Effects of Hydrogen on Hermetically Packaged GaAs MMICs

In hermetically sealed package, effects of residual hydrogen on HEMT devices evolving from a package and trapped within the package have been well characterized both at Northrop Grumman Space Technology (NGST) and at other GaAs production facilities. The mechanism is that hydrogen diffuses through the passivation layer (SiN in this case) and then reacts with Pt metal in the gate and causes a positive threshold voltage shift in the device, often 300-500 mV as shown in Figure 1. Key parameters that impact the time before the hydrogen effect takes place are nitride thickness, hydrogen concentration and temperature (Ea ~ 0.6 or 0.7 eV).

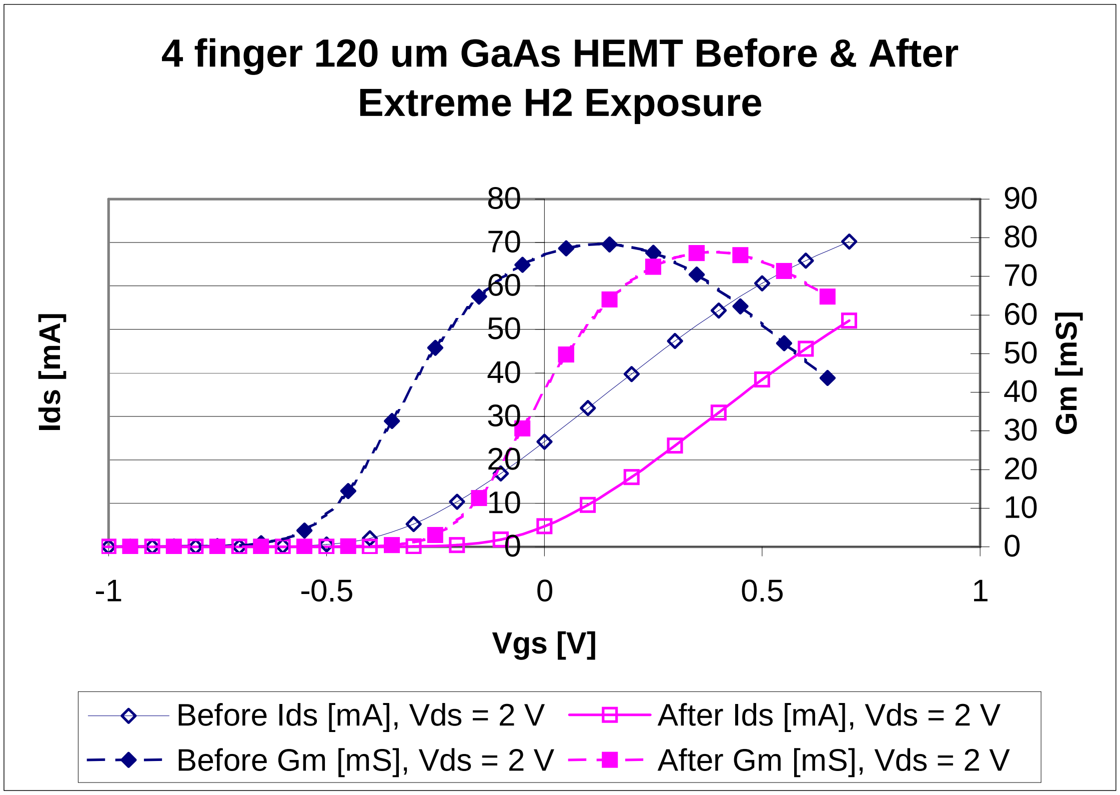

Figure 1. DC IV of GaAs HEMT before and after hydrogen effect. Device was subjected to more than 100000 ppm hydrogen at 200C ambient temperature for more than 100 hours.

NGST HEMT devices employ Pt metal in the gate and can be susceptible to this hydrogen effect. Most current commercial applications do not involve hermetically sealed packages due to their high cost. However, if a hermetic package is desired, the hydrogen level must be kept below 100 ppm and preferably below 10 ppm to ensure reliable operation of NGST MMICs over 10 years at typical commercial use conditions.

A plot of projected MTTF at typical maximum baseplate temperature of 60C is shown in Figure 2 as a function of residual hydrogen concentration. These were based on accelerated hydrogen concentration tests conducted on NGST's GaAs HEMT amplifiers. It should be noted that the hydrogen effect impacts GaAs MMICs operating as an active three terminal device only. Gm and linear gain are the most sensitive to the hydrogen effect while saturated amplifiers are less sensitive to the hydrogen effect.

To achieve <10 ppm hydrogen levels, hydrogen getters have been developed over the past 10 years and adapted to assembly packages. NGST has used both commercially available getters and custom developed package getters (NGST proprietary) and has demonstrated <10 ppm levels.

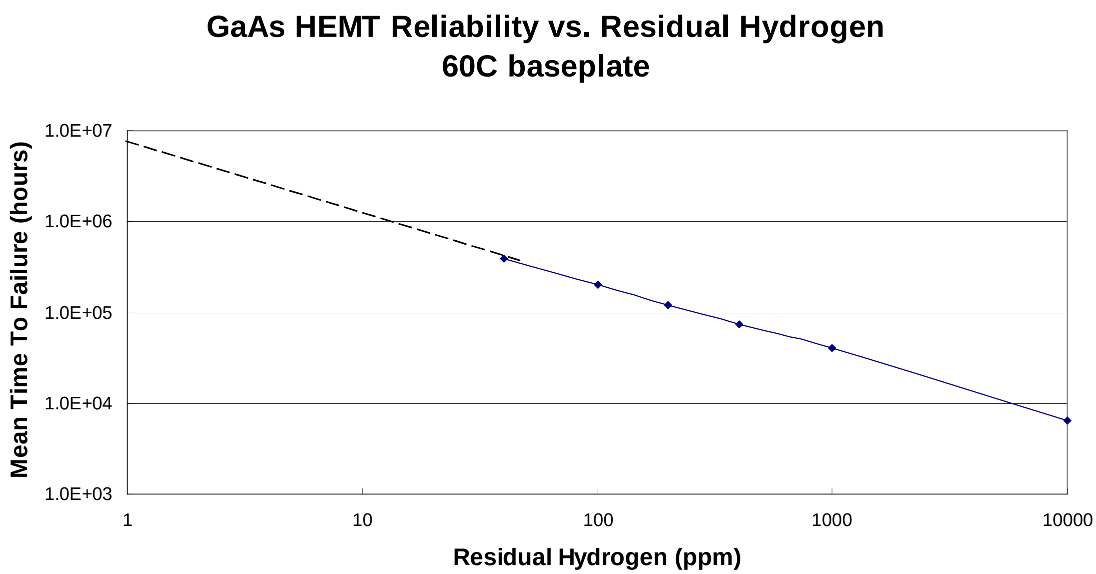

Figure 2. GaAs HEMT Reliability vs. Residual Hydrogen at 60C baseplate temperature. Note that baseplate temperature is used instead of junction temperature for reliability model of H2 effect

Examples of commercially available getters can be found through the following vendors:

1) Cookson Electronics: http://www.cooksonsemi.com - H2-3000 getter film
2) Dietz and Associates: http://www.gdietz.com - hydrogen getter

Three good references on hydrogen effect on GaAs devices are:

1) http://nppp.jpl.nasa.gov/mmic/9-VII.pdf A. Immorlica et. al., "Hydrogen Poisoning of GaAs MMICs in Hermetic Packages" a JPL publication
2) http://www.gaasmantech.org/digest/1999/PDF/64.pdf A. Immorlica et. al., " Practical Approaches to Remediation of Hydrogen Poisoning in GaAs Devices" 1999 GaAs MANTECH Proceedings, Vancouver, B.C. Canada, May 1999.
3) http://www.cooksonsemi.com.tech art/pdfs/Article_Final%20report.pdf "Sections I - III Hydrogen Effects on GaAs Microwave Semiconductors", Report sponsored by JEDEC Committee on GaAs, Oct 1997, 41 pages.

Additional methodologies are available to mitigate hydrogen effect in GaAs FET devices. These include package bakeouts at high temperature which have been shown to reduce hydrogen levels to 200-1000 ppm level, purposely creating a controlled leak that will allow the hydrogen to escape and current regulation accounting for the threshold shift. They can be used to further mitigate risk, but are not as effective as a hydrogen getter. The use of hydrogen getters in hermetically sealed packages is accepted as general practice in the military hardware domain. NGST employs a custom proprietary hydrogen getter and a package bakeout step for all of its space flight hardware which is hermetically sealed.
It should be noted that although NGST's GaAs HBTs also employ Pt metal, no evidence of device degradation due to hydrogen has been observed. The hydrogen effect both observed at NGST and in literature solely impacts field effect transistors (HEMT, HFET, MESFET, FET).