Extended Abstracts of the 1991 International Conference on Solid State Devices and Materials, Yokohama, 1991, pp. 293-295 **PC1-2**

# A New Forward-Bias Capacitance Spectroscopy for Characterization of Interface States in GaAs Schottky Gate

Chung Gyune Choi, Sheng San Li* and Kye Hwan Oh

Semiconductor R&D Center, Hyundai Electron. Ind. Co.
San 136-1, Bubal-Eub, Ichon-Kun, Kyungki-Do, Korea
*Dept. of Electrical Engineering, University of Florida, Gainesville, Florida 32611, USA

A new forward-bias capacitance spectroscopy has been developed using a bridge method for the characterization of interface states in the metal-semiconductor Schottky contacts. This method enables one to measure the forward-bias capacitance of a Al/n-GaAs Schottky diode of small area in the full range of low to high forward-bias conditions without any significant errors.

## 1. Introduction

The forward-bias capacitance measurement has been suggested as the nondestructive characterization technique for the investigation of interface states in the metal-semiconductor systems[1-5]. The principal idea of this approach is that sweeping the majority-carrier quasi-Fermi level throughout the bandgap of semiconductor by applying the DC forward-bias with an AC small-signal superimposed enables the modulations of charge states of interface defect levels. The theory for analysis of forward-bias capacitance spectroscopy is well-developed[1,2], but the problem arises from the absence of an appropriate forward-bias capacitance measurement system.

## 2. Development of an New Forward-Bias Capacitance Spectroscopy

If the AC/DC resistances of a Schottky diode under forward-bias condition are examined the relationship of $R_{dc}/R_{ac}$ is found to be equal to $qV_F/nkT$ ( >> 1 )normally. The I-V characteristics of a Schottky diode can be empirically expressed by

$$I = I_s[\exp(qV_F/nkT)-1] \quad (1)$$

or

$$I = I_s\exp(qV_F/nkT) \text{ for } V_F >> nkT/q \quad (2)$$

The DC bias of a Schottky diode is related with its DC resistance as

$$R_{dc} = V_F/I \quad (3)$$

If the imaginary part of the AC impedance of a Schottky diode is neglected, the AC resistance can be expressed by

$$R_{ac} = (dI/dV_F)^{-1} = nkT/qI = nkT/q \times R_{dc}/V_F \text{ for } V_F >> nkT/q \quad (4)$$

or

$$R_{dc}/R_{ac} >> 1 \text{ for } V_F >> nkT/q \quad (5)$$

Now one can conclude that even if $R_{ac}$ is balanced in the previous bridge system, the $R_{dc}$ can be unbalanced. This kinds of unbalanced voltage input into the differential preamplifier easily drives the lock-in amplifier into the overload or nonlinear regime such that the sensitivity of measurement system becomes instrumentally limited.

The prime concept of this method is to null out the AC in-phase component of a Schottky diode as well as the DC unbalance in a bridge circuit. If a resistor, of which value is close to $R_{ac}$ , is parallelly connected to a Schottky diode, then the overall DC resistance of a Schottky diode with a parallel resistor is very close to $R_{ac}$ . Thus the DC unbalance input into the preamplifier of the lock-in amplifier can be avoided. This means that one can concentrate on the adjustments of AC balances of a bridge circuit without overloading the lock-in amplifier and greatly increase the sensitivity of a forward-bias capacitance measurement system, especially in the high forward-bias condition.

The implementation of a new forward-bias capacitance spectroscopy employing the above strategy is shown in Fig. 1. This system consists of two identical resistors, one variable resistor, and a parallel resistor connected to a Schottky diode which is to be measured. A small signal is supplied from the built-in signal generator in the PAR 124A Lock-in Amp and is superimposed onto a DC forward-bias which is applied by the HP 6112A DC power supplier.

## 3. Results and Discussions

This accurate forward-bias capacitance spectroscoppy was applied to the Al/n-GaAs Schottky diode fabricated by the metal-organic chemical vapor deposition (MOCVD) technique. The forward-bias capacitance measurements were carried out at room temperature with changing the small-signal frequency from 2 to 20 Hz as shown in Fig,2. It clearly shows the variations of forward-bias capacitance, $C_{is}$, versus forward-bias in the low-frequency regime. During these measurements, there were no difficulties to measure the capacitance, especially in the high forware-bias conditions. The DC bias to a Schottky diode is the half of the total bias applied by the HP 6112A power supplier. Though the data points were not continuous, it was still very efficient to obtain the data points due to the easiness of adjustments of variable resistor without worrying about overloading the PAR 124A Lock-In Amp. In the previous measurement systems, there used to be significant measurement errors of forward-bias capacitances, especially with high forward-bias conditions. Because the conductance, G, is much larger than the reactance, $w$C, the measured forward-bias capacitance tends to follow the conductance values. In this measurements, there is no such an tendency at all. The density distribution of interface states versus energy can be obtained using the following equation as1,2,6)

$$dC_{is} = q/kT\ N_{iss}F(1-F)\ dE \tag{6}$$

where $N_{iss} = dN_{is}/dE$ and F = occupancy of $N_{iss}$ at E

The observed interface states of a Al/n-GaAs Schottky diode as shown in Fig. 3 are the continuous levels. The density distribution vs energy is the range of 1.95E12 to 2.33E13 $cm^{-2}eV^{-1}$ and its peak value is located at around 0.20 eV below the conduction band. Based on the observed data, no discrete defect levels and no narrow band of donor/acceptor states are found. Only the continuous interface states are observed as in the metal-oxide-semiconductor systems. From the theorectical models, the Fermi-level pinning can take place if the interface state density is over 1.0E14 $cm^{-2}eV^{-1}$. The observed data shows less than that but it shows quite interesting shape as in the theoretical model of metal-induced bandgap states (MIGS). Still further study is necessary to investigate the relationship between the physical parameters of interface states and the process variables such as surface treatments, annealing temperature, and metal deposition techniques.

## References

1] C. Barret, F. Chekir, and A. Vapille, J. Phys. C, 16(1983) 2421.

2) C. Barret and A. Vapille, J. Appl. Phys. 50(1979) 4217.

3) H. L. Evans, X. Wu, and E. S. Yang, Appl. Phys. Lett. 46(1985) 1151.

4) X. Wu, H. L. Evans, and E. S. Yang, Solid-State Electron. 31(1988) 167.

5) P. S. Ho, E. S. Yang, X. Wu, and H. L. Evans, Phys. Rev. Lett. 56(1986) 177.

6) C. Barret and A. Vapille, Solid-State Electron. 18(1975) 25.

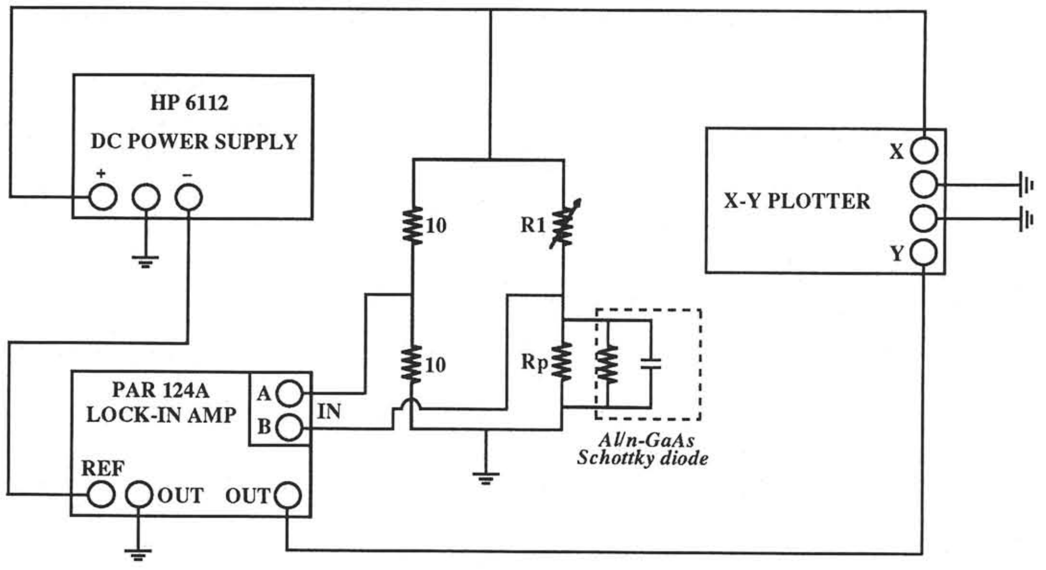


**Fig. 1 Schematic diagram of the accurate forward-bias capacitance spectroscopy**

Fig.2 Forward-bias Cap. of Al/n-GaAs Schottky diode

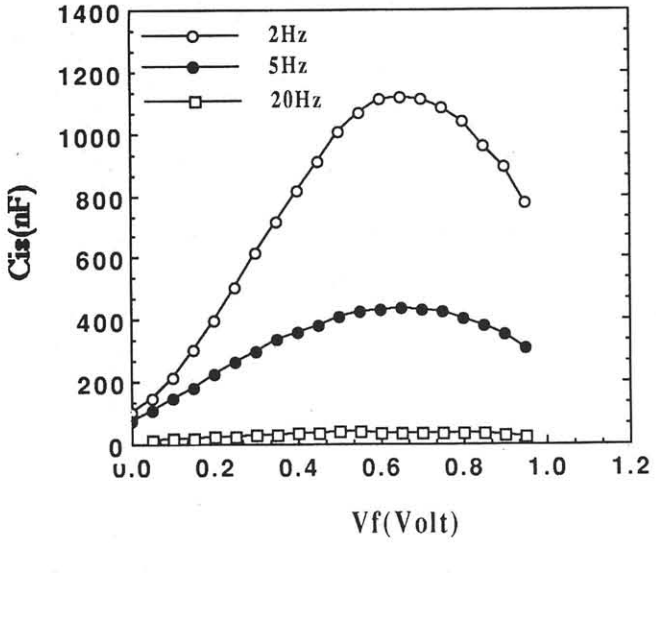


Fig.3 Density distribution of interface states vs. energy