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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Semiconductor devices – Mobile ion tests for metal-oxide semiconductor field effect transistors (MOSFETs)

Dispositifs à semiconducteurs – Essais d'ions mobiles pour transistors à semiconducteur à oxyde métallique à effet de champ (MOSFETs)

IEC 62417:2010

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SEMICONDUCTOR DEVICES – MOBILE ION TESTS FOR METAL-OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTORS (MOSFETs)

FOREWORD

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The text of this standard is based on the following documents:

FDIS	Report on voting
47/2042/FDIS	47/2049/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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SEMICONDUCTOR DEVICES –
MOBILE ION TESTS FOR METAL-OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTORS (MOSFETs)

1 Scope

This present standard provides a wafer level test procedure to determine the amount of positive mobile charge in oxide layers in metal-oxide semiconductor field effect transistors. . It is applicable to both active and parasitic field effect transistors. The mobile charge can cause degradation of microelectronic devices, e.g. by shifting the threshold voltage of MOSFETs or by inversion of the base in bipolar transistors.

2 Abbreviations and letter symbols

This standard uses the following abbreviations and letter symbols:

CV test	capacitance-voltage measurement
HFCV test	high frequency capacitance-voltage measurement
V_g	gate voltage
t_{ox}	oxide thickness
I_{ds}	drain-source current
V_{dd}	positive power supply voltage
$V_{dd,max}$	maximum supply voltage
V_t	transistor threshold voltage
$V_{t,initial}$	the absolute value of the threshold voltage before the test
V_{supply}	the absolute value of the supply voltage
ε_{ox}	dielectric constant of the oxide

3 General description

The stress applied is on test structures at an elevated temperature where mobile ions can overcome the energy barriers at the interfaces and the ion mobility in the oxide is sufficiently high. Two test methods are described in this document.

- Bias temperature stress (BTS)
- Voltage sweep (VS).

The bias temperature stress test is done on transistors. The threshold voltage is determined from an I_{ds} - V_{gs} measurement at room temperature on fresh structures. The threshold voltage is defined as the gate voltage needed to force a fixed drain current through the transistor. Then, a positive gate stress is applied at a high temperature, to sweep the mobile ions towards the substrate. After the stress the test structure is cooled to room temperature with the bias still applied. A second I_{ds} - V_{gs} curve is measured at room temperature. The sequence is completed with a negative gate stress at high temperature followed by an I_{ds} - V_{gs} measurement at room temperature. Mobile charge causes a shift in the I_{ds} - V_{gs} curve. The distance over which the curve is shifted is a measure of the amount of mobile charge in the insulator.

Edge effects of the transistor structure can be taken into account by applying a negative gate bias for 2 minutes duration at the elevated temperature prior to the BTS measurement.

NOTE Mobile charge in dielectric layers above a large area polysilicon or metal-plate cannot be detected, because there is no electric field which drives the ions towards the underlying oxide. To overcome this problem special edge sensitive test structures can be used, that have a large edge/area value, e.g. structures with fingers.

The voltage sweep measurements are done on capacitors. A quasi-static C-V curve is measured and compared with a low-frequency C-V curve. The ionic displacement current, which appears as a peak in the quasi-static C-V curve, is indicative of the mobile ion concentration.

4 Test equipment

The hot chuck shall be capable of maintaining a temperature of 250 °C. A capacitance (LCR) meter is needed for HFCV measurements and quasi-static C-V measurements. A pA-meter is needed for low-frequency C-V (typical frequency = 1 kHz) measurements. The frequency for low-frequency C-V measurements may differ from 1 kHz as long as the accumulation and inversion capacitances differ no more than 10 %.

5 Test structures

The test structures for bias temperature stress are transistors and, for voltage sweep, capacitors are used. The minimum area A_{min} of this capacitor is calculated from the voltage sweep rate dV/dt and the lowest measurable current I_{min} (determined by the resolution of the test equipment) according to the following equation:

$$A_{\mathrm{min}} = \frac{I_{\mathrm{min}} \cdot t_{ox}}{\varepsilon_{ox} \cdot \varepsilon_0 \cdot \mathrm{d}V / \mathrm{d}t} \qquad (1)$$

where

ε_0 is the permittivity of vacuum.

6 Sample size

The recommended sample size is 5.

7 Conditions

The electric field during stress is as follows:

±1,0 MV/cm with a minimum of (operating voltage +10 %) for gate oxide;

±0,2 MV/cm for polysilicon gates on field oxide;

± 0,3 MV/cm for metal gates on field oxide.

The electric field is calculated as V_g/t_{ox}.

8 Procedure

8.1 Bias temperature stress

The test structures are subsequently subjected to the following procedures:

- measure the first I_{ds} - V_{gs} (or HFCV) characteristic at room temperature;
- apply a positive gate bias to collect mobile ions at the silicon/oxide interface;
- ramp the temperature to 250 °C;
- hold 5 min;
- ramp down to room temperature;
- remove bias;
- measure the second I_{ds} - V_{gs} (or HFCV) characteristic;
- apply a negative gate bias to collect mobile ions at the gate/oxide interface;
- ramp the temperature to 250 °C;
- hold 5 min;
- ramp down to room temperature;
- remove bias;
- measure the third I_{ds} - V_{gs} (or HFCV) characteristic.

I_{ds} - V_{gs} characteristics may be measured at 250 °C (fast tests). HFCV and I_{ds} - V_{gs} measurements shall be started with the polarity used in the preceding high temperature stress.

NOTE Reporting of correlation data is required if the stress temperature deviates from 250 °C by more than 10 °C.

8.2 Voltage sweep

The device temperature is 250 °C. The start/stop values of the gate bias are calculated from the oxide thickness, so that the maximum electric field is ±1 MV/cm. The stress field is ±1 MV/cm.

The capacitors are subsequently subjected to

- a positive gate stress of 1 MV/cm for 5 seconds duration to collect mobile ions at the silicon/oxide interface,
- a low-frequency C-V measurement,
- a positive gate stress of 1 MV/cm for a period of 20 s,
- a quasi-static C-V measurement with a negative gate voltage ramp of 100 mV/s.

The electric field is defined as V_g/t_{ox}.

For thick oxides the electric field is limited by the supply voltage of the equipment. The values for the stress field and the start/stop values may then be reduced, but shall be at least 2×10^5 V/cm.

NOTE Reporting of correlation data is required if the temperature deviates from 250 °C by more than 10 °C.

9 Criteria

The shift in the threshold voltage shall be less than

- 0,02 × $V_{dd,max}$ with a minimum value of 100 mV for gate oxides, where $V_{dd,max}$ is the maximum voltage difference between V_{dd} pins and ground;

- $V_{t,initial} - 1{,}5 \times V_{supply}$ for polysilicon and metal gates on field oxide, where $V_{t,initial}$ is the absolute value of the threshold voltage before the test, and V_{supply} is the absolute value of the supply voltage. If $V_{t,initial} - 1{,}5 \times V_{supply} \leq 0$, then the shift shall be less than $V_{dd}/10$.

Typical values for the observed shifts are less than 10 mV for gate oxides, less than 1 V for polysilicon gates on field oxide, and less than 3 V for metal gates on field oxides.

If I/O-pins are subjected to a voltage higher than the supply voltage in any production components, then this value shall be used to determine the maximum shift for field oxide structures.

For bias temperature stress the shift in the threshold voltage in the second and third I_{ds} - V_{gs} with respect to the first I_{ds} - V_{gs} curve (or the shift of the flat band voltage for capacitor measurements) shall be less than the maximum allowed threshold voltage shift defined above.

For voltage sweep the maximum allowed mobile ion density (in cm^{-2}) can be calculated from

$$N_{max} = \frac{\varepsilon_0 \cdot \varepsilon_{ox} \cdot \Delta V_t}{q \cdot t_{ox}} \tag{2}$$

where

ΔV_t is the maximum threshold voltage shift defined above, and

ε_0 is the permittivity of vacuum.

The mobile ion density is given by $N_m = Q_m/(Axq)$, where q is the elementary electronic charge, and A is the area of the capacitor. The total amount of mobile charge Q_m in the insulator equals the area of the peak in the quasi-static C-V curve. This area is found by subtracting the low-frequency C-V curve from the quasi-static C-V curve.

10 Reporting

The sample size, the maximum allowed threshold voltage shift, the test results and any deviations from the given conditions shall be reported.
