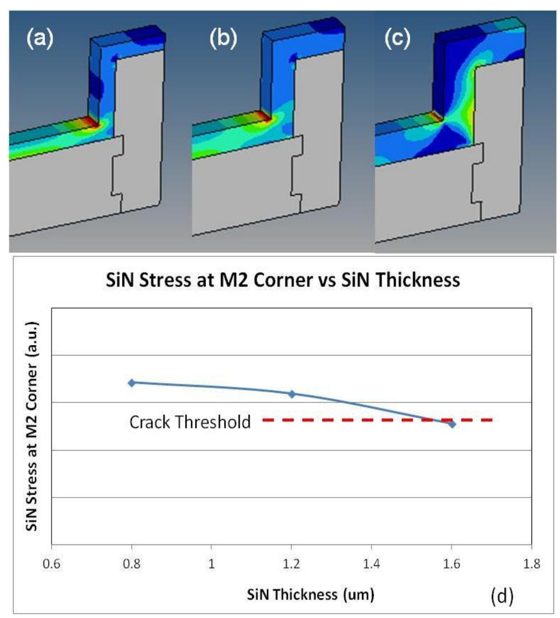

FIGURE 4 SIN HIGHEST STRESS AS A FUNCTION OF SIN THICKNESS

Second, we investigated the SiN highest stress as a function of different sloped angles with a fixed SiN thickness. Figure 5 shows the impact of sloped angle profiles to the SiN stress at the M2 corner. The smaller the M2 sloped angle is, the lower the SiN stress is at the M2 corner. However, by comparing the highest stress at 85° to the stress threshold of crack occurring, the highest SiN stress at 85° is still higher than the crack threshold. This means that even with 85° sloped M2 profile, SiN will still crack at the corner. There are two reasons for choosing 85° here. One is that a smaller angle gives a larger difference between the sizes of the top and bottom of M2, which can cause enclosure concerns in both layout design and wafer process. The other one is the limitation of what we can achieve experimentally.

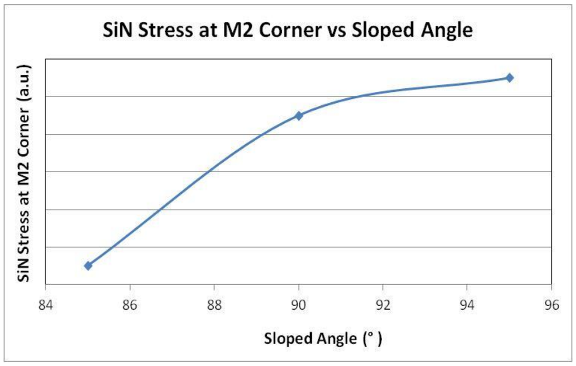

FIGURE 5 SIN HIGHEST STRESS AS A FUNCTION OF M2 SLOPED ANGLE

Finally, we simulated four different M2 profiles as shown in Figure 6. These four profiles are (a) right angle, (b) sloped angle, (c) right angle with curving foot, and (d) sloped angle with curving foot. As expected, the highest stresses for different cases are all at the corner of the M2 foot corner.

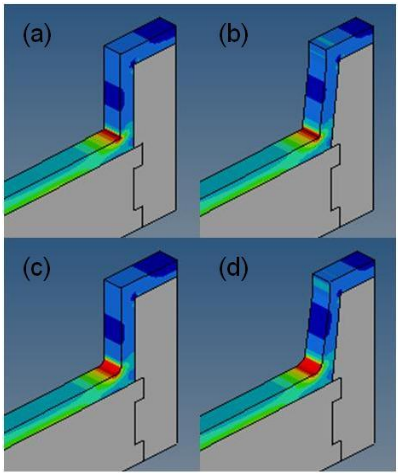

FIGURE 6 FOUR DIFFERENT TOP METAL PROFILES SIMULATED WITH 3D-FEM. (A) RIGHT ANGLE; (B) SLOPED ANGLE; (C) RIGHT ANGLE WITH CURVING FOOT; (D) SLOPED ANGLE WITH CURVING FOOT

The summary and the comparison of the passivation stress of these four different profiles are shown in Figure 7. The slope angle is 85° and the radius of the curving foot is 0.3µm. For easy comparison, the maximum stress values of SiN film for the different M2 profiles are normalized to the value of the basic structure, the right angle profile, which gives the highest stress within the four different profiles we interested. The maximum stresses of both the right angle with curving foot and the sloped angle profiles are improved from the right angle profile. However, by comparing to the crack threshold, these two profiles are still not good enough to fully eliminate the cracks. The only one that has the maximum stress lower than the critical crack threshold is the combination of both the sloped angle and the curving foot profiles.

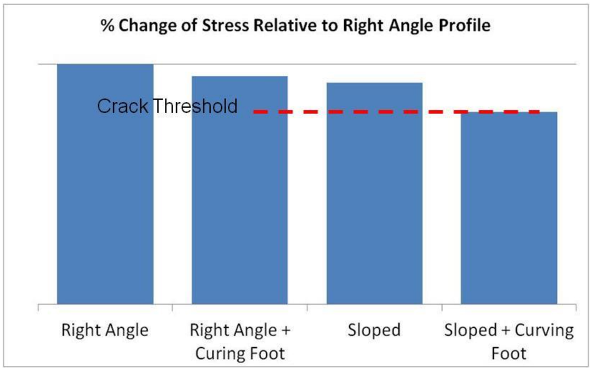

FIGURE 7 STRESS COMPARISON OF 4 DIFFERENT TOP METAL PROFILES RELATIVE TO CRACK THRESHOLD

EXPERIMENT AND DISCUSSION

Experimentally, we fabricated a plated metal with a sloped angle profile and curving foot shown in Figure 8. The slope of the metal profile comes from the optimization of the focus depth, exposure, and development during the metal lithography. The curving foot is realized by controlling the plating process.

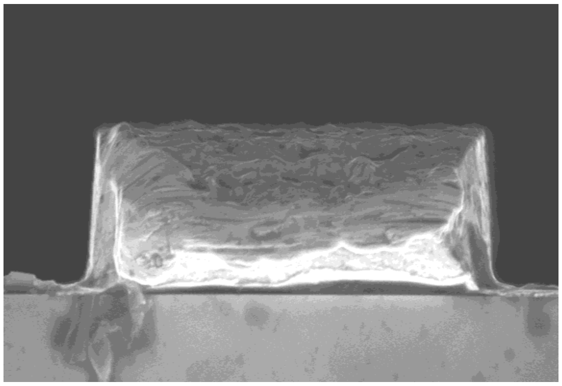

FIGURE 8 PLATED METAL WITH A SLOPED PROFILE AND CURVING FOOT

Clearly, the sloped angle M2 with curving foot changes the original dimension of the metal. The bottom size of the metal becomes larger than the top. Therefore, there should be no concern for the enclosure of M2 to the VIA below practically. Since the M2 is the top metal in the case here and normally the density of the top metal is low comparing to metals underneath, the increasing of the bottom size of the metal should not impact the overall layout and die size. Pad enclosure to the top metal should be considered in the real case. Depending on layout design rules, it could be an issue and the pad size may have to be modified accordingly.

In fact, there should be still a limitation of how small of the slope angle can go and how large the radius of the curving foot can use. The limitation can come from either the fabrication capability or the layout design rules. That is why a slope of 85° and radius of 0.3µm are mostly used in our simulation. The impact of this profile change to the RF performance requires electrical simulation, which is beyond the discussion here, but it should be verified.

CONCLUSIONS

Based on our 3D FEM simulation, neither a sloped profile nor a curving foot profile of the top metal is enough to eliminate the passivation cracks by itself. Only the combination of both sloped and curving foot profiles of the top metal is promising as a solution. Experimentally, we fabricated a sloped metal profile with a curving foot on a monitor wafer. Further effort is needed to transfer it to the product chip, which is still a challenge.

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ACRONYMS

FEA: Finite Element Analysis
FEM: Finite Element Modeling
BCB: bisbenzocyclobutene
TiW: Titanium Tungsten
SiN: Silicon Nitride