HYDROGEN DEGRADATION OF GaAs MMICs AND HYDROGEN EVOLUTION IN THE HERMETIC PACKAGE

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ABSTRACT

An investigation of hydrogen degradation of GaAs MMICs (MESFET, PHEMT and HBT) was conducted to determine the threshold hydrogen concentration for spacecraft application. The maximum hydrogen in the hermetic package is found to be 0.6 torr (based on 10 year mission at ambient temperature of 125°C). Hydrogen evolution in hermetic package is also studied to determine the source of hydrogen and to minimize its level in the package. Both studies demonstrate the high reliability of hermetic A40 (Al/Si) and Kovar (Fe/Ni/Co) packages for spacecraft applications.

INTRODUCTION

Hydrogen degradation of GaAs MMICs in a hermetic package is of great concern for space application because the reported activation energy for failure is much lower (0.4-0.9 eV)[1-3] than the normal thermal aging mechanism (1.6-1.8 eV).[4,5] In the past few years, degradation of GaAs devices due to hydrogen has been extensively studied by many GaAs manufacturers. However, sensitivity of GaAs MMICs to hydrogen degradation, and the amount of hydrogen released from the hermetic package have not been quantified.

In a previous study, we assessed the effect of hydrogen on MESFET, HBT, and PHEMT MMICs. The accelerated lifetest was conducted under 3% and 10% hydrogen at 125° and 200°C. A 0.5μm MESFET distributed amplifier was used as the standard evaluation circuit (SEC) for MESFET MMICs. The high temperature storage lifetest was conducted under 10% hydrogen and the failure criterion was 20% degradation in the drain current (Ids). The MTFs were found to be 200 and 1000 hours at 200° and 125°C, respectively, and activation energy was determined to be 0.37 eV. The SEC for HBT was a 3X10μm logamp (SLDA). The unbiased accelerated lifetest was conducted under 3% and 10% hydrogen at 125° and 200°C. Although a slight shift in Vec offset occurred, no obvious degradation in logamp functionality was observed. The effect of hydrogen on low noise PHEMT MMIC was also investigated using Ka-band two stage balanced amplifier (35BLNA) as SEC. Preliminary test results indicated that PHEMT is as sensitive to hydrogen as is MESFET. The drain current degraded as much as 30%, then recovered as much as 90% under nitrogen purge at 200°C. On the basis of these investigations, MESFET and PHEMT were found to degrade RF performance significantly whereas HBT showed no change in functionality, only a nominal change in the DC parameter.

This paper describes the effect of hydrogen concentration on LN PHEMT MMICs and hydrogen evolution in hermetic packages. It also discusses various mitigation approaches to this problem for hermetic Integrated Microwave Assemblies (IMAs) for spacecraft electronics. Two parallel investigations were performed: **1)** effect of hydrogen concentration and temperature on SEC for LN PHEMT (Ka-band PHEMT MMICs), **2)** hydrogen evolution from plated Ni/Au on Kovar and A40 by Residual Gas Analysis (RGA).

HYDROGEN SENSITIVITY STUDY of LN PHEMT MMICs

The SEC for the low noise HEMT is a 2-stage balanced amplifier (35BLNA, four-100μm T-gate HEMTs) with 2500Å silicon nitride passivation. This SEC has been qualified as low noise PHEMT MMICs through three temperature lifetests.[4] The SECs were mounted on 16 pin DIP package using AuSn eutectic. The accelerated lifetest was conducted both with and without dc bias in 1% (P_{H_2}=7.6 torr) and 3% (P_{H_2}=22.8 torr) hydrogen at 125° and 200°C ambient in a bell jar with a constant flow of premixed gases (hydrogen/nitrogen). The lifetest was performed at a Vds of 2.5 volts with constant gate voltage throughout the lifetest. Six MMICs for dc bias and two MMICs for unbias in each temperature and in H_2 concentration were tested. DC and RF parameters were evaluated at room temperature using HP 4145 and HP 8510C. The failure criteria was 20% degradation in Ids and 1dB in gain.

Figures 1 and 2 show Ids vs time plots of constant stress lifetest at 125° and 200°C in 3% hydrogen. In contrast to a gradual degradation typically seen in thermal aging, stepwise

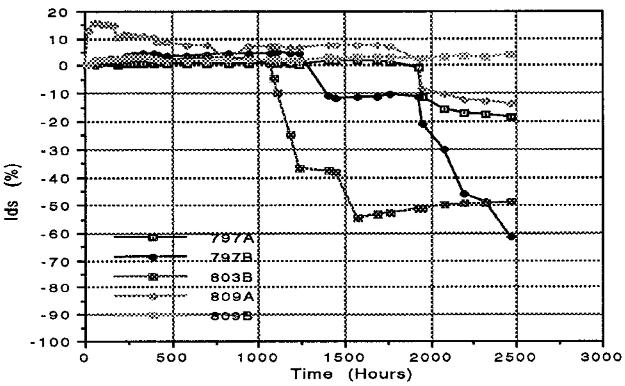

Figure 1. Change of Ids of LN PHEMT MMICs in DC Lifetest

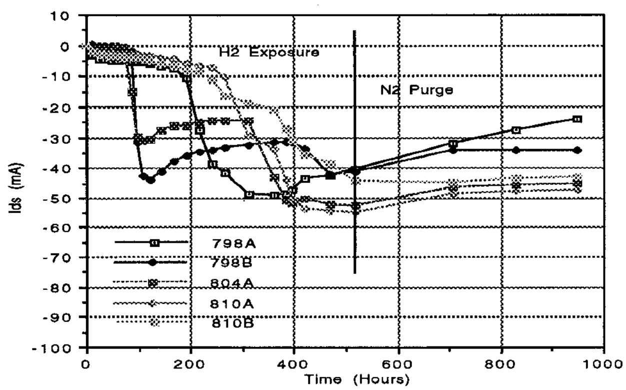

Figure 2. Change of Ids of LN PHEMT MMICs in DC Lifetest at 200°C in 3% H2

degradation of Ids was observed, suggesting that the four HEMT devices in the MMICs failed sequentially. The lognormal plots of constant stress lifetests in hydrogen atmosphere with ΔIds of -20% are shown in Figure 3. The activation

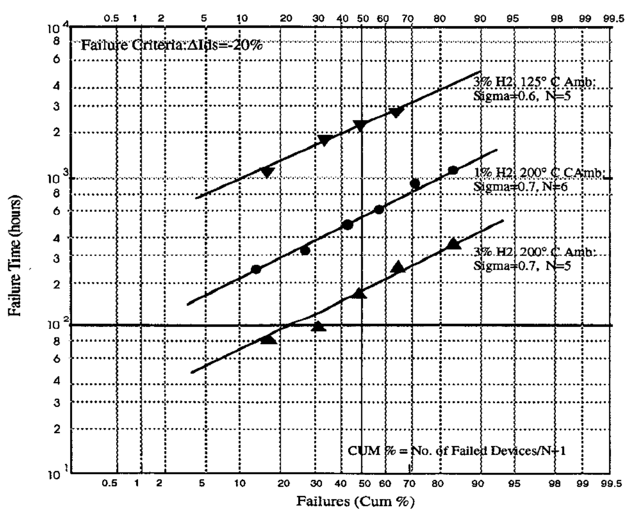

Figure 3. Lognormal Distribution of LN PHEMT MMICS, CS LT Under H2 Atmoshpere

energy was found to be 0.52 eV in 3% hydrogen from Arrhenius plot (see Figure 4), slightly higher than that of MESFET. The MTFs vs hydrogen partial pressure (or H_2%) is plotted in

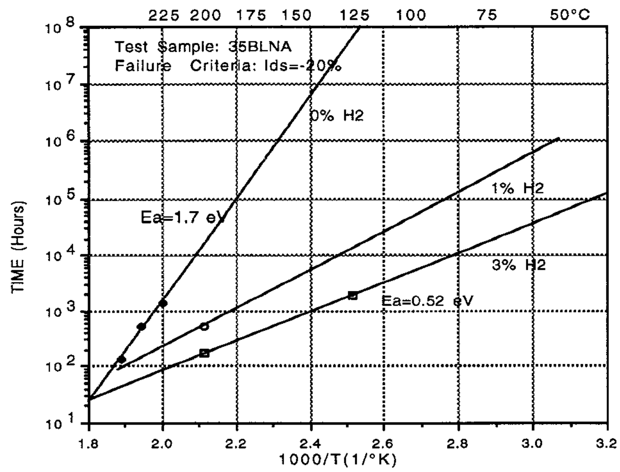

Figure 4. Arrhenius Plot of CSLT under 0/1/3% Hydrogen

Figure 5. It is clearly seen that the MTFs are a function of hydrogen partial pressure and temperature. Based on these plots, it is possible to project a threshold of hydrogen partial pressure in a hermetic package to meet a mission life of 20

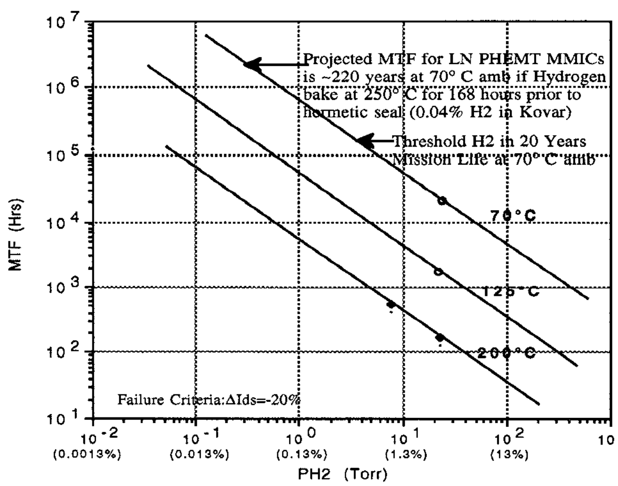

Figure 5. MTF vs PH2 of Ka-band LN PHEMT MMICs

years for low noise HEMT MMICs. In the worst case for LNA (70°C ambient, normally less than 50°C), the maximum PH_2 allowed in the package is projected to be 3.5 torr (~0.46% H_2). If the required ambient temperature is 125°C, the threshold of hydrogen content becomes 0.3 torr (0.04% H_2).

Figure 6 compares the rate of gain degradation under constant Vg and under constant Ids. It is seen that the time of failure-(-1dB) is much higher under constant Ids, indicating that the RF performance degradation by hydrogen can be minimized

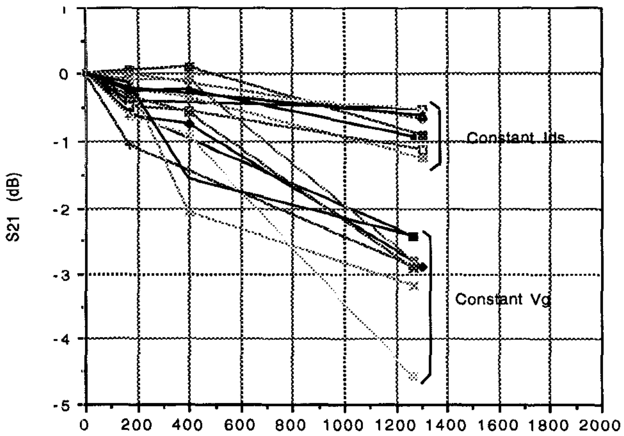

Figure 6. Linear Gain Degradation of LN PHEMT MMICs in CS LT at 200° C Amb under 1% H2

even if 1% hydrogen is present in the hermetic package if constant drain current is kept.

Changes of DC/RF parameters (a large shift of Vg and decrease in gain) indicated that hydrogen exposure neutralized carrier concentration in the channel and also caused hydride formation in the gate metal (TiH_4). These findings are consistent with literature results.[2,6] As hydrogen concentration decreases, the activation energy increases and the failure mechanism of device degradation at low hydrogen level is dominated by normal aging mechanism such as gate sinking, and ohmic metal degradation.

HYDROGEN EVOLUTION from PACKAGING MATERIALS

Preliminary investigation showed that the major source of hydrogen in a hermetic package is from plated Ni in the package housing, as illustrated in Figure 7 (the rate of H_2 evolution from Eccosorb will be approximately 16 times lower at 125°C because of high activation energy of 1.6 eV,[7] thus hydrogen build-up by Eccosorb will be minimal). Kovar was electroplated with nickel sulfamate per QQ-N-290; A40 was electroless plated with nickel-phosphorus per MIL-C-26074. To minimize hydrogen evolution in the hermetic package, we assessed bake-out conditions at 250° and 400°C for up to 8 weeks. Ni/Au plated test specimens placed in aluminum housings were baked out in a nitrogen furnace, and subsequently laser welded for storage lifetest. Figures 8a and 8b show hydrogen contents vs storage lifetest time for both Kovar and A40. In both unbaked and baked A40, hydrogen reached a constant level after 300 hours indicating all hydrogen in Ni being baked out. In contrast, plated Kovar continued to evolve hydrogen, indicating that the hydro-

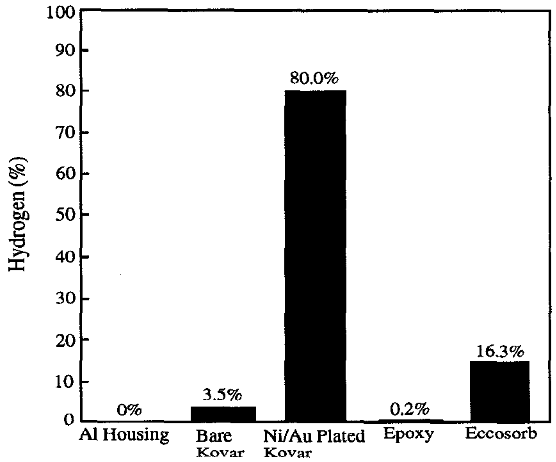

Figure 7. Normalized Evolved Hydrogen from Unbaked Packaging Materials, Storage Lifetested at 150° C for 336 hours

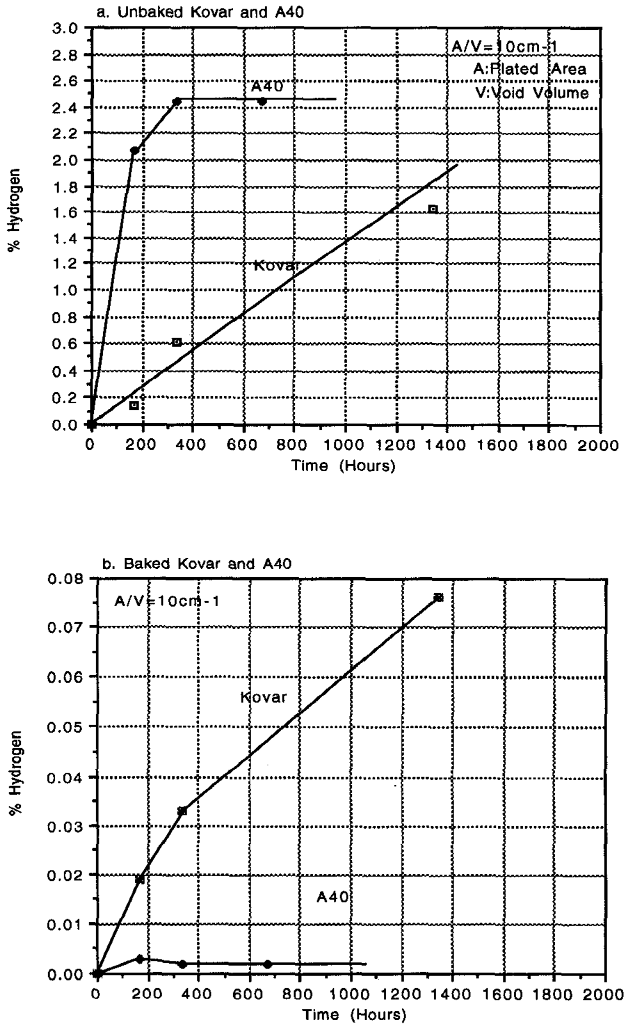

Figure 8. Hydrogen Evolution from Plated Ni/Au on Kovar and A40 during Storage LT at 150° C

gen in plated Ni diffuses into Kovar at much higher rate than into aluminum. The hydrogen bake-out is considerably more beneficial for A40 and other aluminum-based alloy than Kovar and iron based alloys.

It is well known that the temperature must be higher than 350°C to bake-out hydrogen from iron-based alloy. However, wire bondability degrades as bake-out temperature increases. The optimization for the bake out is based on the amount of evolved hydrogen and wire bondability. The wire bondability criteria was a destructive bond-pull test of (average -3 sigma)>7g. We optimized the hydrogen bake-out at 250°C for 168 hours for Ni/Au plated Kovar and A40 housings based on the residual hydrogen contents measured by RGA and wire bondability. For Kovar housings, the evolved hydrogen was reduced from 0.6% to 0.0033% with a post-plating hydrogen bake. For A40 housings, the hydrogen content (0.002% after the hydrogen bake) is significantly lower than that of Kovar.

ASSESSMENT OF LN PHEMT MMICs RELIABILITY IN THE HERMETIC PACKAGE

From both studies, we can project MTF of LN PHEMT MMICs at operating condition in spacecraft applications. The amount of hydrogen evolution during burn-in at 125°C and temperature cycling (Tmax=125°C) can be estimated assuming activation energy of hydrogen diffusion from Ni is 0.4 eV. In addition, continuous evolution of hydrogen at ambient (~70°C) for 20 years can also be estimated. The total maximum hydrogen content is estimated to be 0.04% (0.3 torr) and 0.004% (0.03 torr) for baked Kovar and A40, respectively. From Figure 6, the MTFs of LN PHEMT MMICs at 70°C ambient are 2×10^6 hours (228 yrs) and 2×10^7 hours (>2,200 yrs) for Kovar and A40, respectively.

MITIGATION TO HYDROGEN DEGRADATION

A three pronged approach has been recommended to mitigate hydrogen degradation; **1)** eliminate hydrogen source, **2)** bake out hydrogen prior to seal, **3)** implement constant Ids. The first one can be implemented by reducing hydrogen evolution during Ni plating and not to use organic Eccosorb, the second is discussed, the third can be implemented by incorporating constant drain current scheme to alleviate hydrogen degradation. Another mitigation is to use hydrogen getter; there are many types of commercially available hydrogen getter and it can be implemented to reduce the hydrogen contents in hermetic package.

CONCLUSIONS

GaAs based MMICs with Ti/Pt/Au gate metal is susceptible to hydrogen-induced RF performance degradation. The activation energy is found to be 0.52 eV at 22.8 torr (3%) hydrogen. The primary source of hydrogen is from plated Ni in the package housing. Hydrogen bake-out prior to laser weld can reduce hydrogen evolution, particularly for aluminum-based alloys. Bake-out conditions have been developed to ensure excellent reliability of IMAs against hydrogen-induced degradation in hermetic A40 and Kovar housings for spacecraft applications.

ACKNOWLEGEMENTS

The authors would like to thank R. Okamoto, D. Okazaki, and A. Grilli for setting up the lifetest system, device assembly, and performing lifetest and measurements. We also would like to thank Drs. E. Rezek, W. Bjorndahl and H.C. Yen for technical discussions and support.

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