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Modeling of MOSFET with Different Materials

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ABSTRACT

This paper provides the designing of mosfet with different materials and compare which material is better for the designing. In previous time the mosfet is design by the combination of silicon and silicon oxide now we are using gallium arsenide and silicon dioxide as one combination and gallium arsenide and silicon nitride as another combination.

Introduction

The compound gallium arsenide was first discovered in 1926. However, its application as a high speed semiconductor was not known until the 1960′s. Both Gallium Arsenide and Silicon need the same lithographic process. Some of the advantages in using Gallium Arsenide when compared to Silicon are

- The high speed electron mobility of gallium arsenide with respect to silicon.
- A semi-insulating substrate with consequent lower parasitics.
- An improvement factor of 1.4 for carrier saturation velocity of GaAs over silicon.
- Better opto-electrical properties
- Less power dissipation than silicon and radiation hardness

From a comparison of various physical and electronic properties of GaAs with those of Si the advantages of GaAs over Si can be readily ascertained. Unfortunately, the many desirable properties of gallium arsenide are offset to a great extent by a number of undesirable properties, which have limited the applications of GaAs based devices to date.Properties of Si and GaAs

Properties	Si	GaAs
Dielectric Constant	11.9	13.1
Intrinsic carrier conc. (cm^{-3})	1.45 x 10^{10}	1.79 x 10^{6}
Intrinsic Debye Length(Microns)	24	2250
Mobility (cm^2/V.s),electrons	1500	8500
Mobility (cm^2/V.s),hole	475	400
Band gap (eV) at 300 K	1.12	1.424
Intrinsic resistivity (ohm.cm)	2.3 x 10^{5}	10^{8}
Formula weight	28.09	144.63
Crystal structure	diamond	zinc blende
Lattice constant	5.43095	5.6532
Melting point (°C)	1415	1238
Density (g/cm^3)	2.328	5.32
Thermal conductivity (W/cm.K)	1.5	0.46

Mathematical Analysis

For Germenium and silicon dioxide

For N- devices

The gain factor of MOS transistor beta is given by

$$\beta_n = \frac{\mu\varepsilon}{t_{ox}}\left(\frac{W}{L}\right) \quad \ldots\ldots (1)$$

Where μ is the effective surface mobility of the carriers in the channel ,ε is the permittivity of the gate insulator, t_{ox} is the thickness of the gate insulator, w is the width of the channel , and L is the length of the channel.

The gate oxide capacitance is given by

$$\frac{\varepsilon_{ox}}{c_{ox}} = t_{ox}$$

Assume t_{ox}= 200Å

$$c_{ox} = \frac{3.9 \times 8.85 \times 10^{-14}}{0.2 \times 10^{-5}}$$

c_{ox} =1.726$\times 10^{-7}$ Farads/cm^{-2}

Put the value of c_{ox} in equation (2)

$$\beta_n = \frac{\mu_n \varepsilon_{Ge} \varepsilon_o c_{ox}}{\varepsilon_{ox}}\left(\frac{W}{L}\right) \quad \ldots (2)$$

$$\beta_n = \frac{3900 \times 16 \times 8.85 \times 10^{-14} \times 1.726 \times 10^{-7}}{3.9 \times 8.85 \times 10^{-14}}\left(\frac{W}{L}\right)$$

$$\beta_n = \frac{0.0107}{3.9}\left(\frac{W}{L}\right)$$

$$\beta_n = 2.7616 \times 10^{-3}\left(\frac{W}{L}\right)$$

$$\beta_n = 2761.6\left(\frac{W}{L}\right)\frac{\mu A}{v^2} \quad \ldots . (3)$$

Length of Germenium =0.68 microns

Assume β_n=4 β_p

Taking β_n = 50

Put the value of β_n and length in equation (3)

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$$\beta_n = 2761.6 \times \left(\frac{W}{0.68}\right)$$

$$50 = 2761.6 \times \left(\frac{W}{0.68}\right)$$

W= .012

For P- devices

$$\beta_p = \frac{\mu\varepsilon}{t_{ox}}\left(\frac{W}{L}\right)$$

$$\beta_p = \frac{\mu_p \varepsilon_{Ge} \varepsilon_o c_{ox}}{\varepsilon_{ox}}\left(\frac{W}{L}\right) \quad \dots(4)$$

$$\beta_p = \frac{1900 \times 16 \times 8.85 \times 10^{-14} \times 1.726 \times 10^{-7}}{3.9 \times 8.85 \times 10^{-14}}\left(\frac{W}{L}\right)$$

$$\beta_p = \frac{5.247 \times 10^{-3}}{3.9}\left(\frac{W}{L}\right)$$

$$\beta_p = 1.3453 \times 10^{-3}\left(\frac{W}{L}\right)$$

$$\beta_p = 1345.3\left(\frac{W}{L}\right)\frac{\mu A}{v^2} \quad \dots..(5)$$

$$\beta_p = 200$$

put the value of β_p and length in equation (5)

$$\beta_p = 1345.3\left(\frac{W}{0.68}\right)$$

$$200 = 1345.3\left(\frac{W}{0.68}\right)$$

W= 0.010

For Gallium Arsenide and silicon dioxide

For N- devices

$$\beta_n = \frac{\mu_n \varepsilon_{GaAs} \varepsilon_o c_{ox}}{\varepsilon_{ox}}\left(\frac{W}{L}\right) \quad \dots(6)$$

$$\beta_n = \frac{8500 \times 13.1 \times 8.85 \times 10^{-14} \times 1.726 \times 10^{-7}}{3.9 \times 8.85 \times 10^{-14}}\left(\frac{W}{L}\right)$$

$$\beta_n = \frac{0.0192}{3.9}\left(\frac{W}{L}\right)$$

$$\beta_n = 4.927 \times 10^{-3}\left(\frac{W}{L}\right)$$

$$\beta_n = 4927\left(\frac{W}{L}\right)\frac{\mu A}{v^2} \quad \dots.(7)$$

Length of Gallium Arsenide = 2250 microns

Assume β_n=4 β_p

Taking β_n= 50

Put the value of β_n and length in equation (7)

$$\beta_n = 4927 \times \left(\frac{W}{2250}\right)$$

$$50 = 4927 \times \left(\frac{W}{2250}\right)$$

W= 22.8

For P- devices

$$\beta_p = \frac{\mu\varepsilon}{t_{ox}}\left(\frac{W}{L}\right)$$

$$\beta_p = \frac{\mu_p \varepsilon_{GaAs} \varepsilon_o c_{ox}}{\varepsilon_{ox}}\left(\frac{W}{L}\right)$$

$$\beta_p = \frac{400 \times 13.1 \times 8.85 \times 10^{-14} \times 1.726 \times 10^{-7}}{7.5 \times 8.85 \times 10^{-14}}\left(\frac{W}{L}\right)$$

$$\beta_p = \frac{9.044 \times 10^{-4}}{3.9}\left(\frac{W}{L}\right)$$

$$\beta_p = 2.319 \times 10^{-4}\left(\frac{W}{L}\right)$$

$$\beta_p = 231.9\left(\frac{W}{L}\right)\frac{\mu A}{v^2} \quad \dots..(8)$$

$$\beta_p = 200$$

put the value of β_p and length in equation (8)

$$\beta_p = 231.9\left(\frac{W}{2250}\right)$$

$$200 = 231.9\left(\frac{W}{2250}\right)$$

W= 1940.4

For Gallium Arsenide and silicon Nitride

For N- devices

The gate oxide capacitance is given by

$$\frac{\varepsilon_{ox}}{c_{ox}} = t_{ox}$$

Assume t_{ox}= 200Å

$$c_{ox} = \frac{7.5 \times 8.85 \times 10^{-14}}{0.2 \times 10^{-5}}$$

c_{ox} =3.31$\times 10^{-7}$ Farads/cm^{-2}

Put the value of c_{ox} in equation (9)

$$\beta_n = \frac{\mu_n \varepsilon_{GaAs} \varepsilon_o c_{ox}}{\varepsilon_{ox}}\left(\frac{W}{L}\right) \quad \dots(9)$$

$$\beta_n = \frac{8500 \times 13.1 \times 8.85 \times 10^{-14} \times 3.31 \times 10^{-7}}{7.5 \times 8.85 \times 10^{-14}}\left(\frac{W}{L}\right)$$

$$\beta_n = \frac{0036}{7.5}\left(\frac{W}{L}\right)$$

$$\beta_n = 4.927 \times 10^{-3}\left(\frac{W}{L}\right)$$

$$\beta_n = 4927\left(\frac{W}{L}\right)\frac{\mu A}{v^2} \quad \dots.(10)$$

Length of Gallium Arsenide = 2250 microns

Assume β_n=4 β_p

Taking β_n= 50

Put the value of β_n and length in equation (10)

$$\beta_n = 4927 \times \left(\frac{W}{2250}\right)$$

$$50 = 4927 \times \left(\frac{W}{2250}\right)$$

W= 22.8

For P- devices

$$\beta_p = \frac{\mu\varepsilon}{t_{ox}}\left(\frac{W}{L}\right)$$

$$\beta_p = \frac{\mu_p \varepsilon_{GaAs} \varepsilon_o c_{ox}}{\varepsilon_{ox}}\left(\frac{W}{L}\right)$$

$$\beta_p = \frac{400 \times 13.1 \times 8.85 \times 10^{-14} \times 3.31 \times 10^{-7}}{7.5 \times 8.85 \times 10^{-14}}\left(\frac{W}{L}\right)$$

$$\beta_p = \frac{1.734 \times 10^{-3}}{7.5}\left(\frac{W}{L}\right)$$

$$\beta_p = 2.312 \times 10^{-4}\left(\frac{W}{L}\right)$$

$$\beta_p = 231.2\left(\frac{W}{L}\right)\frac{\mu A}{v^2} \quad \dots..(11)$$

β_p =200

put the value of β_p and length in equation (11)

β_n =4927 x $\left(\frac{W}{2250}\right)$

200 =4927 x $\left(\frac{W}{2250}\right)$

W= 1946.3

For Gallium Arsenide and Titanium oxide

The gate oxide capacitance is given by

$\frac{\varepsilon_{ox}}{c_{ox}} = t_{ox}$

Assume t_{ox}= 200Å

$$c_{ox} = \frac{40 \times 8.85 \times 10^{-14}}{0.2 \times 10^{-5}}$$

c_{ox} =1.77$\times 10^{-6}$ Farads/cm^{-2}

Put the value of c_{ox} in equation (12)

For N- devices

$$\beta_n = \frac{\mu_n \varepsilon_{GaAs} \varepsilon_o c_{ox}}{\varepsilon_{ox}} \left(\frac{W}{L}\right) \quad ...(12)$$

$$\beta_n = \frac{8500 \times 13.1 \times 8.85 \times 10^{-14} \times 1.77 \times 10^{-6}}{40 \times 8.85 \times 10^{-14}} \left(\frac{W}{L}\right)$$

$$\beta_n = \frac{0.1970}{40} \left(\frac{W}{L}\right)$$

$$\beta_n = 4.927 \times 10^{-3} \left(\frac{W}{L}\right)$$

$$\beta_n = 4927.2 \left(\frac{W}{L}\right) \frac{\mu A}{v^2} \quad ....(13)$$

Length of Gallium Arsenide = 2250 microns

Assume β_n=4 β_p

Taking β_n= 50

Put the value of β_n and length in equation (13)

β_n =4927.2 x $\left(\frac{W}{2250}\right)$

50 =4927.2 x $\left(\frac{W}{2250}\right)$

W= 22.8

For P- devices

$$\beta_p = \frac{\mu\varepsilon}{t_{ox}} \left(\frac{W}{L}\right)$$

$$\beta_p = \frac{\mu_p \varepsilon_{GaAs} \varepsilon_o c_{ox}}{\varepsilon_{ox}} \left(\frac{W}{L}\right)$$

$$\beta_p = \frac{400 \times 13.1 \times 8.85 \times 10^{-14} \times 1.77 \times 10^{-6}}{40 \times 8.85 \times 10^{-14}} \left(\frac{W}{L}\right)$$

$$\beta_p = \frac{9.2748 \times 10^{-3}}{40} \left(\frac{W}{L}\right)$$

β_p =2.3187 x$10^{-4}\left(\frac{W}{L}\right)$

β_p =231.8$\left(\frac{W}{L}\right) \frac{\mu A}{v^2}$ …..(14)

β_p =200

put the value of β_p and length in equation (8)

β_p = 231.8 $\left(\frac{W}{2250}\right)$

200= 231.8$\left(\frac{W}{2250}\right)$

W= 1941.3

For Gallium Arsenide and Aluminum oxide

For N- devices

The gate oxide capacitance is given by

$\frac{\varepsilon_{ox}}{c_{ox}} = t_{ox}$

Assume t_{ox}= 200Å

$$c_{ox} = \frac{9 \times 8.85 \times 10^{-14}}{0.2 \times 10^{-5}}$$

c_{ox} =3.9825$\times 10^{-7}$ Farads/cm^{-2}

Put the value of c_{ox} in equation (15)

$$\beta_n = \frac{\mu_n \varepsilon_{GaAs} \varepsilon_o c_{ox}}{\varepsilon_{ox}} \left(\frac{W}{L}\right) \quad ...(15)$$

$$\beta_n = \frac{8500 \times 13.1 \times 8.85 \times 10^{-14} \times 3.98 \times 10^{-7}}{9 \times 8.85 \times 10^{-14}} \left(\frac{W}{L}\right)$$

$$\beta_n = \frac{0.0443}{9} \left(\frac{W}{L}\right)$$

$$\beta_n = 4.924 \times 10^{-3} \left(\frac{W}{L}\right)$$

$$\beta_n = 4924 \left(\frac{W}{L}\right) \frac{\mu A}{v^2} \quad ....(16)$$

Length of Gallium Arsenide = 2250 microns

Assume β_n=4 β_p

Taking β_n= 50

Put the value of β_n and length in equation (16)

β_n =4924 x $\left(\frac{W}{2250}\right)$

50 =4924 x $\left(\frac{W}{2250}\right)$

W= 22.8

For P- devices

$$\beta_p = \frac{\mu\varepsilon}{t_{ox}} \left(\frac{W}{L}\right)$$

$$\beta_p = \frac{\mu_p \varepsilon_{GaAs} \varepsilon_o c_{ox}}{\varepsilon_{ox}} \left(\frac{W}{L}\right)$$

$$\beta_p = \frac{400 \times 13.1 \times 8.85 \times 10^{-14} \times 3.98 \times 10^{-7}}{9 \times 8.85 \times 10^{-14}} \left(\frac{W}{L}\right)$$

$$\beta_p = \frac{2.08553}{9} \left(\frac{W}{L}\right)$$

β_p =2.317 x$10^{-4}\left(\frac{W}{L}\right)$

β_p =231.7$\left(\frac{W}{L}\right) \frac{\mu A}{v^2}$ …..(17)

β_p =200

put the value of β_p and length in equation (17)

β_p = 231.7 $\left(\frac{W}{2250}\right)$

200= 231.7$\left(\frac{W}{2250}\right)$

W= 1942.1

Conclusion

CMOS technology has seen an excellent high speed performance achieved through improved design, use of high quality materials and processing innovations over the past decade. Silicon dioxide gate dielectric is replaced with various high-k dielectric materials. The choice of the high-k dielectric and the knowledge of its physical properties helps in changing the various characteristics of the oxide layer in respect to power, current and the layout area covered. The study of the properties of these material was used in modeling the tri-state inverter and its various parameters were tabulated. The modeled inverter with high-k dielectric as gate dielectric material can be used for high gain and for low power applications in various electronic fields.

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