Experiment 9: Measurement of MOSCAP C-V Characteristics

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1 Introduction

This document describes the procedure and calculations involved in measuring the capacitance-voltage (C-V) characteristics of a MOS capacitor (MOSCAP). The experiment involves three parts: setting up the circuit, taking measurements, and analyzing the data to extract significant parameters.

2 Experimental Setup

The Device Under Test (DUT) is a circular MOSCAP with a diameter of 2 mm. The relevant parameters are as follows:

- Feedback Capacitance, $C_{fb} = 100\,\text{pF}$
- Intrinsic Carrier Concentration, $n_i = 1.5 \times 10^{10}\,\text{cm}^{-3}$

3 Measurement Process

The DC voltage V_{DC} was varied from 0V to 5V while observing the output voltage V_{out} and DUT voltage V_{DUT}.

3.1 Hypothetical Measurements

The following measurements were recorded:

Table 1: Hypothetical Measurements of Output Voltage

V_{DC} (V)	V_{out} (mV)	V_{DUT} (mV)
0	200	100
1	180	100
2	160	100
3	140	100
4	120	100
5	100	100

4 Calculating C_{DUT}

Using the AC gain equation:

$$C_{DUT} = C_{fb} \cdot \frac{V_{out}}{V_{DUT}}$$

Since V_{DUT} remains constant at 100 mV, C_{DUT} for each V_{DC} is calculated as follows:

4.1 Calculations for C_{DUT}

$$C_{DUT}(0V) = 100\,\text{pF} \cdot \frac{200}{100} = 200\,\text{pF}$$
$$C_{DUT}(1V) = 100\,\text{pF} \cdot \frac{180}{100} = 180\,\text{pF}$$
$$C_{DUT}(2V) = 100\,\text{pF} \cdot \frac{160}{100} = 160\,\text{pF}$$
$$C_{DUT}(3V) = 100\,\text{pF} \cdot \frac{140}{100} = 140\,\text{pF}$$
$$C_{DUT}(4V) = 100\,\text{pF} \cdot \frac{120}{100} = 120\,\text{pF}$$
$$C_{DUT}(5V) = 100\,\text{pF} \cdot \frac{100}{100} = 100\,\text{pF}$$

4.2 Summary of C_{DUT} Calculations

Table 2: Summary of C_{DUT} Calculations

V_{DC} (V)	C_{DUT} (pF)
0	200
1	180
2	160
3	140
4	120
5	100

5 Extracting Parameters

From the C_{DUT} values obtained, several important parameters can be derived:

5.1 Oxide Capacitance C_{ox}

Taking the capacitance at $V_{DC} = 0V$:

$$C_{ox} \approx C_{DUT} \text{ at } V_{DC} = 0V = 200\,\text{pF}$$

5.2 Oxide Thickness t_{ox}

Using the formula:

$$t_{ox} = \frac{\epsilon_{ox}}{C_{ox}}$$

where $\epsilon_{ox} = 3.45 \times 10^{-11}\,\text{F/m}$:

$$t_{ox} = \frac{3.45 \times 10^{-11}}{200 \times 10^{-12}} = 0.1725\,\text{mm} = 172.5\,\text{nm}$$

5.3 Doping Density N_A

Using the equation for depletion width and flat band voltage:

$$N_A = \frac{2\epsilon_{Si}}{q} \cdot \left(\frac{V_{FB}}{W^2}\right)$$

Assuming $V_{FB} = 1V$ and $W \approx 0.1\,\text{mm}$:

$$\epsilon_{Si} \approx 1.04 \times 10^{-12}\,\text{F/m}, \quad q = 1.6 \times 10^{-19}\,\text{C}$$

$$N_A = \frac{2 \cdot 1.04 \times 10^{-12}}{1.6 \times 10^{-19}} \cdot \left(\frac{1}{(0.1 \times 10^{-3})^2}\right) \approx 1.3 \times 10^{16}\,\text{cm}^{-3}$$

5.4 Flat Band Voltage V_{FB}

Assuming the value measured from the C-V curve is $V_{FB} = 1V$.

5.5 Flat Band Capacitance C_{FB}

Using the formula:

$$C_{FB} = \frac{\epsilon_{ox}}{t_{ox}}$$

Calculating with:

$$C_{FB} = \frac{3.45 \times 10^{-11}}{172.5 \times 10^{-9}} \approx 200.0\,\text{pF}$$

5.6 Debye Length L_D

Using the equation:

$$L_D = \sqrt{\frac{\epsilon_{Si} kT}{q^2 N_A}}$$

where $k = 1.38 \times 10^{-23}\,\text{J/K}$, $T = 300\,\text{K}$:

$$L_D = \sqrt{\frac{(1.04 \times 10^{-12}) \cdot (1.38 \times 10^{-23}) \cdot 300}{(1.6 \times 10^{-19})^2 \cdot (1.3 \times 10^{16})}} \approx 3.64\,\mu m$$

5.7 Debye Capacitance C_{Debye}

Using:

$$C_{Debye} = \frac{\epsilon_{Si} A}{L_D}$$

Where A for a circular MOSCAP of diameter 2 mm:

$$A = \pi \left(\frac{2 \times 10^{-3}}{2}\right)^2 \approx 3.14 \times 10^{-6}\,m^2$$

Calculating:

$$C_{Debye} = \frac{(1.04 \times 10^{-12}) \cdot (3.14 \times 10^{-6})}{3.64 \times 10^{-6}} \approx 0.89\,\text{pF}$$

6 Summary of Results

7 Conclusion

The experiment provided a detailed measurement and analysis of the C-V characteristics of a MOSCAP. The parameters extracted are vital for understanding the semiconductor device behavior and will be useful for future studies.

Table 3: Summary of Parameters Extracted

Parameter	Value
Oxide Capacitance C_{ox}	200 pF
Oxide Thickness t_{ox}	172.5 nm
Doping Density N_A	$1.3 \times 10^{16}\,\mathrm{cm}^{-3}$
Flat Band Voltage V_{FB}	1 V
Flat Band Capacitance C_{FB}	200 pF
Debye Length L_D	3.64 m
Debye Capacitance C_{Debye}	0.89 pF