Gate Leakage Current of Power GaAs MESFET's at High Temperature

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Abstract

Increase of gate leakage current causes decrease of gain and increase of noise. In this paper, gate leakage current of GaAs MESEFTs' has been traced with different temperatures from 27℃ to 350℃ to obtain the zero voltage saturation current J_s which is critical to the temperature dependency of total current. From the results, thermal leakage current coefficient has been proposed to compensate for the total current due to the thermionic emission, tunneling, generation and/or hole injection.

Introduction

GaAs material has fast electron velocity and wide band gap energy which can operate at high frequency and high temperature for military systems and nuclear power industries. Normally silicon-based technologies dominate applications up to 150~200℃ while wide bandgap semiconductor such as GaAs can go beyond 250℃. It is because the wide band gap material has lower intrinsic carrier concentration as narrow band gap material.[1~3]

GaAs MESFET has therefore characteristics of the abrupt increase of gate leakage current at high temperatures. It causes decrease of gain and increase of noise. It is because the depletion layer could not block the carriers of high energy so that electrons move from semiconductor to metal through depletion layer at high temperatures.[4]

In this work, gate leakage current mechanism has been analyzed for GaAs MESFET with different temperatures ranging from 27℃ to 350℃.

From the results, it is proved that thermal stress gradually increases the gate leakage current at the same bias conditions and leads to the breakdown and failure mechanism which are critical in real applications.

Transport Behavior of Gate Leakage Current

The current transport in metal semiconductor contact has four possible processes. First could be a transport of electrons from the semiconductor over the potential barrier into the metal. Quantum-mechanical tunneling of electrons through the barrier would be the next available process. Recombination in the space-charge region and hole injection from the metal to the semiconductor would also be the possible transport mechanisms. Gate leakage current therefore consists of mainly themionic emission, tunneling, recombination-generation, and hole injection process. [5]

It is expected that the thermionic emission at the MS contact will dominate the current flow at relatively high temperatures. It is because increase of temperature will lead to the enhancement of energies of electrons. Therefore the number of active electrons crossing over potential barrier will increase and therefore Schottky barrier height will decrease. The total current then increase due to the thermionic emission as well as tunneling effect.

Gate current and coefficeint α

Gate leakage current density is given by thermionic emission

$$J_t = J_s\left[\exp\left(\frac{qV}{kT}\right) - 1\right] \qquad (1$$

where

$$J_s \equiv A^* T^2 \exp\left(-\frac{q\phi_{BN}}{kT}\right) \qquad (2$$

A* is effective Richardson constant which is a function of effective mass. Φ_{BN} is Schottky barrier height. Reverse saturation current density Js is total gate leakage current at reverse bias of MS junction. Js includes the component of thermionic emission and other processes. Reverse saturation current density Js has been obtained with different temperature by using extrapolation of current with biases. First, gate currents near the zero voltage are measured at each temperature. Second, extrapolation of measured data has been used to calculated the current at zero bias. Fig 1 shows measured saturation currents with different temperatures.

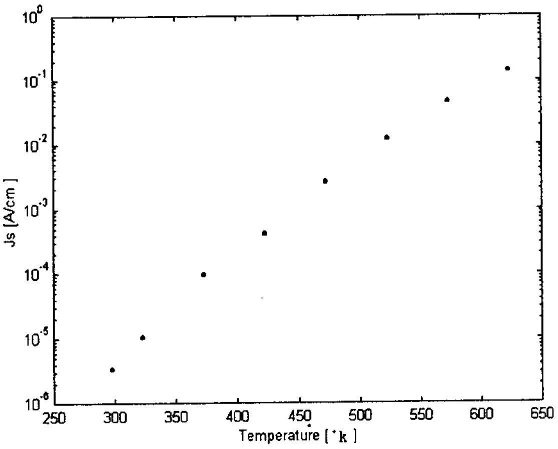

Fig 1 Saturation Current at zero voltage with different temperatures.

Tunneling and other process have much complex form of dependency with different temperatures. So it's analysis is very important but quantitative approach is too complex. We therefore propose simple analytical model. It's analysis based on thermionic emission form. And its expression includes other processes with expanded thermionic emission form.

Equation 2 shows a saturation current by thermionic emission theory. The α then represents saturation current except thermionic emission components and α can be obtained as equation 2.

$$J_s = A^* T^2 \exp\left(-\frac{q\phi_{BN}}{kT} + \alpha\right) \qquad (3$$

and

$$\alpha = \ln\frac{J_s}{A^* T^2} + \frac{q\phi_{BN}}{kT} \qquad (4$$

Effective Richardson constant A* is fuction of effective mass and effective mass is fuction of temperature. Therefore effective Richardson constant has been traced as a function of temperature. Figure 2 shows a relation of effective Richardson constant with temperatures.

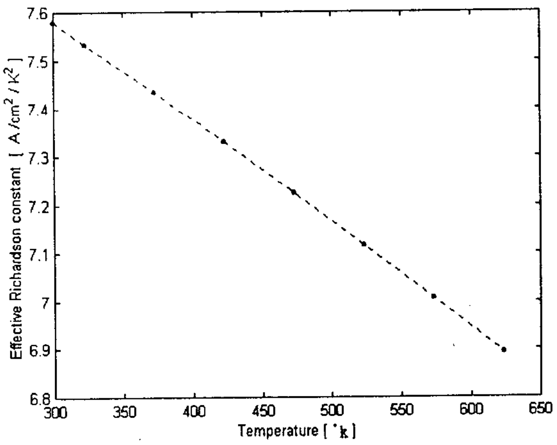

Fig 2 Effective Richardson constant with different temperature.

As temperature increases, Fermi energy level approaches to the intrinsic energy level. Schottky barrier height Φ_{BN} then decreases accordingly. Schottky barrier height Φ_{BN} could be measured by using I-V and C-V methods. Based on the linear dependency of Φ_{BN} at low temperatures up to room temperature, its tendency has been assumed to extract its linear dependency at high temperatures which could be found in the literatures. Fig 3 shows the dependency of Schottky barrier height with temperatures. From the results, α can be obtained by using equation 4 and expressed in equation 5.

Figure 4 depicts its dependency with temperatures.

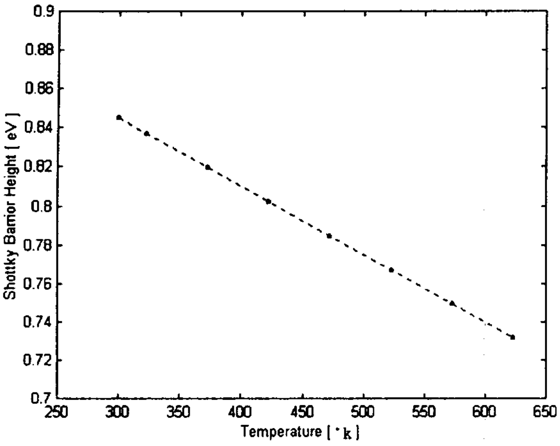

Fig 3 Schottky barrier height vs temperatures

Simple analytical expression could then be obtained to relate the saturation current Js with temperatures. α is obtained by using least mean square method and could be used later to tell the different behaviors of carrier transport with temperatures analytically beyond the thermionic emission over the barrier. Js then reads

$$J_s = A^* T^2 \exp\left(-\frac{q\phi_{BN}}{kT} + 1.61\times10^{-4}T^2 - 0.23T + 114.63 \right)$$

where

$$\alpha = 1.61\times10^{-4}T^2 - 0.23T + 114.63 \qquad (5$$

Figure 5 represents the analytical expression of α(solid line) vs calculated data.

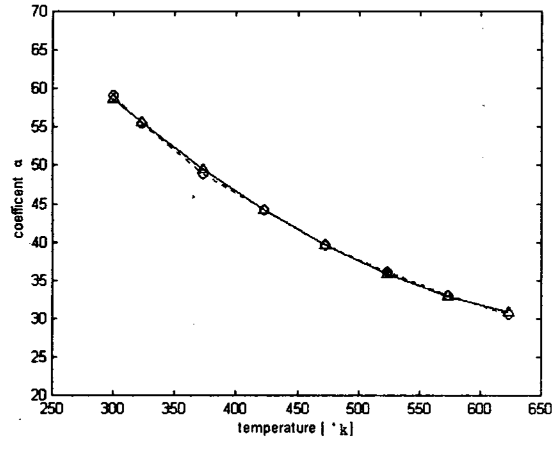

Fig 5 Coefficient α vs temperatures

Conclusion

Transport processes of gate leakage current can be explained by the conduction of electrons from the semiconductor over the potential barrier to the metal, tunneling of electrons through the barrier, recombination in the space-charge region, and hole injection from the metal to semiconductor. Their processes are too complex to form the dependencies of temperature. In this paper, simple analytical model which could explain the behavior of different carrier transport including thermionic emission has been proposed. This model is believed to include other processes such as tunneling, recombination and/or hole injection.

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