Advanced Carbon film for high-voltage power, high-performance SiC devices

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We propose the use of Advanced Patterning Film (APF®), a PECVD Carbon-based film family deposited via Applied *Producer*®, to address several SiC devices processing challenges: in particular, we discuss its advantages as a (i) flexible, high quality ion-implant mask, and (ii) protective capping layer of planar and 3D SiC structures during the post-ion implantation high-temperature activation anneal. The benefits of integrating APF film in the implantation and etch processing blocks are benchmarked against alternative methods like common photo-resist (PR), PVD C- cap and SiO_2 HM.

Silicon Carbide (SiC) has very attractive features[1] including a wide-bandgap (3X Si), high-$E_{break\text{-}down}$ (10X Si), high thermal conductivity (3X Si or GaN). Availability of large substrates (up to 200 mm) have led to the wide adoption of SiC-based devices with a forecasted TAM[2] of \$6.3B in 2027. However, SiC processing presents some unique challenges which need to be solved to fully exploit the potential of this compound semiconductor.

In this work, we propose the use of Advanced Patterning Film (APF®), a PECVD Carbon-based film family deposited via Applied Materials *Producer*®, to address several SiC device processing challenges: in particular, we discuss its advantages AS A (i) flexible, high quality ion-implant mask, (ii) PROTECTIVE CAPPING layer of planar and 3D SiC structures during the post-ION implantation high-temperature ACTIVATION anneal, and (iii) FILM to improve the hard-mask (HM) patterning of SiC trenches for next generation SiC devices. The benefits of integrating APF in the implantation and etch processing blocks are benchmarked against alternative methods like common photo-resist (PR), PVD C-cap and SiO_2 HM.

APF as a Hard Mask for Implant Process

Both *p*- (Al) and *n*- (P or N) SiC doping require ion-implantation due to extremely low dopant diffusion into the SiC crystal[3]. Current implant masks present several issues: (1) PR can only be used for room temperature (RT) implant and its use introduces particle contamination, outgassing[4], and post-implant ashing difficulties; (2) SiO_2 HM allows hot implants (~400 -700°C), a process desired to improve implant damage recovery (dynamic anneal), but it requires longer and more complex processing, which comes at the expense of throughput. As-deposited APF density is ~1.5 g /cm^3 as measured by XRR (Fig. 1).

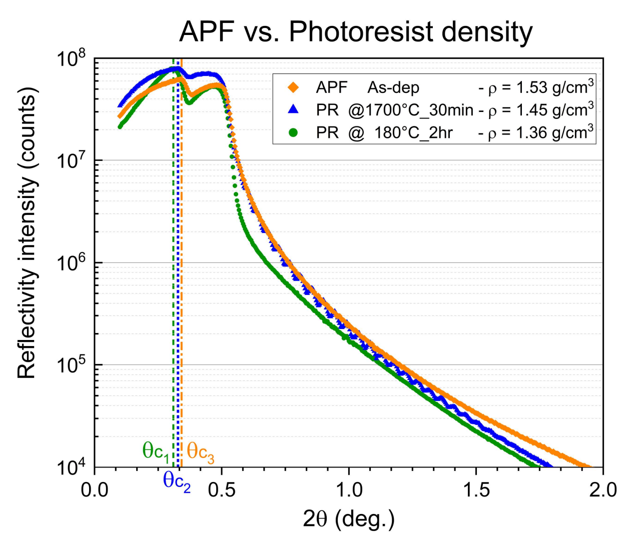


Fig. 1 XRR spectra of PR after Hard Bake, after annealing at 1700°C - 30 min and as-deposited APF

APF allows both RT & hot implantation by a simpler and cheaper process than SiO_2 HM. Furthermore, it does not present the common drawbacks of photoresist implant masks, allowing also a precise and aggressive scaling of implanted regions for very high performance and advanced SiC devices. Fig. 2 & 3 show respectively simulation and experimental results of APF used as an implant mask.

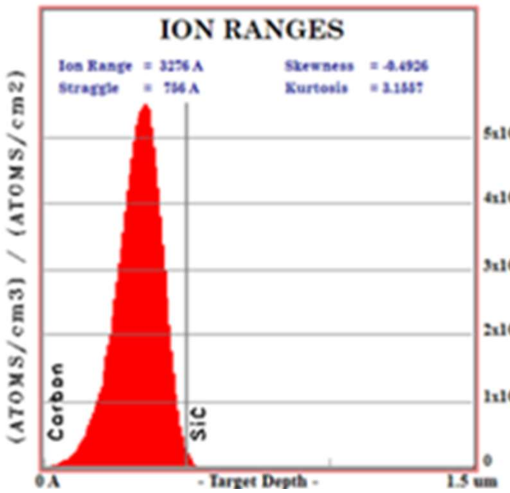


Fig. 2 SRIM simulation of APF film ion implant stop capability

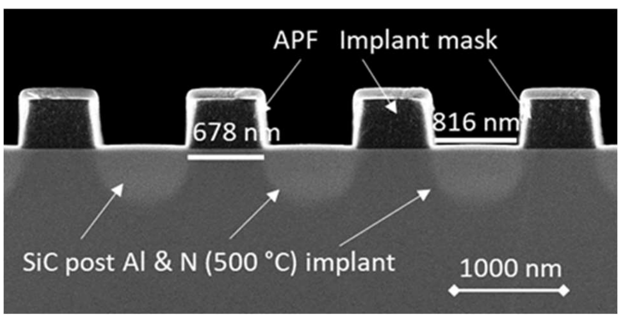


Figure 3 APF as a HM for Ion Implantation

APF as a Cap Layer for Surface Protection During Anneal

The Si component of the SiC crystal sublimates at the high-T anneal (T ≥ 1650°C) necessary to electrically activate both *p*- (Al) and *n*- (P or N) dopants. This causes surface roughening (step bunching) of the SiC surface[5], which can lead to issues in Gate Oxide (GOX) formation and reliability and in metal contact quality. Protective PVD-based C-caps have low throughput, require expensive targets, and cannot cover high aspect ratio SiC structures. Although widely adopted due to its low cost, PR is prone to outgassing causing contamination downstream vacuum process equipment. In addition, Fig 4 shows PR's shrinkage through a high-T anneal process which can lead to possible film cracking and delamination.

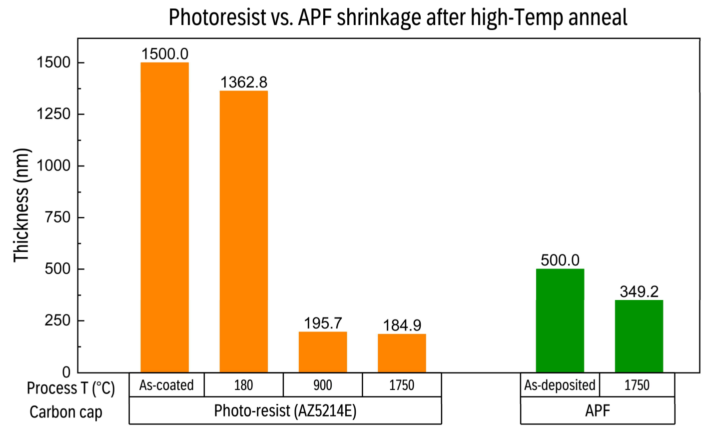


Figure 4 PR vs. APF thickness variation at different annealing temperature

Due to its high C-content, as-deposited APF offers instead a minimum shrinkage as indicated in high-Temp anneal experiments run in a Centrotherm c.ACTIVATOR200 tool, while maintaining an equivalent (or better) capacity in preserving SiC surface fidelity as shown by the AFM RMS results of Fig. 5.

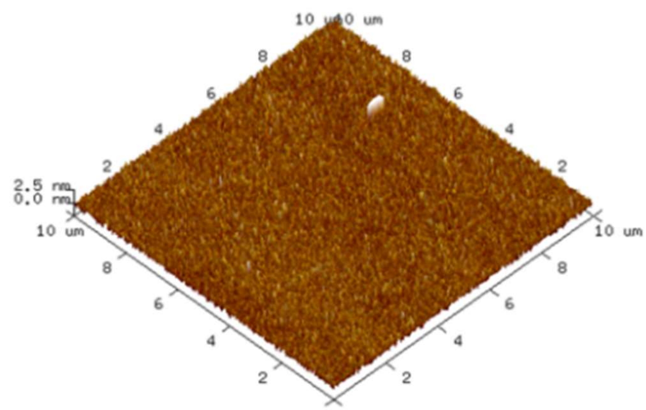
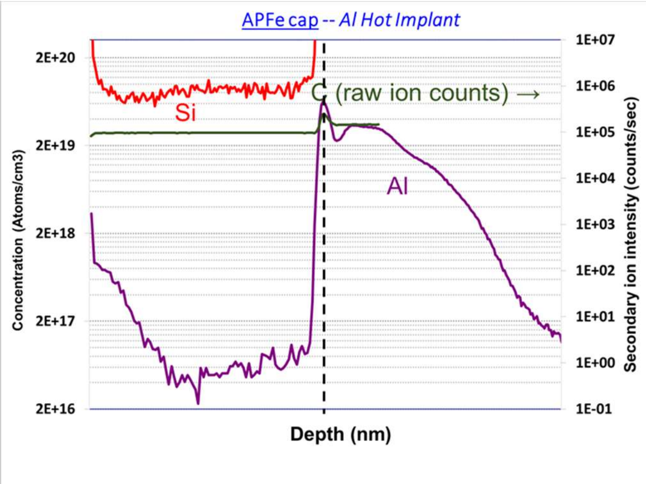


Figure 55 AFM of N- / Al- implanted surface post 1700°C - 30 min post APF cap strip

SIMS analysis suggests that APF can better prevent Al & P dopant out-diffusion (Fig. 7: Al- case). This can help reducin electrical parameter variation of devices and improve production yield, as well as it may enable next-generation devices requiring an extremely tight doping control, such as SiC super-junctions.



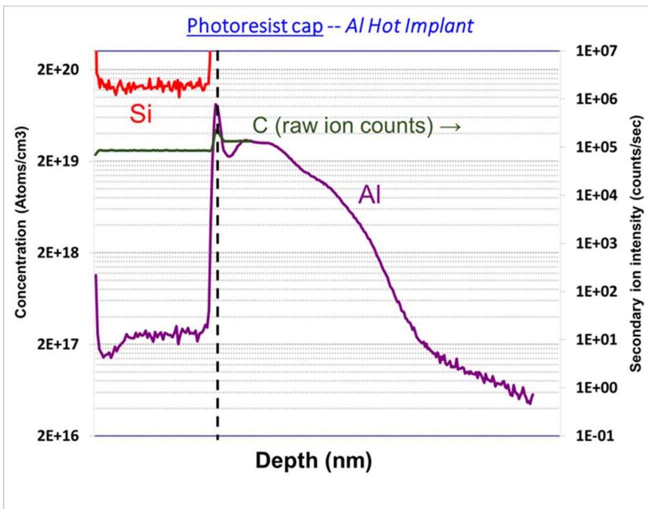


Figure 6 SIMS profiles (analysis with APF or PR cap still present) of Al- implanted and annealed at 1700°C - 30 min SiC wafers show lower Al- dopant out-diffusion in APF cap than in PR cap

Conclusions

We have shown how APF can help solvin several SiC processing issues and thus it represents a viable solution in high-volume manufacturing of high-voltage power SiC devices with superior performance and a tighter processing control.

References

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Acronyms

APF: Advanced Patterning Film
PR: Photo-resist
SiC: Silicon Carbide
SiO2: Silicon DiOxide
AFM: Atomic Force Microscope
GOX: Gate Oxide
RBS: Rutherford Back-Scattering
XRR: X-Ray Reflectivity