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THE POSSIBILITIES OF THE EXACT MEASUREMENTS AND THE FAST CALIBRATION OF C-V QUASI-STATIC CHARACTERISTICS OF MOS STRUCTURES

Summary. The paper presents a description of an experimental set-up for quasi-static measurements of C-V characteristics of MOS structures in which specially constructed interference - proof electrometer equipped with a system of compensating the structure leakage current as well as the input cable capacitance has been used. The way of calibrating of C axis of the obtained C-V characteristics has been shown. The correctness of the measuring set-up has been checked by examing the $Si-SiO_2-Al$ structures obtained on n-type (100) and (111) Si by the oxidation in dry O_2 and with HCl addition.

1. INTRODUCTION

The measurements of voltage - capacitance characteristics (C-V) of MOS (metal-oxide-semiconductor) structures are the source of information on phenomena taking place in a dielectric, semiconductor and on the oxide-semiconductor interface [1]. Among numerous experimental methods, the ones often used are: the quasi-static [2], differential [3] and temperature [4] methods.

In the experimental set-up suggested by Kuhn [2] for the quasi-static method, the displacement current (proportional to the capacitance of the examined structure) forced by voltage linearly increasing at such rate that the state of thermodynamic equilibrium in the structure is kept constant is measured.

In the case of typical structures, the rates of voltage increase are contained within 1-500 $\frac{mV}{s}$, while the registered currents are $10^{-11} \div 10^{-14}$ A [1, 2].
This makes high demands on electronic systems used for measuring current intensity and requires a particularly careful screening of the equipment. This paper presents an experimental set-up for measuring quasi-static C-V characteristics of MOS structure, interference proof and enabling to eliminate some factors distorting the registered dependence. The method of calibrating of C axis of the obtained C-V characteristics has been described. The correctness of the system has been checked by examining the

$Si-SiO_2-Al$ structures obtained on n-type (100) and (111) Si by the oxidation in dry O_2 and with HCl addition.

2. MEASURING SET-UP

The measurement idea is presented on Fig. 1 and the block-diagram of the set-up used is shown on Fig. 2.

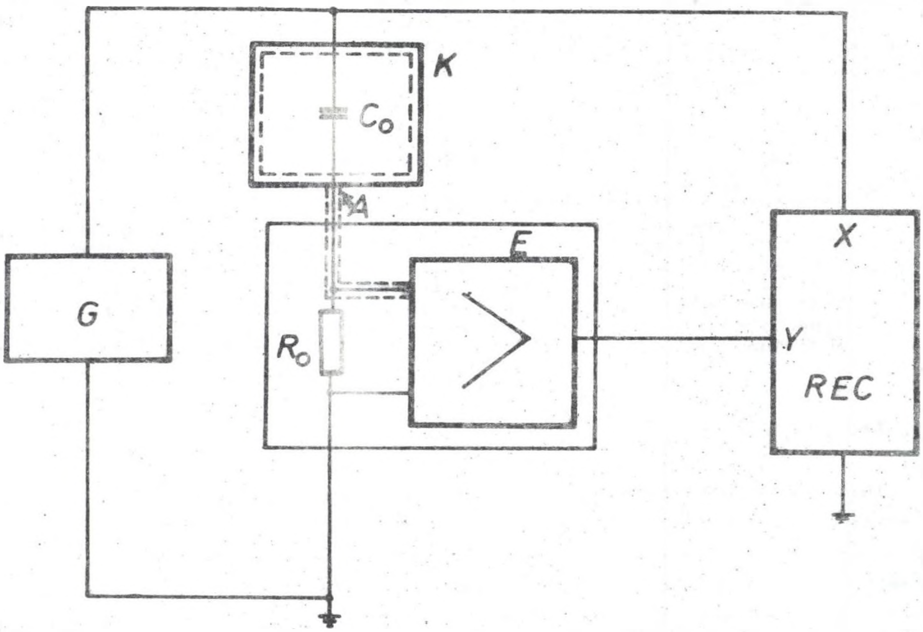

Fig. 1. Idea of measurements of the quasistatic MOS structures characteristics
G - linear ramp voltage generator with ± 100 V amplitude and α from 5 $\frac{mV}{s}$ to 10 $\frac{V}{s}$, K - measurement chamber, C_o - MOS structure, REC - XY recorder, E - electrometer

C-V characteristics of the examined MOS structure are plotted on a X-Y recorder. On the X input, the linearly increasing voltage U_G is given, while on the Y input - the signal from the electrometer proportional to the capacitance of the structure C_o and to the rate of the voltage increase α.

In the system, a specially designed and constructed electrometer of input resistance $\geq 10^{16}\ \Omega$ and of input capacitance $\leq 10^{-5}$ pF has been used. Such parameters have been reached by making use of transistor FET type 2N 3823 (or MOSFET BSWP-80 type CEMI-POLAND) in the input system.

The capacitance of the input cable connecting the electrometer with the measurement chamber is compensated to point A on Fig. 1.

Very small imput capacitance of the electrometer is the reason why its time constant is negligible at the applied rates of voltage increase 5--100 $\frac{mV}{s}$. In this way, one of the factors distorting the registered characteristics is eliminated. The use of the electrometer of high input resistance has made it possible to depart from the principle of using minimum value of resistor R_o while measuring the current flowing through the structure. As the result, the voltages on the R_o resistor and corresponding measured current, are considerabla bigger (thus easier for registration) than analogous voltages in electrometers based on the principle of minimum resistance R_o. In the discussed set-up the R_o values are in the 10^9-$10^{12}\Omega$ range.

However, the departure from the above mentioned principle of minimum R_o during current measurement causes the following:

a) the voltage U_o measured on R_o and defined by the dependence

$$U_o(t) = \alpha R_o C_o \left[1 - \exp(- \frac{t}{R_o C_o})\right] \qquad (1)$$

differs for $t < t_1$ from the asymptotic value $\alpha R_o C_o$ (t_1 is time when $U_o(t_1) \cong \alpha R_o C_o$).

It follows from the above that for each series of structures, time t_1, measured from the moment of switching the generator of linearly increasing voltage, is estimated after which the difference $(U_o(t_1) - \alpha R_o C_o$ is negligible. On this basis, the value of voltage correction $\Delta U_{G1} = \alpha t_1$ is determined by which the amplitude of the input voltage of the generator used for plotting the C-V characteristics of the given structure should be increased.

b) the C-V plots are shifted along the V-axis by the value of the voltage depositing on the R_o resistor,

c) the voltage axis scale isn't linear in the voltage range which corresponds to the changes of the MOS structure capacitance.

For the effects mentioned in b) and c) elimination the W_2 operational amplifier has been used (Fig. 2). To its non - inverting input the linearly increasing voltage from the supply has been fed whereas the voltage on R_o has been fed to the inverting input.

The output W_2 amplifier signal which corresponds to the MOS structure voltage has been applied to the X input of the X-Y recorder.

2.1. Compensation system of leakage current

The leakage current in the real MOS structure causes the slanting of the C-V characteristics which makes it difficult to compare it with the

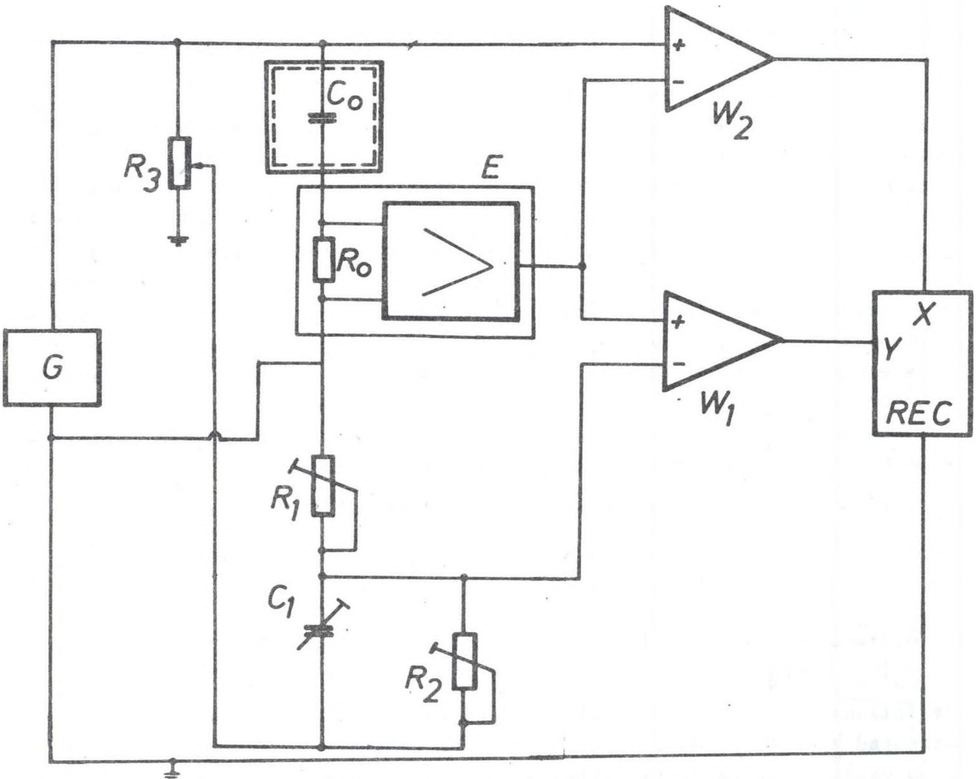

Fig. 2. Block - scheme of the measurement arrangement

characteristics of the ideal structure. In the discussed experimental set-up, a compensation system, whose block diagram is presented on Fig. 2, has been used. Compensation is achieved by the selection of values R_1, C_1, R_2, R_3 out of which a signal simulating the real MOS structure is passed onto inverting input of the operational amplifier W_1, while the signal from electrometer is passed onto the non-inverting input. Practically one aims at realizing conditions $R_oC_o = R_1C_1$, $C_oR_{st} = C_1R_2$, where R_{st} is MOS structure resistance. For the typical structures were been used R_1 to 1 MΩ, R_2 from 1 to 20 MΩ, R_3 to 42 kΩ, C_1 to 100 μF.

2.2. Calibration of capacitance axis

Determining of the capacitanee of the examined MOS structures as well as calibration of C axis are usually carried with the aid model capacitors and capacitance bridges. However, it is troublesome in practice and causes additional interferences. The maximum value C_{max} as well as the minimum value C_{min} of the capacitance of the examined structure and by this to calibrate C axis are determined in the discussed experimental set-up in the following way:

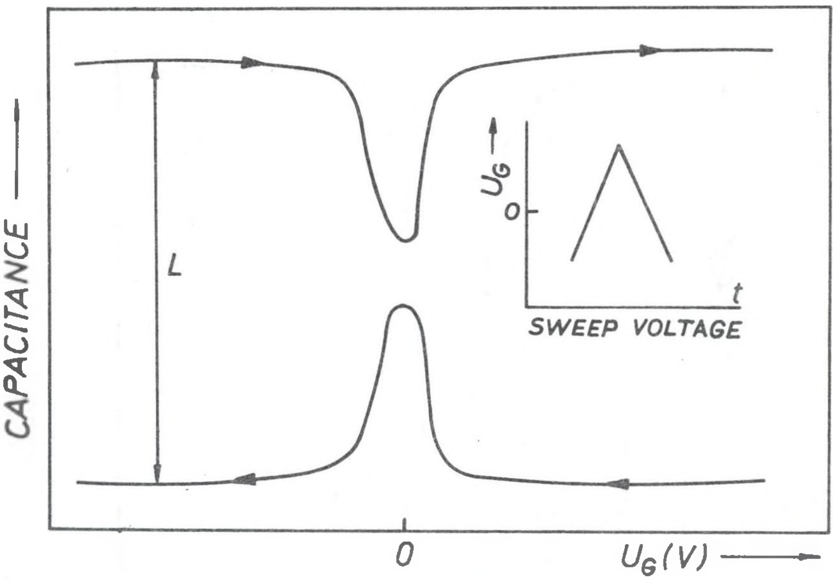

Fig. 3. C-V characteristic for determining of the MOS structure maximum capacitance

a) one plots the C-V characteristic for the applied triangular voltage (Fig. 3)

C_{max} is determined from dependence

$$C_{max} = \frac{1}{2} \frac{K_1}{R_o \cdot \alpha} \cdot L \qquad (2)$$

where

K_1 - amplification range of the Y amplifier of the recorder $\left[\frac{V}{cm}\right]$

L - characteristic "lopp value" $[cm]$ (Fig. 3)

R_o - Fig. 1

α - rate of voltage increase $\left[\frac{V}{s}\right]$.

b) C_{min} is determined from C-V characteristics drawn with the optimum system parameters (Fig. 4) and used for the quantitative analysis on the basis of the following equation

$$C_{min} = C_{max} - \Delta C \qquad (3)$$

where

$$\Delta C = \frac{K_2}{R_o \cdot \alpha} \cdot M$$

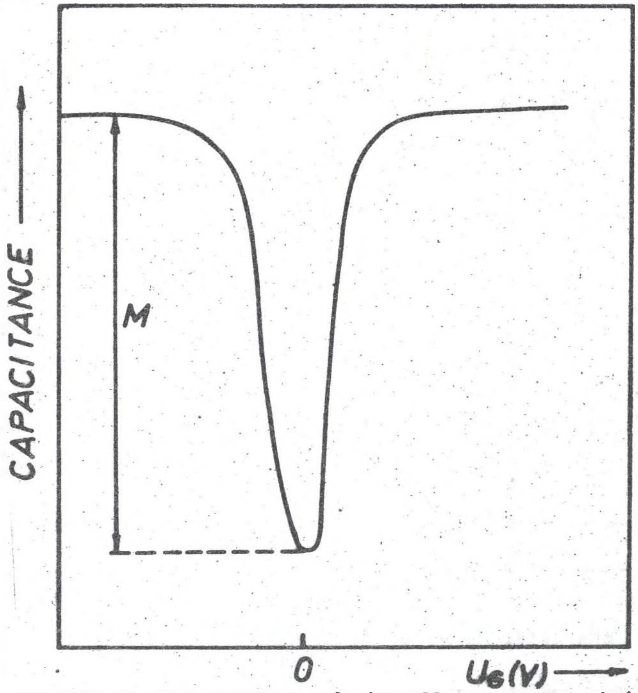

Fig. 4. Principle for determining of the MOS structure minimum capacitance

K_2 - amplification range of the Y amplifier of the recorder $\left[\frac{V}{cm}\right]$,
M - as on Figure 4 [cm]
R_o and α - as above.

In the range within C_{min} and C_{max} the scale is linear: therefore, it easy to calibrate the whole of the capacitance axis.

$\frac{K_1}{2R_o\alpha}$ and $\frac{K_2}{R_o\alpha}$ quantities are constant for the given series of MOS structures.

The error of this quantities determination is $\leqslant$ 0,4%. Determination accuracy of the geometric dimensions L and M is no worse than 0,3%.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In the described experimental set-up the $Al\text{-}SiO_2\text{-}Si$ structures produced[x] on the n-type Si ("Monsanto" firm. ρ = 3-9Ω cm) with (100) and (111)

x) The structures have been received from Electronic Technology Institute "CEMI" Warsaw.

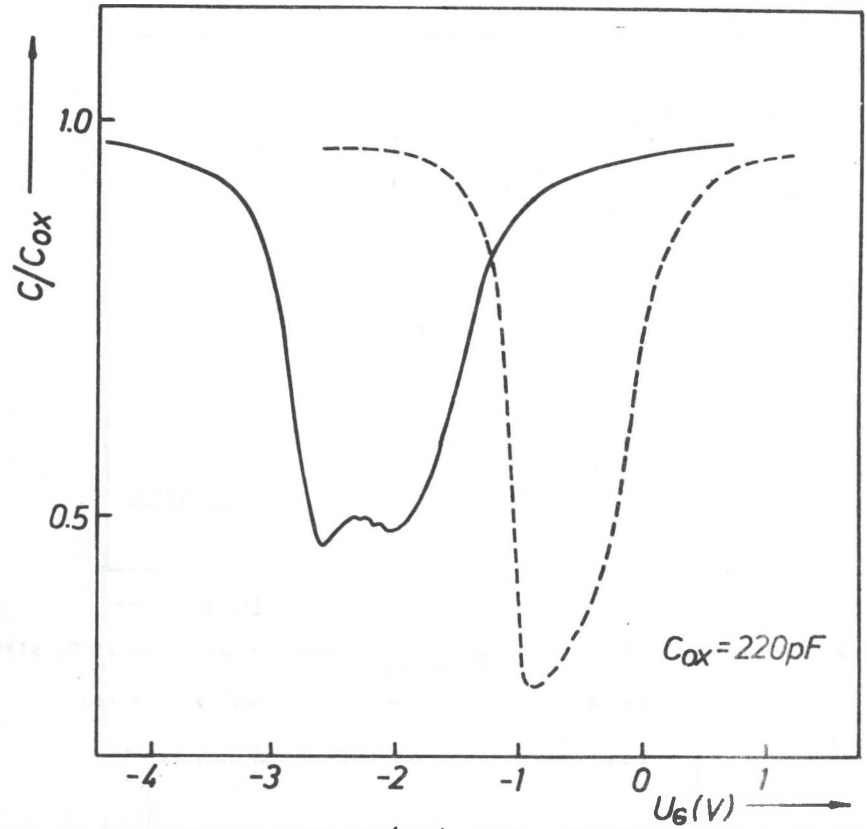

Fig. 5. C-V characteristic of (111) n-type structure oxidized in dry O_2
——— experimental - - - theoretical (ideal structure)

orientation by the oxidation at 1100°C in dry oxygen or with HCl addition and annealing in N_2 were investigated.

The quasistatic C-V characteristics measurements were performed in the dark and in air atmosphere.

The example curves are presented on Fig. 5, 6, 7, 8.

They were plotted with the rate of the voltage increase 15 $\frac{mV}{s}$. From Fig. 5 one can see that the C-V characteristics of the structures obtained by (111) Si exidation in dry O_2 show the noticeably distortions from the ideal strueture characteristics. It reveals by shift of the experimental curves in regard to theoretical ones, the experimental characteristics broadening and occuring of the double minimum in the depletion region. The similar effects were observed by Castagne et al. [5] and Baccarani et al. [6] and attributed to the structural defects near the oxide - semiconductor interface in (111) Si case and larger surface state concentration in the case of (111) Si. Addition of HCl in the oxidation process leads to the reduction of this defects concentration [6].

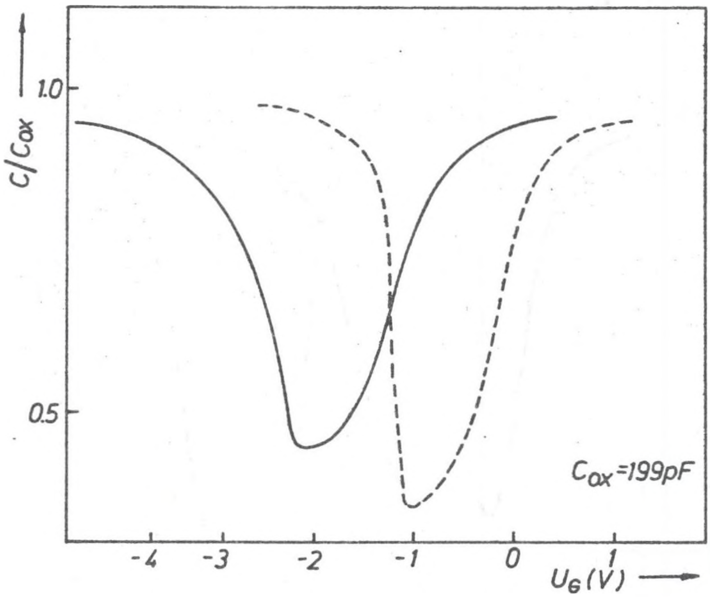

Fig. 6. C-V characteristic of (111) n-type structure oxidized in O_2 with 7% HCl addition

——— experimental ------ theoretical (ideal structure)

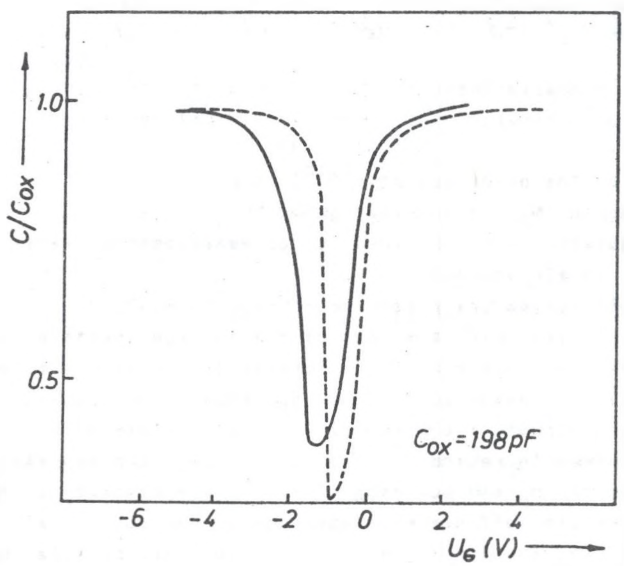

Fig. 7. C-V characteristic of (100) n-type structure oxidized in O_2 with 2% HCl addition

——— experimental -------- theoretical (ideal structure)

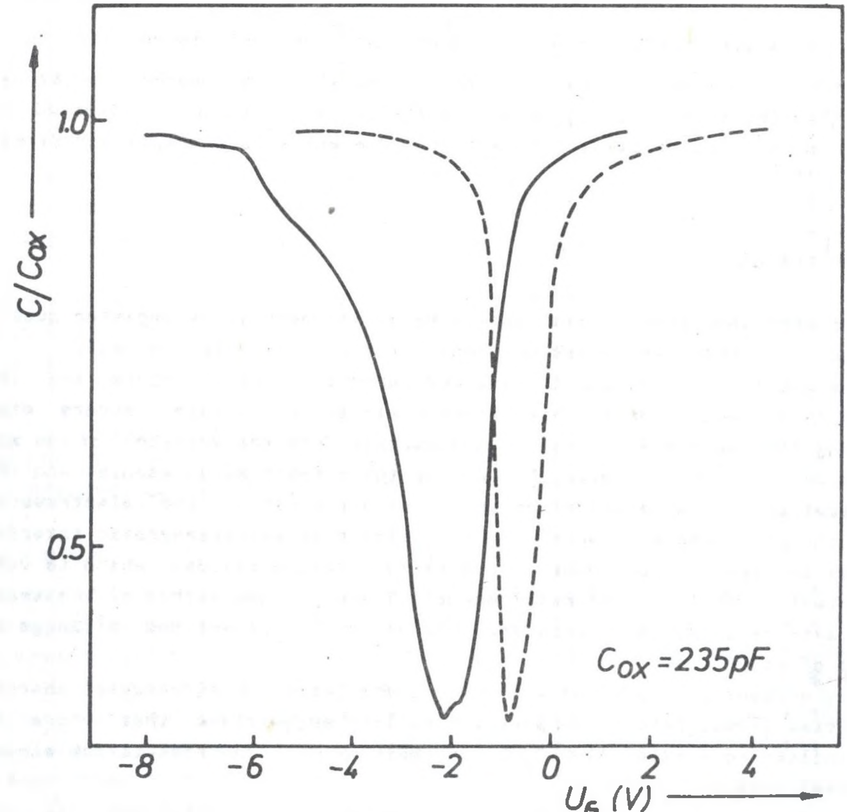

Fig. 8. C-V characteristic of (100) n-type structure oxidized in dry O_2
——— experimental ------ theoretical (ideal structure)

The C-V characteristics of the structures obtained in HCl presence and subsequently annealed in N_2 have the closed to the ideal structure characteristic shape but they are brouder and shifted along the voltage axis in comparison with ideal ones (Fig. 6).

The structures produced on (100) Si by oxidation in dry O_2 with HCl addition and annealing in N_2 have the characteristics only in significantly shifted in regard to the ideal ones (Fig. 7). In investigated in this work structures the noticeable influence of HCl on the experimental characteristics shape has been observed in the case of 2%-7% HCl concentration. The similar HCl concentration were used by Razouk et al. [7] whereas Baccarani et al. [6] reached the analogous effects with 0,5% HCl concentration.

In some cases of the investigated structures produced on (100) Si with O_2 presence only it has been observed that the experimental characteristics deviate from ideal ones noticeably in the depletion and inversion region (Fig. 8).

For this structures the value of $\int(1 - \frac{C(U)}{C_{ox}})dU$ calculated from accumulation to inversion (span of surface potential) has reached larger values than the silicon energy gap. The similar effects were observed by Berglund [8]. The cause of this effects were analysed by Lopez and Strain [9].

4. CONCLUSIONS

The described experimental set-up makes it possible to register quasi-static C-V characteristics convenient for the accurate analysis.

The system compensating the leakage current in the structure and the small time constant of the electrometer eliminate the main factors distorting the registered curves. The departure from the principle of the minimum value of the resistor R_e during the cureent measurements and the application of system solutions in the construction of the electrometer make the electrometer practically insensitive to electromagnetic interferences in high - industry centre conditions during all day, which is very important in this kind of measurements. The described method of the capacity axis calibration is peculiary useful for investigations of large amount of structures.

The presented results of the C-V quasistatic MOS structures characteristics investigations support the earlier suggestions that there is possibility to obtain $Al-SiO_2-Si$ structures with characteristics closed to ideal ones.

For this purpose the oxidation process should be carried out in the some per cent HCl presence and subsequently followed by the structure annealing in N_2.

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MOŻLIWOŚĆ DOKŁADNYCH POMIARÓW I SZYBKIEJ KALIBRACJI QUASI-STATYCZNYCH CHARAKTERYSTYK C-V STRUKTUR MOS

S t r e s z c z e n i e

Opisano układ do pomiaru quasi-statycznych charakterystyk C-V structur MOS, wyposażony w kompensację prądu upływności struktury i pojemności kabla wejściowego. Pokazano sposób kalibracji rejestrowanych charakterystyk.

Działania układu sprawdzono badając struktury Al-SiO_2-Si otrzymane przez termiczne utlenianie powierzchni (100) i (111) krzemu typu n w suchym O_2 oraz z dodatkiem HCl.

ВОЗМОЖНОСТЬ ТОЧНЫХ ИЗМЕРЕНИЙ И БЫСТРОЙ КАЛИБРАЦИИ КВАЗИСТАТИЧЕСКИХ C-V ХАРАКТЕРИСТИК МДП СТРУКТУР

Р е з ю м е

Предоставлена экспериментальная установка для измерений квазистатических C-V характеристик МДП структур. В ней возможна компенсация паразитного емкостного тока в структуре и емкости входного кабеля. Показано способ калибрации полученных C-V характеристик.

Действие установки исследовано на основе измерений характеристик структур Al-SiO_2-Si полученных термическим окислением поверхностей (100) или (111) кремния типа n в сухом O_2 и с добавлением HCl.