Reduction of Thin Film Stress-induced Micro-masking by Using Ti/Ni Hard Mask for High Power SiC RF Transistor Fabrication

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Abstract:

Thin film stress is a problem for compound semiconductor device fabrication; metal thin film stress can cause undesirable surface cracking during deposition. Depending on the severity of stress, the surface cracking can lead to buckling and peeling of the film. This buckled or curled film can perform as a micro-mask during further metal deposition and leave behind an incomplete metal film. When using this metal film as a hard mask, the micro-masking defect transfers during the dry etch process and ultimately poses a risk to device performance. In this paper we discuss methods to mitigate the stress induced micro-masking for SiC etch processing and present results from implementation into our device processing.

INTRODUCTION

Silicon Carbide (SiC) has intrinsic properties of large bandgap, high voltage breakdown, high strength and hardness which make it suitable for use in high-power, high temperature solid-state electronics. Schottky SIT (static induction transistor), RF power amplifiers as well as high voltage power devices are some typical applications [1]. However, due to its chemically and mechanically stable nature, the fabrication of devices on SiC wafers is very difficult. In particular, patterning or etching of the SiC material is difficult because of the hardness and chemical stability. The bonding between Si and C (Si-C bond strength = 1:34 x Si-Si) is very high, and plasma-based (dry) etching plays a crucial role of patterning SiC for transistor fabrication [2]. One of the most important parts of etching is an adequate masking layer which must adhere to the SiC and resist the deep dry etching. In this work we needed to define the trench of the transistor, etched to a depth of 1.3 µm. In prior work, 700 Å nickel (Ni) was adequate to use as hard mask for dry etching, and chromium (Cr, 400 Å) was used as the adhesion layer of Ni. In this paper, the tensile stress-induced cracking, curling and micro-masking of the Cr/Ni layer has been addressed by replacing it with a compressive titanium/nickel (Ti/Ni) thin film with less stress that does not produce any cracking or micro-masking.

FABRICATION PROCESS

The vertical SIT device requires a deep trench for the sidewall gate. Our production process uses 4H-SiC, n-type substrates with epitaxial layers. The process consists of 11 lithography steps, including two etches that utilize the same hard mask process.

At the level of interest photo step, to create a metal hard mask, a standard bi-layer, (lift-off layer, LOL and photoresist) photolithography process was used to create the pattern. The cross section of the hard mask fabrication is shown in Figure 1. Here, LOL is not photoactive, and any LOL not protected by the PR will be developed. This creates an overhang of the PR at the edges of the features, which shadows/protects the anisotropic deposition of evaporated metal, and allows for a clean lift-off.

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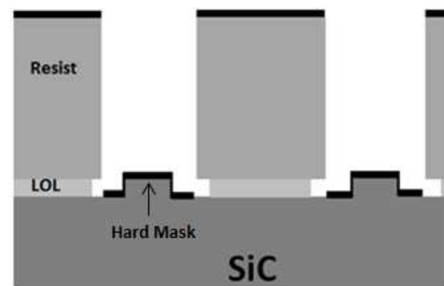


Figure 1: Cross section of hard mask fabrication

MICRO-MASKING DEFECT

In general, all vacuum-deposited thin films are in a state of stress. The total stress depends on overall thermal and intrinsic stresses. The difference of thermal expansion coefficients of the material and subsequent substrate materials contribute to the thermal stress. The intrinsic stress of the metal thin film is due to the accumulating effect of the crystallographic flaws that are built into the material during deposition [2].

When higher melting point materials, such as Cr and Ni, are deposited at low temperatures, intrinsic stresses accumulate and tend to dominate over thermal stresses. As a result, stress cracking and buckling are often observed [3].

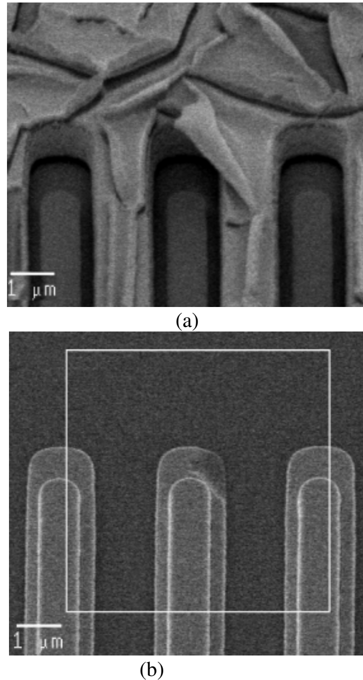


Figure 2: SEM (a) Post e-beam Cr/Ni deposition; (b) Post lift-off: Micro-masking of middle finger

Figure 2(a) shows the SEM images of a Cr (400Å)/Ni (700 Å) film deposited on a photoresist-patterned wafer. The stress-related cracking and buckling which micro-masks (or shadows) further Ni deposition is shown at the top of the middle structure. This results in an incomplete hard-mask, the "micro-masking" defect, as seen in Figure 2(b) after liftoff. These micro-masking defects, with insufficient Ni masking material, lead to incomplete pattern formation and result in a defective etched structure during dry etch which affects device performance. The measured stress of the Cr/Ni layer was 1000MPa.

Anisotropic deep-trench etching of SiC was performed using a Plasmatherm reactive ion etch (RIE) tool. The RIE was powered with a base pressure of 2.5×10^{-5} Torr and SF_6, O_2, CHF_3, and Ar/H_2 gases. Fluorine-based chemistries are the most effective plasmas for SiC etching in terms of providing the fastest etch rates. High energy ions and fluorine radicals from the plasma attack the surface and react with SiC, producing volatile compounds. Figure 3 shows that the Cr/Ni micro-masking defect transfers during the RIE etch, resulting in an uneven, performance-degrading trench sidewall

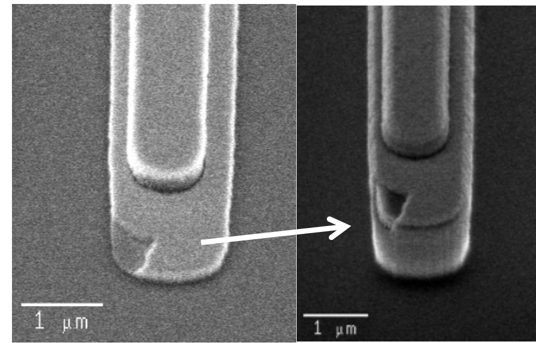


Figure 3: Cr/Ni mask: Micro-masking defect transfers during RIE dry etch. Left: Post lift-off: Metal missing due to micro-masking; Right: Post RIE etch: Pattern transfers

EXPERIMENTS

During metal deposition using E-beam evaporation, the magnitude of the intrinsic stresses may depend on the sensivity of the processing and evaporator operating conditions [4]. A number of experiments were performed to find the root cause and potential solution for this micro-masking defect.

a) UV flood exposure on photoresist to cure before metal deposition
b) Cr-only deposition to observe stress induced cracking
c) Changing thickness of the Cr/Ni stack –a thinner film was predicted to induce less stress and minimize cracking
d) Different E-beam deposition rates to observe any variation of cracking
e) Different E-beam sources
f) Different E-beam evaporator tools
g) Relacement of Cr (tensile stress) with Ti (compressive stress) as an adhesion layer

RESULTS

Most of the experimental results had similar levels of stress induced cracking. Figure 4 shows there was no significant change in film cracking when the evaporator deposition rate and Cr/Ni thickness were varied. Comparable results were found when different sources and different evaporators were used, as shown in Figure 5. The stress induced buckling/peeling of the deposited metal was not observed in all experiments but the presence of cracking was still significant.

Reduction of the stress/cracking/buckling is predicted by changing the adhesive layer Cr, which is tensile. Of the available adhesion layers considered

as a replacement, Ti was considered the best candidate material. Titanium has good adhesion, compressive stress (shown in Table 1), and a high melting point. The compressive stress of Ti would potentially compensate for the high tensile stress of Ni and produce less stress of the overall stack, resulting in no cracking or micro-masking defects. This would serve as a solution for the metal micro-masking problem.

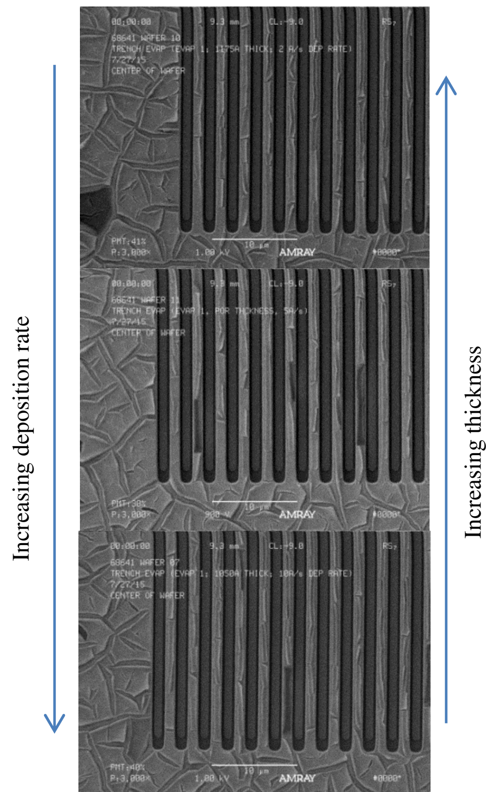


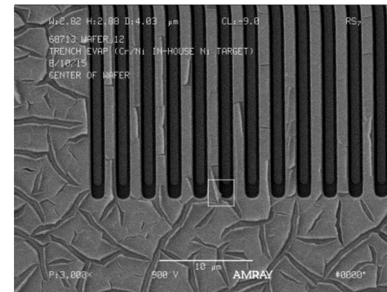
Figure 4: SEM – variation of evaporator deposition rate and Cr/Ni thickness

Table 1: Library of available adhesion metals

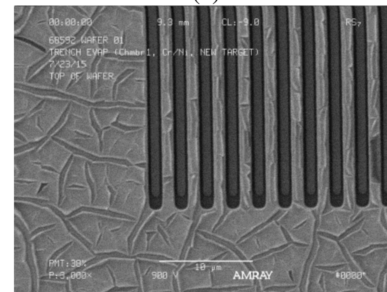
Material	Rate (Å/s)	Thickness (Å)	Stress (MPa)
Cr	5	1000	1143
Ti	10	1000	-539
Al	20	1000	5.2

The final experiment conducted was replacment of the Cr adhesion layer with Ti. Three different Ti thicknesses were considered for this experiment:

Ti/Ni (300Å /700Å)
Ti/Ni (400Å /700Å
Ti/Ni (500Å /600Å).

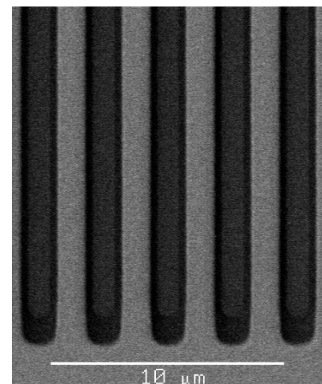


(a)



(b)

Figure 5: SEM e-beam source variation (a) in-house source – less crack in between fingers; (b) pre-formed- more crack in between fingers



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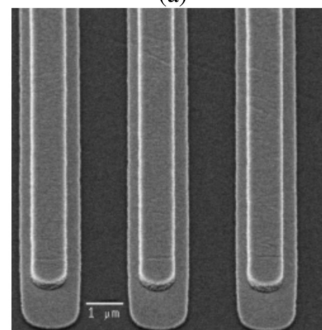

(b)

Figure 6: SEM - (a) Post e-beam Ti/Ni deposition – no stress induced cracking; (b) Post lift-off: No metal missing

Significantly improved results were found for the Ti/Ni mask material. Figure 6 shows SEM images of the Ti/Ni(400Å /700Å) film – there is no visible

stress-induced cracking or peeling of the metal film. As a result, no micro-masking defects were observed.

The measured stress of Ti/Ni (400Å /700Å) layer was 234 MPa tensile, which is significantly lower than the Cr/Ni layer (1000 MPa). Figure 7 - the SEM image of the trench etch profile after etching in the plasmatherm tool – the Ti/Ni mask can withstand the etch. A good etch profile should have near-90°, vertical sidewall and sharp features. The post etch profile achieved with the plasmathem tool shows vertical sidewalls in alignment with the metal mask.

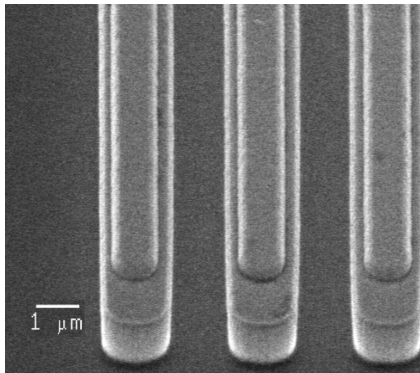

Figure 7: Ti/Ni mask: Holds during RIE etch

CONCLUSIONS

To mitigate the stress-induced film cracking, curling, and subsequent micro-masking, replacment of a Cr/Ni (tensile) layer with a Ti/Ni (compressive) layer is the long term solution. The SEM results clearly demonstrate the capability of the Ti/Ni mask during plasmatherm dry etch to pattern trenches for SiC RF transistor fabrication. Use of the Ti/Ni hardmask process has eliminated the rework associated with the intermittent stress cracking and mirco-masking etch defects.

REFERENCES

[1] M. Megregany, C.AA Zorman,, Rajan, C.H. Wu, " Silicon Carbide MEMS for Harsh Environments," Proceeding of the IEEE, vol. 86, No.8 (1998), pp. 1594-1609

[2] P. H. Yih, V. Saxena, and A. J. Steckl, "A Review of Si C Reactive Ion Etching in Fluorinated Plasmas," Phys. stat. sol. (b) 202, 605 (1997)

[3] J. A. Thornton, D.W. Hoffman, "Stress-related effects in thin films," Thin Solid Films, Vol.171, 5–31(1989)

[4] Gustava Giovia, "Delamination of Compressed Thin Films," Advances in Applied Mechanics, Vol. 33, 1997.