Analysis on Influence of Hydrogen Content Exceeding Standard in GaAs Device

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Abstract. Aiming at the problem of hydrogen content exceeding the standard in GaAs device, the influence mechanism of hydrogen content exceeding the standard on the device is analyzed, the failure model of hydrogen content exceeding the standard in GaAs device in engineering is given, the source of hydrogen is analyzed, and the protective measures of hydrogen content exceeding the standard are given. It is of certain guiding significance for future engineering application.

1. Introduction

With the increasingly fierce competition in aerospace, equipment and information fields, high-tech competition is not only reflected in the advancement of single performance index, but also in the competition of device life and reliability. At present, a large number of studies can prove that the composition and content of gas in sealing components (various packaging structures) will have a significant impact on reliability, such as water vapor will accelerate circuit aging and corrosion, oxygen will cause oxidation failure, etc. Among them, hydrogen is a component that needs to be focused on: it has a small atomic radius and is easy to diffuse into the material as an atomic state, so it is relatively difficult to remove it. The damage to GaAs devices is very obvious, and its role in the packaging structure is also associated with multiple types of failures.

GaAs device has gone through nearly 60 years of development since its appearance, and has gone through three typical stages in terms of the evolution of mainstream gate metal technology. The first-generation GaAs device uses Al as the gate metal, which is vulnerable to corrosion by water vapor due to its insufficient resistance to electrical migration. The second-generation GaAs device uses Ti/Au as the gate metal, which leads to the lack of long-term reliability at high temperatures due to the diffusion of Au to GaAs and the formation of gate metal sink. The third generation GaAs device uses Ti/Pt/Au as the gate metal. Due to the high melting point and large atomic mass of Pt, it can prevent downward diffusion of Au. Moreover, Pt is added into the gate metal. Because of its high temperature resistance, strong resistance to electrical migration ability and strong diffusion resistance, Pt has become the mainstream gate metal at present.

2. Influence of Hydrogen Content Exceeding Standard on Device

The performance, parameter stability and reliability of GaAs microwave devices may be seriously affected if hydrogen content in metal encapsulated microwave components (modules) exceeds a certain value.
The typical structure of GaAs devices is shown in Figure 1. If there is H2 in the metal encapsulated microwave components, the H2 molecule is small and can penetrate most materials, including SiN passivation layer commonly used in GaAs devices. Meanwhile, H2 molecule is also active and can react with a variety of materials. Generally speaking, the influence of excessive hydrogen content in metal encapsulated microwave components on devices is as follows.

2.1. React with Oxide to Form Water Vapor
In the gold-plated structure, the nickel layer at the bottom will diffuse to the surface and form nickel oxide. When H2 meets the nickel oxide, it is easy to react with it and generate water vapor. Too much water vapor will aggravate the corrosion of the circuit and eventually cause circuit failure.

2.2. Hydrogen-induced Cracking
Hydrogen in metal-encapsulated microwave components is easy to generate and accumulate in the gap, and reacts with oxide to generate water vapor. This part of water vapor accumulates in the gap, forming local high pressure. When the pressure reaches a certain value and exceeds the damage strength, cracks will occur, and micro-cracks will gradually expand, which will cause hidden dangers to the reliability of devices.

2.3. Piezoelectric Effect Caused by Hydrogenation
When hydrogen passes through the passivation layer and reaches the gate metal, hydrogen atom is generated under the catalysis of Pt, and the hydrogen atom reacts with Ti to form the hydride of Ti, thus expanding in volume. The gate is subjected to compressive stress, while the underlying heterostructure is subjected to tensile stress. Due to the piezoelectric effect, the bound charge is generated in the vertical direction of the force after the deformation of the crystal, and the piezoelectric polarization charge leads to the decrease of the threshold voltage.

2.4. Semiconductor Function Degradation Caused by Hydrogen
After passing through the passivation layer, H2 will also reach the channel of GaAs device and react with the channel semiconductor, so as to inhibit the donor in the channel and reduce the concentration of channel carriers, thus causing performance degradation.

2.5. Changing the Schottky Barrier
Hydrogen atom enters into the interface between metal gate and semiconductor, that is, channel, which affects channel state, and then changes the Schottky barrier of metal gate and semiconductor. Leakage current will decrease under certain gate bias voltage.
3. Failure Model with Excessive Hydrogen Content
After passing through the passivation layer, H2 reaches the gate metal and channel of GaAs device and reacts with the gate metal and channel semiconductor, resulting in the change of electrical properties of GaAs device. Generally speaking, there are three main failure models.

3.1. Compensation Model
As H molecules are very small, they can penetrate the passivation layer to reach the surface of the device, and then Pt in Ti/Pt/Au structure metal is catalyzed to decompose into H atoms with high activity, which combine with Si donor impurities in the channel to form Si-H. In other words, the donor impurities are neutralized, and the two-dimensional electron gas concentration in the channel is reduced, leading to the degradation of device performance.

3.2. Schottky Barrier Model Influenced by H Molecule
H molecules penetrate the passivation layer to reach the surface of the device, and then continue to diffuse into the GaAs material, thereby affecting the built-in potential field of metal-semiconductor contact and changing the schottky barrier height (resulting in a lower barrier height). Due to the change of barrier height, the transport characteristics of tube core will be affected to a certain extent, but the range of change is small.

3.3. Reaction Model of Gate Metal with Hydrogen Atom/Molecule
The introduction process of hydrogen is illustrated by taking the cutting shell as an example. Figure 2 is the flow chart of cove shell production.

![Flow Chart of Cutting Shell Production](image)

**Figure 2.** Cutting shell production flow chart
Step1: Metal materials enter the furnace in the process of smelting. The ore, slag and water vapor in the air decompose into hydrogen gas at high temperature. At the same time, hydrogen gas is often used as reducing agent in the smelting process. Therefore, this process will lead to a large amount of hydrogen adsorption on the surface and deep inside the shell material, with the passage of time, hydrogen will continue to precipitate the sealed shell cavity.

Step2: A small amount of hydrogen may also be introduced into oil stains and other residues in this process;

Step3: Cleaning in the production process of the shell is generally under high temperature with acidic cleaning agent and organic cleaning agent, so as to introduce hydrogen ions and organic matter containing hydrogen elements

Step4: The annealing process is generally carried out under the protection of hydrogen atmosphere;

Step5 and 8: in order to ensure the quality of sintering and fusion sealing, hydrogen is usually introduced into the protective atmosphere of this process;

Step9: Nickel plating and electroplating is an electrochemical process. The shell is placed in an acidic electroplating solution and electroplating is carried out by adjusting the current. This process will introduce a large amount of hydrogen

4. Protective Measures Against Excessive Hydrogen Content

The protection measures of hydrogen content exceeding the standard are mainly from two aspects: on the one hand, from the source of hydrogen to control the introduction of hydrogen; on the other hand, from the failure mechanism to improve the reliability of the device itself.

Basically, the introduction of hydrogen is controlled by temperature release, adding hydrogen absorbing materials into the sealing structure, and using hydrogen-free materials as the packaging material system. Temperature release is when the product is baked for a long time at a certain temperature before it is finally sealed, allowing hydrogen to escape. This method is also mainly used for dehydrogenation of encapsulated enclosures. Adding hydrogen absorbing material is adding hydrogen absorbing material in the sealing structure, using hydrogen absorbing material efficiency is low, and will introduce new problems; However, it is still difficult to use materials without hydrogen in application, so the temperature release method is widely used at present, that is, hydrogen is spilled through high-temperature baking before packaging, so as to reduce the H2 content in GaAs microwave components.

Hydrogen from hydrogen content exceeds bid failure mechanism, the first through the passivation layer can react with metal gate and channel semiconductor, because H2 is way by diffusion through the passivation layer, so the average penetration time follows the diffusion equation, and the passivation layer thickness is E index relations, namely with the increase of passivation layer thickness, average penetrate the time according to the index law increases rapidly. Therefore, increasing the thickness of the passivation layer can effectively prolong the time for H2 to reach the gate metal and channel, thus improving the reliability of the product.

5. Conclusion

In this paper, the influence mechanism of hydrogen content exceeding the standard on GaAs device is discussed, and the failure model of hydrogen content exceeding the standard in engineering is given, and the source of hydrogen is analyzed, and the protective measures of hydrogen content exceeding the standard in GaAs device are given.

6. References

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