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An Investigation Of Low Field Electrical Conduction
In Thin Au-SiO₂-Si Mos Structures

by

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An Investigation Of Low Field Electrical Conduction In Thin Au-SiO$_2$-Si Mos Structures

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ABSTRACT

The DC conduction in thin MOS structures constructed in the form of Au-SiO$_2$-Si is studied experimentally, and it is found that thermionic emission-diffusion theory describes the conduction mechanism when the thin insulating layer is in a tunnel conduction mode with negligible voltage drop across it. The average hole potential barriers at the Au-SiO$_2$ and SiO$_2$-Si contacts are determined to be about 0.78 eV and 0.75 eV respectively.

INTRODUCTION

The nature of the conduction in the SiO$_2$ interfacial layer has not yet been completely characterized. However, the most probable mechanism is metal-semiconductor tunneling. The case of tunnel conduction has been treated by Card and Rhoderick$^1$, more recently by Green et al.$^2$, and Bonnet and Lassabatere$^3$. In Bonnet and Lassabatere's work, pulsed voltage was used to be able to apply electric field of the order of 10$^7$ V/cm, and it was observed that tunnel conduction was possible for the fields above 8.10$^6$ V/cm. At low fields, less than 3.5. 10$^6$ V/cm, Schottky injection, and at moderate fields hot carrier injection were found to be the mechanisms of conduction. In this communication low field DC conduction is studied in thin MOS structures. It is shown that the thermionic emission-diffusion theory of Crowell and Sze$^4$ is adequate to explain the experimental results when one assumes the thin SiO$_2$ layer to be in tunnel conduction mode with negligible voltage drop across it.
EXPERIMENTAL

Thin MOS structures were prepared on p-type Si wafers having a resistivity of about 2 Ohm. cm. The wafers were chemically polished and etched prior to oxidation. All oxidations were carried out in dry oxygen between 750–800ºC for 25 minutes giving an oxide thickness of about 5 70–80 Å. The oxidized surfaces were metallized with evaporated Au. Contact areas were defined with a photoresist and etching process to give areas of about 7,8.10⁻² cm². Back contacts were made with evaporated Al followed by alloying.

RESULTS AND DISCUSSION

The typical current-voltage characteristics of Au-SiO₂-Si MOS structures are illustrated in Figure (1) together with the energy level diagram. The dependence of forward current (Au negative) upon voltage is plotted as log I against V. This is shown in Figure (2). It is seen from the Figure that the plot is a straight line obeying the following relation⁴.

\[ I = I_0 \exp \left( \frac{eV}{nkT} \right) \]  \hspace{1cm} (1)

where

\[ I_0 = AR^* \exp \left( \frac{eV_D}{kT} \right) \]  \hspace{1cm} (2)

In equations (1) and (2) \( e \) is electronic charge, \( k \) Boltzmann constant, \( T \) absolute temperature, \( V_D \) diffusion potential (Figure 1), \( A \) contact area, \( n \) ideality factor and \( R^* \) effective Richardson constant given by⁴

\[ R^* = \frac{f_pf_q R}{(1+f_pf_q v_r/v_d)} \]  \hspace{1cm} (3)

In equation (3) \( R \) is the Richardson constant for thermionic emission in the vacuum⁶, \( f_p \) the probability of hole emission over the potential maximum, \( f_q \) the theoretical ratio of the total current flow considering tunneling and quantum-mechanical
Figure 1. Energy level diagram and low-voltage I-V characteristics of Au-SiO₂-Si MOS structures.
Figure 2. Plot of log I versus V when Au contact is biased negatively.
reflection to the current flow neglecting these effects, \( v_r \) and \( v_d \) recombination and diffusion velocities of holes respectively. \( R^* \) changes with electric field, but it remains essentially constant in the range of \( 10^4 - 2 \times 10^5 \) V/cm having a value of about 30 Amp./cm\(^2IMATION OF LOW FIELD...\)

\( R^* \) changes with electric field, but it remains essentially constant in the range of \( 10^4 - 2 \times 10^5 \) V/cm having a value of about 30 Amp./cm\(^2/°K^2\) for holes\(^7\). The deviation from the straight line at higher voltages in Figure (2) can therefore be attributed to the voltage dependence of \( R^* \). Extrapolation of this straight line to the axis where \( V = 0 \) yields \( I_0 \) (equation 2). For \( I_0 \approx 2 \times 10^{-9} \) Amp., \( A \approx 7.8 \times 10^{-3} \) cm\(^2\) and \( T \approx 300°K \), \( V_D \) is calculated to be \( V_D \approx 0.75 \) eV. Using the slope of the straight line, the ideality factor can also be obtained as \( n \approx 2.98 \). Eight values for \( V_D \) belonging to different devices are tabulated in Table (1) together with \( n \) values. It is believed that these values are due to the electrons (minority carriers) tunneling through \( SiO_2 \) from the negatively biased Au into the p-type bulk. These electrons can cause a generation-recombination current in the depletion zone\(^8\) increasing the measured \( n \) values from unity.

<table>
<thead>
<tr>
<th>Sample</th>
<th>( V_D(\text{eV}) )</th>
<th>( n )</th>
<th>( \Phi_{ox}(\text{eV}) )</th>
<th>( d_i(A^\circ) )</th>
<th>( d_c(A^\circ) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.70</td>
<td>3.65</td>
<td>0.74</td>
<td>80</td>
<td>95</td>
</tr>
<tr>
<td>B</td>
<td>0.74</td>
<td>1.97</td>
<td>0.74</td>
<td>84</td>
<td>105</td>
</tr>
<tr>
<td>C</td>
<td>0.78</td>
<td>1.86</td>
<td>0.81</td>
<td>92</td>
<td>100</td>
</tr>
<tr>
<td>D</td>
<td>0.69</td>
<td>3.10</td>
<td>0.76</td>
<td>129</td>
<td>140</td>
</tr>
<tr>
<td>E</td>
<td>0.72</td>
<td>2.80</td>
<td>0.76</td>
<td>105</td>
<td>80</td>
</tr>
<tr>
<td>F</td>
<td>0.75</td>
<td>2.88</td>
<td>0.78</td>
<td>110</td>
<td>130</td>
</tr>
<tr>
<td>G</td>
<td>0.75</td>
<td>2.65</td>
<td>0.84</td>
<td>96</td>
<td>90</td>
</tr>
<tr>
<td>H</td>
<td>0.79</td>
<td>1.58</td>
<td>0.86</td>
<td>90</td>
<td>120</td>
</tr>
</tbody>
</table>

The reverse bias I-V characteristic illustrated in Figure (1) is plotted as \( \log I \) versus \( V^{1/2} \). This is shown in Figure (3). The straight line indicates that the reverse current (Au positive) is related to voltage by the expression of\(^8\).

\[
I = I_0 \exp \left( \frac{\Delta \Phi_{ox}}{kT} \right) \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (4)
\]

where

\[
I_0 = AR^* T^2 \exp \left( -\frac{e\Phi_{ox}}{kT} \right) \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (5)
\]

and
\[ \triangle \varnothing_{ox} = \left( \frac{e^3 V}{4 \pi \varepsilon \varepsilon_0 d_i} \right)^{1/2} \cdot \frac{1}{kT} \]  

In the above expressions \( \varnothing_{ox} \) is the height of the potential barrier over which holes tunnel through SiO\(_2\) from positively biased Au contact into silicon, \( \triangle \varnothing_{ox} \) the barrier lowering, \( \varepsilon \) dielectric constant of SiO\(_2\), \( \varepsilon_0 = 8.85 \times 10^{-12} \) F/m and \( d_i \) the thickness of SiO\(_2\). Using equations (4), (5), and (6) together with Figure (3), it is possible to determine \( \varnothing_{ox} \) and \( d_i \). These are given in Table (1) for 8 devices. For the device considered here, sample F, \( \varnothing_{ox} \approx 0.78 \) eV and \( d_i \approx 110 \) Å. It is of interest to point out that \( V_p \) and \( \varnothing_{ox} \) values obtained in this investigation are in good agreement with those reported previously\(^9\) and that SiO\(_2\) thicknesses (\( d_i \)) found in reverse current measurements are not far from those expected by the present oxide growth technique\(^5\).

The thickness of SiO\(_2\) layer can also be determined approximately by measuring the capacitance of the MOS structure when sufficiently biased (Au negative) to cause the semiconductor surface to be accumulated, (Figure 4). Using \( C_{ox} \approx 2100 \) pF, \( \varepsilon_{ox} \approx 4 \) and \( A \approx 7.8 \times 10^{-3} \) cm\(^2\), the thickness of SiO\(_2\) layer is calculated to be \( d_e \approx 130 \) Å. Table (1) compares the thicknesses of SiO\(_2\) layers of 8 devices obtained from the current measurements (\( d_i \)) with those calculated from the capacitance measurements (\( d_e \)). As it is seen from the Table, \( d_e \) values are generally greater than \( d_i \) values. It is believed that this is caused by the error introduced in contact area \( A \). In fact, the value used for \( A \) in the calculations is the mask area which might be larger than the effective area. A correction of 30% in \( A \) brings \( d_e \) values close to \( d_i \) values.
Figure 3. Plot of log I versus $V^\frac{1}{2}$ when Au contact is biased positively.

$\text{Au}(+)$

$T=300^\circ\text{K}$

$A=7.85 \times 10^{-3} \text{cm}^2$
Figure 4. C-V characteristics of Au-SiO$_2$-Si MOS structures.
REFERENCES


ÖZET

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