Hydrogen Poisoning Mitigation in GaN Systems HEMT Devices White Paper - by James F. Salzman

It is well know that hydrogen plays an important role in semiconductor manufacturing processes, and is used to stabilize gain (hFE) in bipolar transistors. It is also known to cause CMOS Vt shifts by interface state generation under radiation exposure and is the root cause of enhanced low-dose rate sensitivity (ELDRS) in bipolar transistors. Hydrogen can become trapped in interlevel dielectric oxides during the manufacturing and passivation process. This trapped hydrogen can become mobile (ionic) during ionizing radiation exposure leading to interface state generation. It is also know that mobile hydrogen is a main contributor to negative-bias temperature instability (NBTI) and other semiconductor parametric shifts. Hydrogen is often trapped in interlevel oxides during the packaging process, leading to additional available molecular hydrogen, which can become ionized with ionizing radiation exposure. There are many papers published on this subject in IEEE NSREC. One example is, "The Impact of Hydrogen Contamination on the Total Dose Response of Linear Bipolar Microcircuits" by Philippe C. Adell and "The Effects of Hydrogen in Hermetically Sealed Packages on the Total Dose and Dose Rate Response of Bipolar Linear Circuits" - Ronald L. Pease*,*

Nitride passivation, being composed of silane and ammonia, is a major contributor to ELDRS in bipolar technology. Nitride passivation is produced using ammonia NH_3, + silane SiH_4 where 11 hydrogen atoms are released in the formation of a single molecule of Si_3NH_4 (nitride) passivation.
One approach used by several manufactures to improve the ELDRS response of their space products is the use of Tetraethylorthosilicate (TEOS), low-temperature oxide (LTO), or phosphosilicate glass (PSG) as a passivation thereby avoiding the additional hydrogen generation by nitride formation. However, these ELDRS improved products in die form become vulnerable to hydrogen exposure becoming ELDRS again if packaged in ceramic modules with hydrogen generating components or during the module packaging process itself where these "soft" die can become exposed to hydrogen. Also, the use of materials, other than nitride passivation in semiconductor devices, can cause glassification integrity (GLIT) failure, especially with TEOS and LTO passivation the use of which is common in space semiconductor products. During the manufacturing process, high temperature bakes can be used to minimize trapped hydrogen and "set" overall device parameters.

As mentioned above, the formation of nitride generates a lot of hydrogen in the manufacturing process. However, it has been found that nitride is also a hydrogen blocker and can be used to block effects in semiconductors typically affected by hydrogen and radiation exposure. This effect is discussed in the two reference documents mentioned above.

The GaN system high electron-mobility transistor (HEMT) uses a unique Island-gate, vs typical metal-insulator-semiconductor (MIS) gate structure. This allows an addition of a thin nitride layer to block mobile hydrogen from potentially entering the active device AlGaN & GaN buffer layers and

Schottky-gate region. This layer is added to a thin SiO_2 layer directly over the AlGaN layer. Any trapped hydrogen in the interlevel dielectric layers that become mobile are blocked by this layer. The devices do have a Nitride passivation that makes these devices resistant to hydrogen contaminated packaging approaches and also is robust in regard to passivation ruggedness unlike die passivated with TEOS or LTO.

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