Universal Mobility-Field Curves For Electrons In Polysilicon Inversion Layer

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Abstract—This paper reports the studies on the inversion-layer mobility in n-channel Poly-Si TFT’s with 10¹⁶ cm⁻³ substrate impurity concentration. The validity and limitations of the universal relationship between the inversion layer mobility and the effective normal field (E_eff) was examined.

Index Term—TFT, Grain boundaries, carrier mobility, polysilicon

I. INTRODUCTION

It is strongly required to understand the inversion – layer mobility from modeling viewpoint for accurate device simulation, as well as from two-dimensional physics viewpoint. Though a qualitative understanding has already been obtained within moderate device parameters, it is indispensable to establish an accurate mobility model in a wide range of device parameters for realizing future ULSI’s. Furthermore, the characterization of mobility degradation is important, in order to predict the performance of Poly-Si TFT’s degraded by electric stress and others like trap, de-trap and surface roughness scattering.

On the other hand, it has already been reported that electron and hole mobilities in the inversion-layer follow universal curves, independent of the substrate impurity concentration, when plotted as a function of effective normal field [1]-[3]. This relationship provides a simple guideline, which gives mobility values under a combination of various device parameters.

This paper reports results of mobility behaviors in n-channel Poly-Si TFT’s with 10¹⁶ cm⁻³ substrate impurity concentration. Also, the mobility degradation by phonon scattering was studied. From these experimental results, the validity and limitations of the universal relationship have been examined.

II. SAMPLE PREPARATION AND MEASUREMENT

The n-channel Poly-Si used in this study was fabricated on (100)Si wafer. The substrate impurity concentration is 10¹⁶ cm⁻³ and the gate oxide’s thickness is 30nm. The measured devices had 1um gate lengths and 100um gate widths. The carrier mobility \( \mu_{\text{eff}} \) was determined from the drain conductance \( g_D \) for the Poly-Si TFT in the linear region (\( V_D = 50 \text{mV} \)),

\[
\mu_{\text{eff}} = \frac{L}{W} \cdot \frac{g_D(V_G)}{qN_s(V_G)}
\]  

(1)

Where,

\[
E_{\text{eff}} = \frac{N_d\phi_b + \eta N_s}{\varepsilon_{\text{Si}}}
\]  

(2)

and

\[
N_d = \frac{4\varepsilon_{\text{Si}}N_{\text{sub}}\phi_b}{q}^{1/2}
\]  

(3)

In order to determine \( \mu_{\text{eff}} \) accurately, the inversion carrier density \( N_s(V_G) \) must be measured with a minimal measurement error. \( N_s(V_G) \) was therefore determined directly through gate-channel capacitance \( C_{gc}(V_G) \) measurement[4-5].

\[
qN_s(V_G) = \int_{-\infty}^{V_G} C_{gc}(V_G) dV_G
\]  

(4)

Here, the measurement frequency was 300kHz (depend on the type of device), which enable to measure capacitance values accurately, even near the threshold voltage[5]. The effective normal field, \( E_{\text{eff}} \), was defined by the following equation.

\[
E_{\text{eff}} = \frac{q(N_d\phi_b + \eta N_s)}{\varepsilon_{\text{Si}}}
\]  

(5)

where \( N_d = (4 \varepsilon_{\text{Si}}N_{\text{sub}}\phi_b/q)^{1/2} \) is the bulk surface charge density. \( N_{\text{sub}} \) is the substrate impurity concentration, and \( \phi_b \) is the bulk Fermi energy. Here, \( \eta=1/2 \) for electron mobility was used, following previous reports [1]-[3].
III. EXPERIMENTAL RESULT AND DISCUSSION

3.1 I-V Measurement Result

![Graph showing I_d vs V_g]

Fig. 1. Measured drain current versus gate voltage.

![Graph showing g_m vs V_g]

Fig. 2. Measured $g_m$ versus gate voltage and the way how threshold voltage was determined.

![Graph showing I_d vs V_d]

Fig. 3. Measured drain current versus drain voltage as a parameter of gate voltage.
3.2 C-V Measurement

Fig. 4. Measured $g_d$ versus drain voltage as a parameter of gate voltage.

Fig. 5. Measured gate-capacitance, $C_{gc}$ versus gate voltage.
3.3 Universal Relationship in N-channel Poly-Si TFT’s

Fig. 8. Effective electron mobility $\mu_{\text{eff}}$ in n-channel Poly-Si TFT’s versus effective field $E_{\text{eff}}$. 

Fig. 6. Calculated (blue line) and measured (red line) channel charge versus gate voltage is plotted on a linear scale.

Fig. 7. Calculated (blue line) and measured (red line) channel charge versus gate voltage is plotted on a logarithmic scale.

Fig. 8. Effective electron mobility $\mu_{\text{eff}}$ in n-channel Poly-Si TFT’s versus effective field $E_{\text{eff}}$. 

Fig. 6. Calculated (blue line) and measured (red line) channel charge versus gate voltage is plotted on a linear scale.

Fig. 7. Calculated (blue line) and measured (red line) channel charge versus gate voltage is plotted on a logarithmic scale.
Figure 8 shows the $E_{\text{eff}}$ dependence of the inversion-electron mobility at about 300K (room temperature). It should be noticed concerning electron mobility in Figure 8 that the $E_{\text{eff}}$ dependence of electron mobility is in proportion to $E_{\text{eff}}^{-0.3}$ at $E_{\text{eff}}$ from 0.4(MV/cm) to 0.45(MV/cm), over the one order of magnitude $E_{\text{eff}}$ range. But electron mobility starts to decrease steeply at $E_{\text{eff}}$ higher than 0.45(MV/cm), though the universality is maintained. Besides, the electron mobility value is degraded to a single figures lower than MOSFET’s mobility.

As is well known, the dominant scattering mechanism in the Si inversion-layer is phonon scattering at high temperature and surface roughness at low temperature and high normal field. Therefore, it can be considered that the mobility which has $E_{\text{eff}}^{-0.3}$ dependence in figure is limited by phonon scattering [6] and also if $E_{\text{eff}}$ higher than 0.45(MV/cm) the mobility value starts to decrease steeply. Hence, the significant decrease in mobility is thought to be caused by surface roughness scattering [7]. But in Poly-Si TFT, the effect by surface roughness is faster because of the grain-boundaries in channel region. This is also can be explained by electrons trap and de-trap phenomenon (Figure 9).

![Fig. 9. Trap and de-trap phenomenon image](image)

IV. CONCLUSION

This paper reports the studies on the inversion-layer mobility behaviors in n-channel Poly-Si TFT’s, from the universal relationship viewpoint. A significant mobility lowering has been observed at low $N_s$ (low effective field), which is due to Coulomb scattering/screen effect. Also, in n-channel Poly-Si TFT’s the significant decrease in mobility is thought to be caused by surface roughness scattering which is faster because of the grain-boundaries in channel region. Besides, the degradation of carrier-mobility in Poly-Si TFT’s has been found. This is thought to be caused by grain-boundaries.

From these facts, it can be concluded that, by adding the term of surface roughness and Coulomb scattering to the universal curves, a more accurate description of inversion-layer motilities can be realized.

REFERENCES