VII. Hydrogen Poisoning of GaAs MMICs in Hermetic Packages

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Microwave packages and modules typically employ iron- and nickel-based alloys and plated layers that contain or use hydrogen in the manufacturing process. Usually, the hydrogen will outgas and not cause a problem, but in a hermetically sealed package, hydrogen can reach partial pressures as high as a few percent [1]. Hydrogen is known to cause degradation of some types of GaAs devices, and hydrogen-induced degradation has been reported over large ranges of hydrogen partial pressures, even down to a few hundred millitorr [2,3].

The degradation of GaAs MESFETs and PHEMTs in hydrogen atmospheres has commanded significant attention over the past several years [4]. The effect was first reported in MESFETs by Camp et al [5] in 1989, and has been observed more recently by others in MESFETs [6,7,8], PHEMTs [2,3,9], and InP HEMTs [10]. This is now a recognized industry-wide problem, particularly for devices incorporating Schottky barrier gates having Pt or Pd, which are widely used.

The poisoning of GaAs devices is manifested by a sudden and dramatic change in device electrical properties, which can occur after several hundred to several thousand hours of hydrogen exposure at elevated temperatures. This is illustrated in Figure 9-24, which shows the percent change in pinch-off voltage of MESFETs over 700 hours [6]. The time for onset of this degradation is dependent on the device technology, which varies greatly among suppliers, and the partial pressure of hydrogen to which the device is exposed.

Several degradation mechanisms have been proposed. Camp et. al. [5] suggested a compensation model in which silicon atoms, a typical n-type dopant in GaAs, are neutralized by hydrogen, causing a loss of channel conductivity and current. Others have proposed models in which the Schottky barrier contact potential is changed, causing a shift in the device pinch-off voltage and transfer characteristics. The latter model appears to be particularly appropriate to PHEMTs. Regardless of the model, almost all reported degradation has been associated with devices having refractory metal gates containing Pt or Pd. It has been theorized that these commonly used gate metals act as catalysts, converting molecular hydrogen to atomic hydrogen, greatly enhancing the degradation reactions. It is interesting to note that there has been no reported degradation for non-refractory gates, such as those made of Al.

The activation energy associated with hydrogen poisoning has been reported to be as low as 0.4 eV [2,7]. This is relatively low compared to the 1.2- to 1.8-eV reported mechanisms in GaAs. Thus, care must be exercised when interpreting or extrapolating accelerated life-test data taken at high temperatures.

A number of options for dealing with this problem have been suggested in the literature. These include

(1) Elimination or minimization of the hydrogen source.

(2) Changing device technology.

(3) Use of an in-package hydrogen getter.

(4) Circuit compensation for device electrical changes.

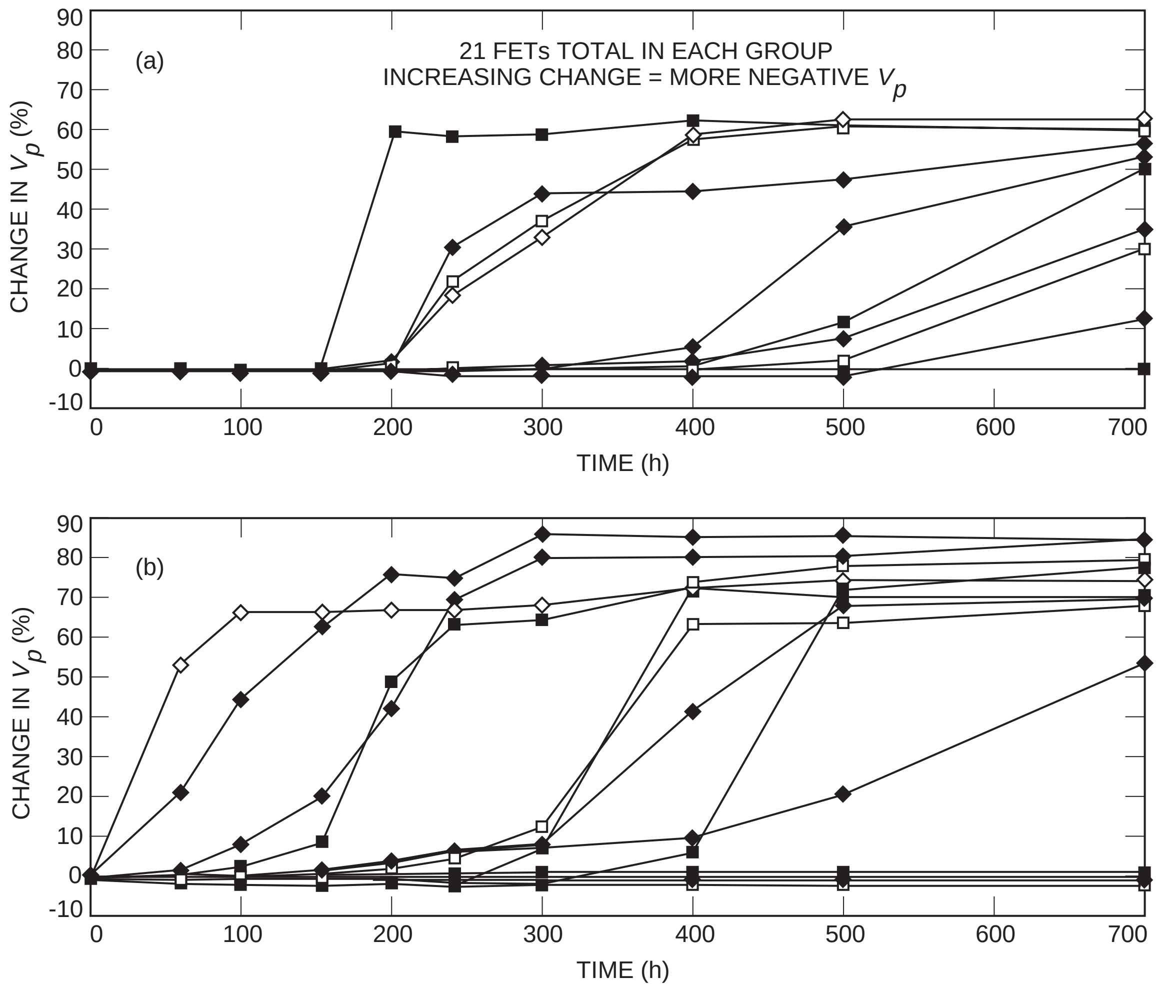

Figure 9-24. Percent change in pinch-off voltage for (a) palladium gate and (b) platinum gate FETs in high hydrogen at 225°C. (From [6].)

Hydrogen is present in many of the common packaging materials used in the microwave industry today. Materials known to outgas hydrogen include Kovar™, Ni and Au plating, ferrite circulators, other iron based materials, and even some RF-absorber materials used for circuit stabilization. Hydrogen can be reduced to some extent by vacuum baking the package parts; however, care must be taken to not impact other package properties, such as solderability. Alternatively, hydrogen can be reduced by the judicious choice of materials that have low hydrogen solubility, such as aluminum, but it is difficult to completely eliminate all hydrogen-bearing materials. (Note that non-hermetic packaging does not pose a poisoning threat, as the leak rate of hydrogen would be sufficient to keep concentrations down to safe levels).

A second approach modifies the device technology with the use of a gate metal that is hydrogen insensitive. As mentioned above, aluminum is one such candidate, and GaAs laboratories are working on other hydrogen-insensitive schemes. While this may be an adequate approach for a relatively new technology such as InP HEMTs, changing processes in relatively mature technologies, which have a heritage of use and field experience, is not usually favorable.

A third approach uses an in-package hydrogen getter to reduce hydrogen partial pressures to safe levels. The use of getters in semiconductor packaging for substances such as water vapor and particulates is common, and there are several commercial as well as proprietary hydrogen getters that can be employed in microwave packaging. To be effective, one must determine the sensitivity of the device technology to hydrogen, and ensure that the getter has adequate capacity to maintain a safe hydrogen partial pressure during the expected mission lifetime of the device.

Finally, the hydrogen sensitivity problem might be circumvented by appropriate circuit design. One generally defines device "failure" as a given percentage change in one or several device parameters. Depending on the circuit design and application, this change may or may not cause failure of the device to meet its intended function. Alternatively, it is sometimes possible to re-bias the circuits to recover the initial conditions, if the device change is caused by a shift in parameters. The nature of the device changes would, of course, have to be well understood.

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