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A METHOD TO OVERCOME THE PROBLEM OF SERIES RESISTANCE IN THE CA--ETC(U)
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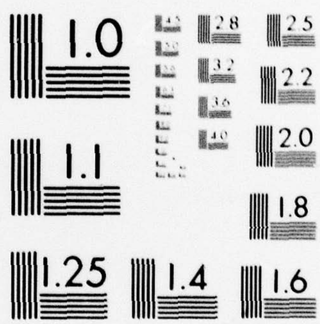


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6 A METHOD TO OVERCOME THE PROBLEM OF SERIES RESISTANCE IN THE CAPACITANCE-VOLTAGE TECHNIQUE FOR CARRIER DENSITY DETERMINATION



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The net donor density of n type GaAs epitaxial layers is commonly determined from capacitance - voltage measurements made on a Schottky barrier deposited on the epitaxial layer. The back ohmic contact is usually alloyed to the substrate, if it is n type, or to the layer itself, if the substrate is semi-insulating (Fig. 1). In the latter case, the resistance R in series with the Schottky diode capacitance C can be significant and can introduce an error in the determination of C. In this note, a practical solution to the problem is proposed.

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The capacitance meter used for C-V characterization usually measures capacitance by phase sensitive detection. Under conditions of constant bias, the a.c. equivalent circuit between the Schottky and ohmic contacts consists of a capacitance C in parallel with a leakage a.c. conductance G, this combination being in series with the resistance R (Fig. 2). The admittance Y between the ohmic and the Schottky contacts at $\omega/2\pi$ hertz can be expressed as

$$Y = G' + j\omega C' \tag{1}$$

where[1]

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$$G' = [GH + \omega^2RC^2]/[H^2 + \omega^2R^2C^2] \quad , \tag{2}$$

and

$$C' = C/[H^2 + \omega^2R^2C^2] \quad , \tag{3}$$

and where

$$H = RG + 1 \quad . \tag{4}$$

A small signal a.c. voltage $\vec{V} = V_o \, e^{j\omega t}$ (typically 15 mV at 1 MHz) is superimposed on the d.c. bias. By detecting the current $90^o$ out of phase with $\vec{V}$, the capacitance meter essentially measures C'. For Schottky barriers on GaAs, G is usually very small. Under the conditions $RG << 1$ and $\omega^2RC^2 >> G$, Eqs. (2) and (3) become

$$G' = \omega^2RC^2/(1+ \omega^2R^2C^2) \tag{5}$$

$$C' = C/(1 + \omega^2R^2C^2) \quad . \tag{6}$$

For high purity ($n^-$) GaAs layers about 10 microns thick, doped in the low $10^{14}$ $cm^{-3}$ range, and grown on semi-insulating substrates, the sheet resistance can be of the order of $10^4$ ohms/□ . For 0.030" diameter Schottky barrier contacts, the zero bias capacitance is typically in the range 10 - 30 pf. Using $\omega = 2\pi \times 10^6 \ sec^{-1}$, C = 15 pf and R = $10^4$ ohms gives $\omega CR \sim 1$. Thus the error in the measurement of C can be quite significant, leading to an even larger error in the estimation of $N_D$-$N_A$.

## Solution

The problem of series resistance may be overcome if in addition to measuring C' the instrument also obtains G' (by detecting the current in phase with $\vec{V}$ on a second phase sensitive detector). Then C may be extracted from C' and G' as

$$C = C' + \frac{G'^2}{\omega^2 C'} \tag{7}$$

A simple substitution of Eqs. (5) and (6) into the R.H.S. of (7) proves this identity. Using suitable calibrations, the outputs C' and $G'/\omega$ can be made available as analog voltages. The squaring, division and addition operations can all be accomplished by appropriate analog circuitry[2] to yield an analog output representing C.

The extent of the error made in assuming $RG \ll 1$ can be determined by substituting Eqs. (2) and (3) into the R.H.S. of Eq. (7). This gives upon simplification the elegant equation (see Appendix)

$$C' + \frac{G'^2}{\omega^2 C'} = C + \frac{G^2}{\omega^2 C} \quad . \tag{8}$$

Thus even if RG is not $\ll 1$, Eq. (7) will still hold provided $\omega C \gg G$.

## Appendix - Derivation of Equation (8)

$$C' + \frac{G'^2}{\omega^2 C'} = \frac{C}{H^2+\omega^2R^2C^2} + \frac{(GH + \omega^2RC^2)^2/(H^2+\omega^2R^2C^2)^2}{\omega^2C/(H^2 + \omega^2R^2C^2)}$$

$$= \frac{\omega^2C^2 + G^2H^2 + 2GH\omega^2RC^2 + \omega^4R^2C^4}{\omega^2C(H^2 + \omega^2R^2C^2)}$$

Expanding the third term in the numerator gives

$$\text{numerator} = \omega^2C^2\,[1 + 2GR + G^2R^2 + \omega^2R^2C^2\,]$$

$$+ \omega^2C^2G^2R^2 + G^2H^2 \quad .$$

$$= (\omega^2C^2 + G^2)(H^2 + \omega^2C^2R^2) \quad .$$

Thus

$$C' + \frac{G'^2}{\omega^2C'} = \frac{\omega^2C^2 + G^2}{\omega^2C} = C + \frac{G^2}{\omega^2C} \quad .$$

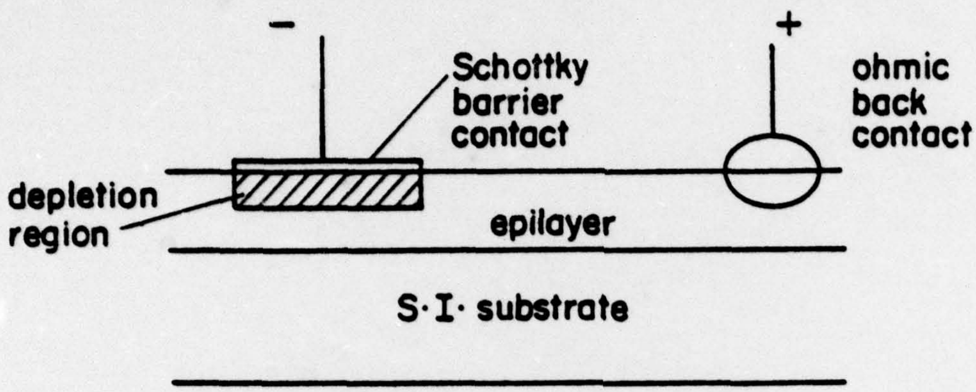
## References


1. A.M. Goodman, J. Appl. Phys., 34, 329 (1963).
2. J.G. Graeme, G.E. Tobey, L.P. Huelsman (editors), Operational Amplifiers, McGraw-Hill Co., New York.

## Figure Captions

Fig. 1. Reverse biased Schottky barrier on epilayer.

Fig. 2. A.C. equivalent circuit of reverse biased Schottky barrier.



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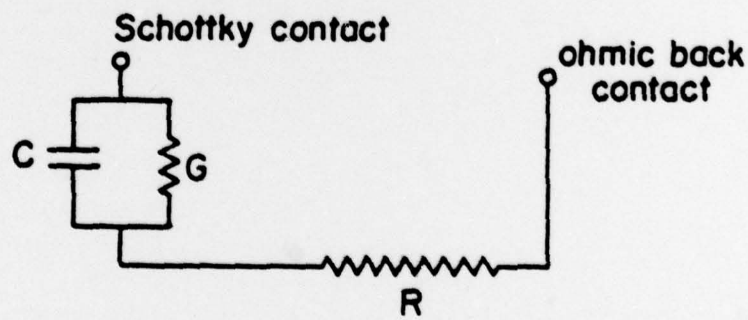
Schottky barrier contact
ohmic back contact
depletion region
epilayer
S·I· substrate


Schottky contact
ohmic back
contact
C
G
R

## List of Symbols

| | |
|---|---|
| $C$ | Capacitance across Schottky depletion region (a.c.) |
| $C'$ | Equivalent capacitance seen across circuit (a.c.) |
| $G$ | Leakage conductance across Schottky depletion region (a.c.) |
| $G'$ | Equivalent conductance seen across circuit (a.c.) |
| $H$ | $RG + 1$ |
| $j$ | $\sqrt{-1}$ |
| $N_D-N_A$ | Net donor density |
| $R$ | Resistance in series with Schottky barrier |
| $t$ | Time |
| $V$ | Applied d.c. bias voltage |
| $\vec{V}$ | Small signal a.c. modulation voltage |
| $V_o$ | Amplitude of $\vec{V}$. |
| $Y$ | A.C. admittance of circuit |
| $\omega$ | Angular frequency of $\vec{V}$. |