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DEPLETION LAYER OF A NONUNIFORMLY DOPED SCHOTTKY BARRIER DIODE

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ABSTRACT
A detailed analysis of the depletion layer of a nonuniformly doped Schottky barrier diode is presented in this work. The calculation of depletion width of such a Schottky barrier diode is rarely treated in the literature. Previous works on Schottky barrier diodes considered only uniformly doped doping density. The present analysis is of great importance for the design of Schottky barrier MOSFET where doping density is not uniform.
Keywords: Schottky barrier diode; nonuniform doping and depletion width of a junction.

I. INTRODUCTION

Recently the application of Schottky barrier as Schottky barrier MOSFET is gaining popularity [1-2]. As MOS transistors are continuously scaled, parasitic effects begin to diminish performance improvements and can lead to device failures. One proposed solution to the problematics relating to source and drain (S/D) junctions is the introduction of metallic materials in place of conventional doped semiconductor. There are numerous motivations for replacing doping (n^+ or p^+) with metal in the S/D regions, including low parasitic S/D resistance, low-temperature processing for S/D formation, elimination of parasitic bipolar action, which is due to the low resistance of metal [3]. Doping profile in Si region of such SBMOSFET is not uniform [4-6]. No analytical work considering non-uniformly doped Si SDB has been done till now. In the present work, the depletion layer of nonuniformly doped SBMOSFET is determined analytically. The expression for depletion layer can be used in studying characteristics of SBMOSFET.

II. THEORY

The structure of SBMOSFET is shown in Fig. 1. In conventional PMOSFET source and drain regions are formed by

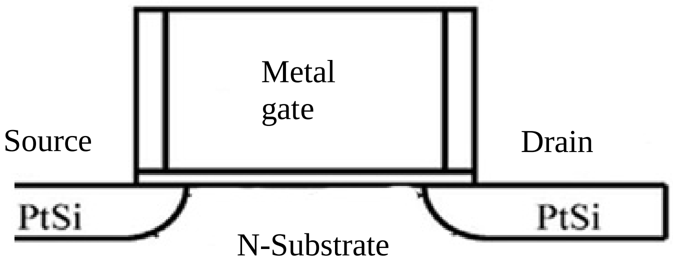

Fig. 1:. Cross sectional view of a SB-PMOSFET.

p^+ doping. In SBMOSFET heavily doped source and drain regions are replaced by metal. SBMOSFET with N-substrate performs better than its counter part SBMOSFET with P-substrate. A depletion region will be formed at metal-silicon junction. Fig. 2 shows a planer n-Si Schottky barrier diode for the analysis. The doping profile is not exactly exponential or Gaussian. It can be approximately given by [7]

$$N_D(x) = N_o e^{-(ax+bx^2)} \tag{1}$$

where N_o is peak doping density at x = 0, a and b are arbitrary constant.

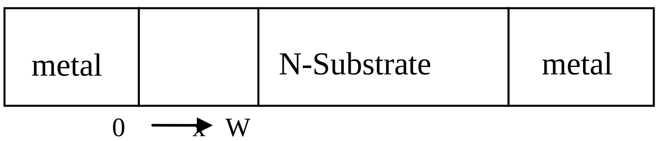

Fig. 2:. A planer n-Si Schottky barrier diode with depletion region of width W and total length L.

In order to simplify the Poisson's equation one approximation is introduced, as follows,
Vanishing electric field at the edge of the depletion region [8]:
It may be justified by noting that the magnitude of the electric field inside the depletion region is much higher compared to the neutral region.

Poisson's equation within the depletion region

$$\frac{dE}{dx} = \frac{q}{\varepsilon_s} N_0 e^{-(ax+bx^2)} \tag{2}$$

Integration of eqn. (2) gives

$$E(x) = \left(\frac{q}{\varepsilon_s} N_o\right)\left(\frac{1}{2}\sqrt{\frac{\pi}{b}}\right)\left(e^{\frac{a^2}{4b}}\right) erf\left(\sqrt{b}x + \frac{a}{2\sqrt{b}}\right) + \mathrm{C} \quad \text{for } \mathrm{b} \neq 0 \tag{3}$$

At the edge of the delpetion region i.e. at x = W, E(W) = 0. Using this boundary condition the arbitrary constant C can be evaluated . The electric field E (x) can be written as

$$E(x) = \left(\frac{q}{\varepsilon_s} N_o\right)\left(\frac{1}{2}\sqrt{\frac{\pi}{b}}\right) exp\left(\frac{a^2}{4b}\right)\left(erf\left(\sqrt{b}x + \frac{a}{2\sqrt{b}}\right) - erf\left(\sqrt{b}W + \frac{a}{2\sqrt{b}}\right)\right) \tag{4}$$

The voltage within the depeletion region can be obtained by integrating E(x) obtained from eqn. (4)

$$V(x) = -\int E(x)\, dx + C_1$$
$$= \left(\frac{q}{\varepsilon_s} N_o\right)\left(\frac{1}{2}\sqrt{\frac{\pi}{b}}\right) exp\left(\frac{a^2}{4b}\right)\left[xerf\left(\sqrt{b}\, W + \frac{b}{2\sqrt{b}}\right) - \frac{1}{\sqrt{b\pi}}\left\{\sqrt{\pi}\left(\sqrt{b}x + \frac{a}{2\sqrt{b}}\right) erf\left(\sqrt{b}x + \frac{a}{2\sqrt{b}}\right) + exp\left(-\left(\sqrt{b}x + \frac{a}{2\sqrt{b}}\right)^2\right)\right\}\right] + C_1 \tag{5}$$

Using boundary condition V(0) = 0 at x = 0, the arbitrary constant C_1 can be easily evaluated. The voltage V(x) will become

$$\mathrm{V(x)} = \left(\frac{q}{\varepsilon_s}\mathrm{N_o}\right)\left(\frac{1}{2}\sqrt{\frac{\pi}{b}}\right) exp\left(\frac{a^2}{4b}\right)\left[xerf\left(\sqrt{b}W + \frac{a}{2\sqrt{b}}\right) - \frac{1}{\sqrt{\pi b}}\left\{\sqrt{\pi}\left(\sqrt{b}x + \frac{a}{2\sqrt{b}}\right)\mathrm{erf}\left(\sqrt{b}x + \frac{a}{2\sqrt{b}}\right) - \sqrt{\pi}\left(\frac{a}{2\sqrt{b}}\right) erf\left(\frac{a}{2\sqrt{b}}\right) + exp\left(-\left(\sqrt{b}x + \frac{a}{2\sqrt{b}}\right)^2\right) - exp\left(-\frac{a^2}{4b}\right)\right\}\right] \tag{6}$$

The voltage V(x) for Gaussian profile can be obtained from eqn. (6) by using a = 0,

$$V(x) = \left(\frac{q}{\varepsilon_s} N_o\right)\left(\frac{1}{2}\sqrt{\frac{\pi}{b}}\right)\left[xerf(\sqrt{b}W) - \left\{xerf(\sqrt{b}x) + \frac{1}{\sqrt{\pi b}} exp(-bx^2)\right\}\right] \tag{7}$$

At thermal equilibrium the voltage across the junction is called built-in voltage V_{bi} and is given by [9]

$$V_{bi} = \emptyset_B - \frac{kT}{q}\left(\ln\frac{N_c}{N_D(W_0)}\right) = \emptyset_B - \frac{kT}{q}\ln\frac{N_c}{N_o} - \frac{kT}{q}(aW_o + bW_o^2) \tag{8}$$

Where, φ_B is the barrier height and W_0 is the width at thermal equilibrium and N_C ($\approx 2.8\text{x}10^{19}$ cm^{-3}) is the effective density of states in the conduction band.

Using eqn. (6) the depletion width W_o can be written

$$V_{bi} = \left(\frac{q}{\varepsilon_s}N_o\right)\left(\frac{1}{2}\sqrt{\frac{\pi}{b}}\right)exp\left(\frac{a^2}{4b}\right)\left[\left(\frac{a}{2b}\right)\left\{erf\left(\frac{a}{2\sqrt{b}}\right) - erf\left(W_o\sqrt{b} + \frac{a}{2\sqrt{b}}\right)\right\} + \frac{1}{\sqrt{\pi b}}\left\{exp\left(-\frac{a^2}{4b}\right) - exp\left(-\left(W_o\sqrt{b} + \frac{a}{2\sqrt{b}}\right)^2\right)\right\}\right] \quad (9)$$

From equations (8) and (9), W_o can be obtained.

III. RESULTS AND DISCUSSIONS

The electric field E(x) within the depletion region can be obtained from eqn.(4). The electric field distribution for a given peak doping density N_o and the length L =1μm is shown in Fig. 3. The peak of E(x) occurs at x = 0. For uniformly doped SDB, E(x) varies linearly. For the doping density given by eqn. (1), E(x) does not vary linearly with x.

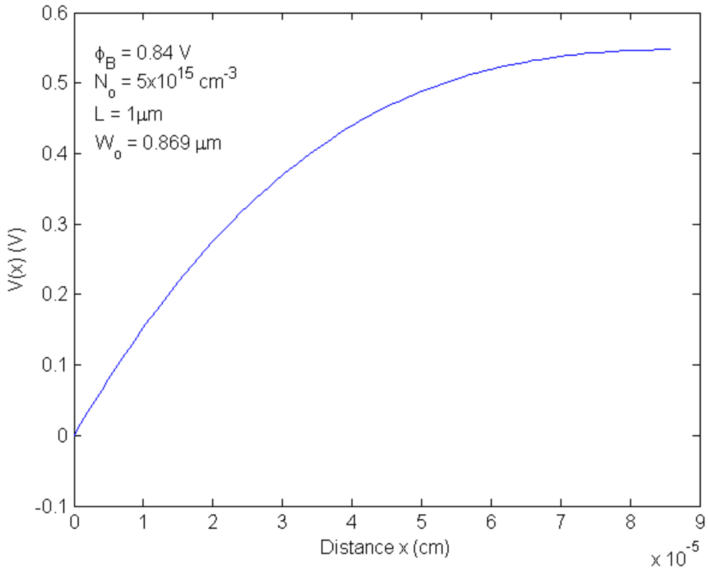

Fig. 3: Electric field distribution within the depletion region.

The voltage V(x) within the depletion region as function of x is shown in Fig. 4. It is zero at the metal-Si interface. V(x) increases with x and becomes maximum at the edge of the depletion region i.e at x = W_o.

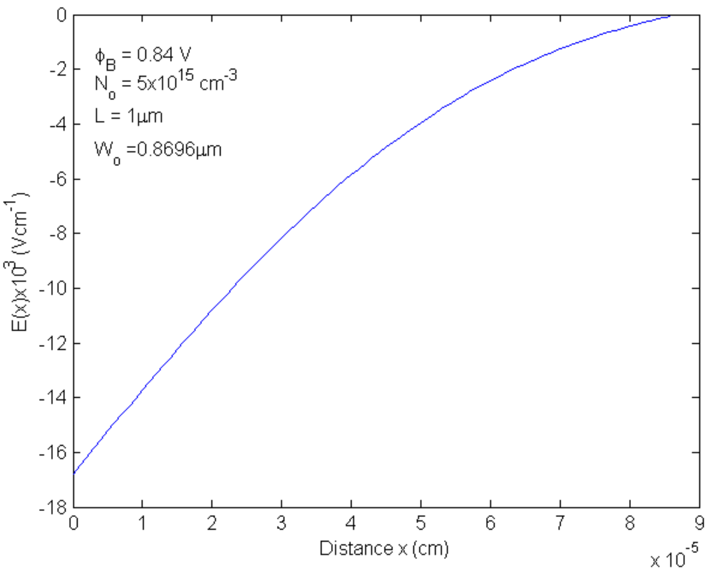

Fig. 4: Voltage within the depletion region of a SBMOSFET.

IV. CONCLUSION

In this work, mathematical expressions for electric field distribution E(x) and voltage distribution V(x) within the depletion region of a nonuniformly doped Si substrate of SBMOSFET are obtained. In studying current-voltage characteristics and breakdown voltage of the metal-substrate of SBMOSFET eqn. (7) can be used. This is the first time a mathematical formulation for voltage within the substrate of a SBMOSFET is obtained.

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