NONSTATIONARY TRANSPORT OF ELECTRONS AND HOLES IN THE DEPOLARIZED MODE OF MNOS DEVICES: AN EXPERIMENT AND NUMERICAL MODELING

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In experiments performed while investigating stationary conduction in metal–nitride–oxide–semiconductor (MNOS) devices in the nonequilibrium depletion mode [1, 2] and separating the electron and hole components of current in MNOS transistors [3], it was proved that the transport voltage at both polarities near the semiconductor insulator interface is created by carriers injected from the silicon. It was uniquely established in experiments on blocking the injection of holes from the silicon that at a negative voltage (V < 0) on the metal (Al, Au) in MNOS devices having a tunneling-thin layer of SiO_2 that charge transport was caused by holes and that the injection of electrons from the silicon was negligible [4]. Thus, when V < 0 conduction in an MNOS device is a monopolar hole current (Fig. 1b).

It was established through experiment [1, 3, 5] that conduction in MNOS devices does not depend on the polarity of the voltage applied to the metal. This can be explained by two models. For the monopolar, two-zone model (A) charge is transported by holes when V < 0, and by electrons when V > 0 (Fig. 1a). Model A assumes that the parameters of the hole and electron traps in the Si_3N_4 are identical.

Model B for hole conduction assumes that, just as in model A, charge is transported by holes injected from the silicon when V < 0 (Fig. 1c), and when V > 0, transport in the body of the Si_3N_4 is limited by the transport of holes injected from the metal (Fig. 1c). The electrons injected from the silicon in model B recombine with holes in the traps that are responsible for the memory effect [6, 7].

The relationship between the hole and electron traps parameters in the Si_3N_4 can be ascertained using either model of stationary conduction. A method for determining electron trap energy was developed in [8] in the isothermal depolarization mode. However, the interpretation of positive charge scattering adopted in this work was ambiguous.

The purpose of this article is to study hole and electron transport in the body of the Si_3N_4 in the isothermal depolarization mode, to determine the parameters of the hole and electron traps, to compare the experimental results with those obtained through numerical analysis, and to discuss a possible model for deep trapping centers.

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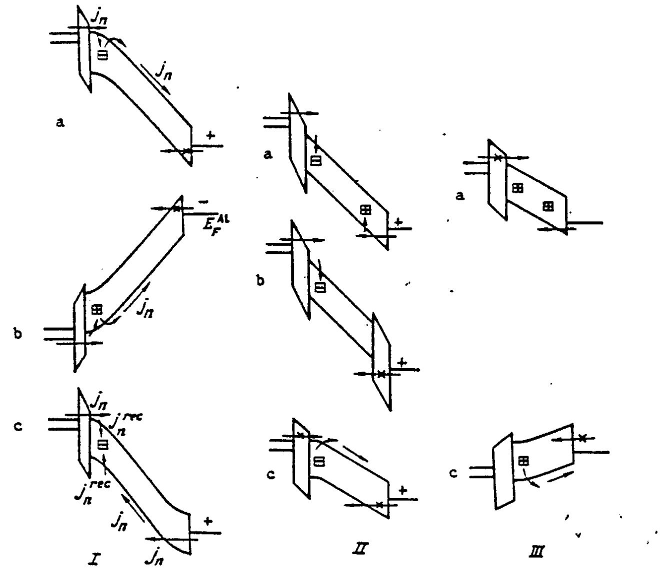

Fig. 1. Energy diagrams for MNOS devices: I) a tunnelling-thin oxide, stationary conduction; when V > 0: a), b) a monopolar, two-zone model A; b), c) hole conduction models B; b) monopolar conduction when V < 0; c) bipolar conduction when V > 0. II) a tunnelling-thick oxide; a), b) nonstationary polarization mode for MNOS- (a) and MONOS- (b) devices; c) depolarization of MNOS devices — trapped electrons draining onto a metal electrode. III) accumulation (a) and depolarization (c) of holes.

Specimens. The parameters of deep trapping centers in silicon nitride depend on fabrication conditions. So that the results could be generalized, MNOS devices were studied in which the Si_3N_4 was fabricated in low-pressure reactors by three different techniques. The SiO_2 layers of thickness d_0 = 1.6-14 nm were formed by thermally oxidizing silicon. Layers of aluminum and gold were used for the electrodes. A blocking layer of Si_3N_4 was grown between the SiO_2 and the metal in the metal—oxide—nitride—oxide—semiconductor (MONOS) devices.

The Mathematical Model. The one-dimensional model proposed in [9, 10]:

$$\frac{\partial n_e}{\partial t} + v_d \frac{\partial n_e}{\partial x} = -\sigma_t n_e v_d (N_t - n_t) + \nu^* n_t \exp[-(\Phi_t^* - \beta F^{1/2})/kT] + I_e; \quad (1)$$

$$\frac{\partial n_t}{\partial t} = \sigma_t n_e v_d (N_t - n_t) - \nu^* n_t \exp[-(\Phi_t^* - \beta F^{1/2})/kT]; \quad \frac{\partial^2 \varphi}{\partial x^2} = \frac{q}{\varepsilon_N \varepsilon_0} n_t; \quad \xi = \frac{4}{3\hbar}(2m^* q)^{1/2}, \quad (2)$$

$$I_e = j_{ox} F_{ox}^2 P_{ox} P_N \Theta(x); \quad \Theta(x) = \frac{\exp(-\alpha(\Phi_0 - \Phi_1 - \varphi(x)))}{\int_0^{d_N} \exp(-\alpha(\Phi_0 - \Phi_1 - \varphi(x)))\,dx}; \quad (3)$$

$$P_{ox} = \exp[-\xi(\Phi_0^{3/2} - (\Phi_0 - \varphi(0))^{3/2})/F_{ox}];$$
$$P_N = \exp[-\xi(\Phi_0 - \Phi_1 - \varphi(0))^{3/2}/F(0)]$$

was used for analyzing the experimental data and studying the physical processes as the silicon nitride layers were polarized and depolarized. The initial and boundary conditions were chosen as

$$n_c(0,t)=I_0(0,t);\quad n_c(x,0)=n_t(x,0);\quad \varphi(0)=d_{ox}\frac{\varepsilon_N}{\sigma}F(0);\quad \varphi(d_N)=V. \qquad (4)$$

Here, n_c, n_t are the concentrations of free and trapped electrons respectively; v_d is the drift velocity; Φ_t is the energy at the trapping center; ν is a frequency factor; $\Phi_0 = 3.1$ eV; $\Phi_1 = 1.05$ eV is the height of the barriers at the Si–SiO_2 and SiO_2–Si_3N_4 interfaces respectively; I_0 is the rate of carrier injection from the contact; V is the amplitude of the applied voltage; α is the tunnel constant; d_{ox} and d_N are the oxide and silicon nitride layer thicknesses respectively, and j_{ox} is a constant that describes the current through the Si–SiO_2 contact.

The initial system of equations (1)–(3) were written as difference equations and Newton's iterative method, done by means of a matrix run, was used to solve them. The field and temperature dependence of the trapping section and the frequency factor were negligible in comparison with exponential factors.

ELECTRON TRANSPORT AND A COMPARISON OF THE EXPERIMENT WITH THE EXACT AND APPROXIMATE MODELS

The experiments were performed on MNOS devices having SiO_2 tunneling-impervious and tunneling-thick $Si_3N_4\left(d_N>\bar{x}=\int_0^{d_N} x n_t\,dx \Big/ \int_0^{d_N} n_t\,dx\right)$. Electrons were accumulated by applying a positive pulse to the Al-electrode (Fig. 1, IIa, b). The device was depolarized by an "attracting" positive voltage on the metal contact (Fig. 1, IIc). Parasitic effects may appear in this experiment and they must be considered: a) holes may be injected from the metal and accumulated near the Al–Si_3N_4 interface during device polarization (Fig. 1, IIa), b) as electrons are scattered toward the metal electrode, the field at the Si–SiO_2 interface increases, increasing the probability that electrons will be injected from the silicon (Fig. 1, IIc).

As a rule, holes were seen to be injected from the metal when a positive voltage was applied to the aluminum in the polarizing mode. To reduce this injection a "natural" oxide was released from the Si_3N_4 surface in a 10% solution of HF in water prior to depositing the aluminum. This treatment sharply curtailed the injection of holes. Holes injection was completely suppressed in the polarizing mode in MONOS devices because of the large barrier at the SiO_2–Al interface (Fig. 1, IIb).

To block the injection of electrons from the silicon into the Si_3N_4 in the depolarizing mode control experiments were arranged in which the critical value of the field at the Si–SiO_2 interface was experimentally determined at which the injection of electrons in the depolarizing mode was small.

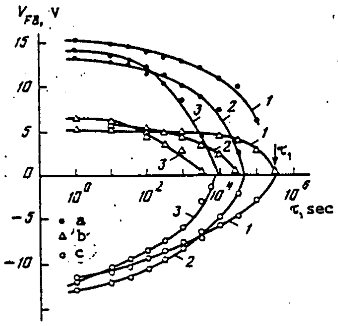

Fig. 2. Kinetics of depolarization for a), c) MNOS, and c) MONOS devices: a), b) electrons, c) holes; V (volts): 1) 30 V; 2) 40 V; 3) 50 V; T = 403°K. MNOS) d_{ox} = 10 nm, d_N = 180 nm; MONOS) d_{ox}^{I} = 10 nm, d_N = 175 nm, d_{ox}^{II} = 5 nm. Fabrication technique) I (see Table 1).

TABLE 1. Parameters of Hole and Electron Traps in a Silicon Nitride Fabricated by Different Techniques (LPR = low press. reactor)

Fabrication parameters	Electron traps parmeters	Hole traps parameters
I LPR, 750° C $SiCl_4 : NH_3 = 1:10$	$\Phi_t^e = 1.4 \pm 0.1$ eV $\nu^e = 3 \cdot 10^{7\pm1}$ sec^{-1} $N_{tt}^e = (2\pm1) \cdot 10^{18}$ cm^{-3} $\sigma_t^e = (2\pm1) \cdot 10^{-13}$ cm^2	$^{**}\Phi_t^h = 1.35 \pm 0.05$ eV – $N_t^h = (3\pm1) \cdot 10^{18}$ cm^{-3} $\sigma_t^h = 10^{-13}$ cm^2
II LPR, 900° C $SiCl_4 : NH_3 = 1:20$	$\Phi_t^e = 1.5 \pm 0.1$ eV $^*\Phi_t^e = 1.45 \pm 0.05$ eV $\nu^e = 10^{7\pm1}$ sec^{-1} $\nu^e = 10^{8\pm1}$ sec^{-1} $N_t^e = 2 \cdot 10^{18}$ cm^{-3} $\sigma_t^e = 3 \cdot 10^{-13}$ cm^2	$\Phi_t^h = 1.5 \pm 0.1$ eV – $\nu^h = 10^{7\pm1}$ – – –
III LPR, 850° C $SiH_4 : NH_3 = 1:30$	$\Phi_t^e = 1.4 \pm 0.1$ eV $\nu^e = 10^{6\pm1}$ sec^{-1} $N_t^e = 4 \cdot 10^{18}$ cm^{-3} $\sigma_t^e = 4 \cdot 10^{-13}$ cm^2	$\Phi_t^h = 1.4 \pm 0.1$ eV $^*\Phi_t^h = 1.5 \pm 0.1$ eV $\nu^h = 10^{6\pm1}$ sec^{-1} – –

Comment. Values of $\phi_t^{e,h}$ and $\nu^{e,h}$ were determined by the discharge in MNOS devices having a thick SiO_2 layer according to the simplified model; $^*\phi_t^e$ and $\nu^{e,h}$ were obtained by comparing the experiments on discharge with the exact model; and $^\dagger\phi_t^h$ were determined in an MNOS device having a thin SiO_2 layer in the stationary conduction mode.

The kinetics of negative charge scattering in an MNOS device (a specimen in which holes were seen to be strongly injected from Al) and a control MONOS device are shown in Fig. 2. Under identical polarizing conditions, V = +75 V and τ = 5 sec, it is obvious that the initial negative charge stored in the MNOS device is substantially less than that in the MONOS device. This difference is caused by holes injected from the aluminum during polarization being trapped (Fig. 1, IIa).

An approximation

$$\tau \simeq \nu^{-1} \exp\left[(\Phi_t - \beta \bar{F}^{1/2})/kT\right] \tag{5}$$

of the characteristic information storage time was used to analyze experimental data in [8], where $\bar{F}$ is the characteristic field in which depolarizing is performed. A qualitative estimate of the applicability of Eq. (5) for analyzing experimental data was made via mathematical modeling.

A simple model based on Eq. (5) assumes that repeated trapping can be neglected in the Si_3N_4. This is in line with the smallness of the first term in the right-hand side of Eq. (1) in comparison with the second term.

The evolution of the distribution of populated traps when repeated trapping is and is not present is shown in Fig. 3a. When repeated trapping is not present, the traps are discharged from the strong field-metal electrode side. A region that was initially unoccupied by electrons remains unfilled throughout the entire scattering process.

In considering repeated trapping the maximum traps populating region is displaced toward the metal electrode (Fig. 3a) which produces a more uniform spatial distribution of the field (Fig. 3c). This effect is caused by a strong retrapping effect. The trapping and ionization rates differ insignificantly (see Fig. 3b) and, in spite of the fact that the ionization rate over long time spans is a maximum in the region near the anode because of strong trapping in this region, the region near the cathode makes the principal contribution to emptying the traps.

At first glance the data of Fig. 3 indicate that the simplified model used in [8] is inapplicable. A more detailed inspection, however, reveals that this is not the case. It can be seen from Fig. 3c that although the maximum difference in the field caused by the charge from local electrons is about 25%, and the difference between the local field and the anode field at the point of maximum ionization is about 10%. Thus, using Eq. (5) gives a relative error $\delta = \beta \Delta F / 2\Phi_t^e \bar{F}^{1/2} \sim 1.5\%$ (for $\bar{F} \sim 1 \cdot 10^6$ V/cm) in determining the energy of the level that is substantially less than the experimental error.

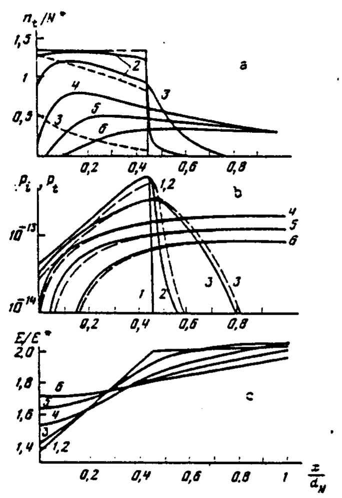

Fig. 3

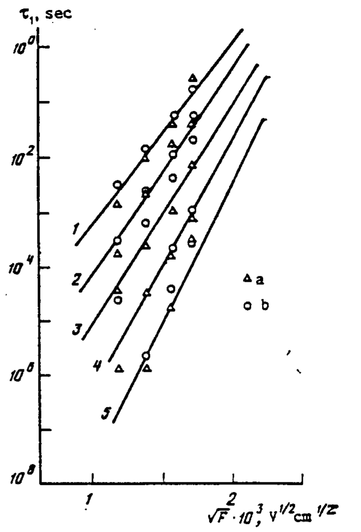

Fig. 4

Fig. 3. Spatial distribution of local electron concentrations (a), the electric field (c), and the trapping rate P_t (dashed line) and traps ionization P_i (solid line) (b) in the Si_3N_4 at different moments in time as an arbitrarily stored charge is scattered; t (seconds)=: 1) 0; 2) 1.6; 3) 22; 4) 104; 5) 203; 6) 303. d_N – 180 nm, d_{ox} = 10 nm, $N_t = 6 \cdot 10^{18}$ cm^{-3}, Φ_t^e = 1.4 eV, $\nu^e = 10^8$ sec^{-1}, $\sigma_t = 4 \cdot 10^{-13}$ cm^2, $N^* = 3 \cdot 10^{17}$ cm^{-3}, $F_0 = 1.35 \cdot 10^6$ V/cm, V = +50 V, T = 453 K, $P_t = \sigma_t n_c \nu_d (N_t - n_t)$, $P_i = \nu^e n_t \exp[(\Phi_t^e - \beta F^{1/2})/kT]$.

Fig. 4. Characteristic time τ_1 as a function of the electric field in silicon nitride at coordinates corresponding to the Frenkel effect of Eq. (5): (a) electrons, (b) holes; d_{ox} = 50 nm, d_N = 150 nm. Fabrication technique) III. (1) 573°K, (2) 513°K, (3) 473°K, (4) 413°K, (5) 373°K.

The physical basis for using the simplified model is that the characteristic time τ_i for thermally ionizing the traps is more than ten times greater than the characteristic trapping time $\tau_i = (N_t \sigma_t \nu_d)^{-1} \approx 10^{-12}$ sec (for $N_t = 10^{18}$ cm^{-3}, $\sigma_t \approx 10^{-13}$ cm^2 and $\nu_d \approx 10^7$ cm/sec) and the characteristic drift time is $\tau_{dr} \approx d_N/\nu_d \approx 10^{-12}$ sec so that traps ionization is the limiting factor and, on the whole, the kinetics of scattering are satisfactorily described by the Frenkel effect of Eq. (5). An analysis of the experimental data by the approximate model and by comparison with exact numerical computations shows that, within the limits of experimental error, the parameters Φ_t and ν coincide.

Numerical modeling of the depolarization process showed that the kinetics of charge scattering significantly depends on the initial voltage bias of the plane zones ΔV_{FB}, but depends only weakly on the combined effects of the magnitude of the charge and its centroid $\bar{x}$. In consideration of this fact, the characteristic discharge time τ_1 assumed a value obtained by extrapolating the dependence ΔV_{FB} (log τ) to zero. It follows from Fig. 2 that values of τ_1 in an MONOS device, where the injection of holes during polarization is blocked, and in an MNOS device, where the injection of holes is substantial, are close. The function $\tau_1 = f(\bar{F}, T)$ for electrons is shown in Fig. 4 for a different Si_3N_4 fabrication technique. Functions corresponding to Eq. (5) for $\varepsilon_\infty = n^2 = 4$ are shown by lines in Fig. 4. An analysis of the experiment by the approximate model yields $\Phi_t^e = 1.37 \pm 0.1$ eV, $\nu^e = 10^{6 \pm 1}$ sec^{-1}. Devices having the silicon nitride obtained by the other fabrication techniques were studied in a similar fashion. The parameters for deep trapping centers in the nitride, obtained by different techniques, are shown in Table 1.

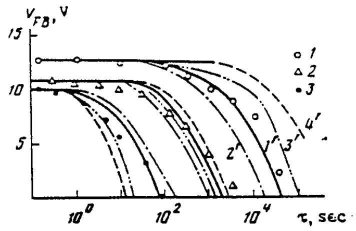

Fig. 5. Kinetics of electron scattering at different temperatures; V = +40 V, experiment: T = (1) 403°K, (2) 453°K, (3) 523°K. Computation of Φ_t^e and ν^e respectively: (1') 1.4 eV, $2\cdot10^8$ sec^{-1}; (2') 1.35 eV, 5×10^7 sec^{-1}; (3') 1.5 eV, $2\cdot10^9$ sec^{-1}; (4') 1.6 eV, $2\cdot10^{10}$ sec^{-1}. Device parameters are the same as in Fig. 2.

numerical analysis showed that varying the electric field F (when T = const) allows to be determined, but does not offer the opportunity of uniquely determining Φ_t and ν. ›ossible to uniquely determine the magnitudes of the frequency factor and the level by comparing the results of the computations and the experiments performed at differ- nperatures with a constant electric field intensity. Varying ν shifts the kinetic func- along the lg τ axis and the value of Φ_t affects the value of the characteristic spacing its of lg τ_i) of curves taken at different temperatures. This analysis for the data of yields $\Phi_t^e = 1.45 \pm 0.05$ eV and $\nu^e = 10^{8 \pm 1}$ sec^{-1}. Processing these experiments by the ap- ate model yielded $\Phi_t^e = 1.5 \pm 0.1$ eV and $\nu^e = 10^{7 \pm 1}$ sec^{-1}. The parameter values de- ed by the exact and the approximate models are in good agreement.

NONSTATIONARY HOLES TRANSPORT

ın MNOS device having a gold electrode was used to store a positive charge. Storing the from silicon in devices having a thick SiO_2 layer is difficult because of the large po- ıl barrier at the Si—SiO_2 interface and holes are therefore stored in MNOS devices by :ing a charge from the positively biased gold electrode (Fig. 1, IIIa) at a temperature)0°K. It was established that carrier injection in this case was caused by a thermally :ed tunneling mechanism [3]. To explain the affect of the contribution made by the pos- injection of electrons from the silicon during polarization, the bias voltage in the r zones ΔV_{FB} was compared with the charge in the external circuit. The following equation

$$\Delta V_{FB} \simeq \int_0^\tau j_{ext}(t)\,dt. \qquad (6)$$

'ound to be accurate to within 10%, where j_{ext} is the current in the external circuit. :ion (6) is satisfied when the amount of electrons injected from the silicon is small. In :ion, direct support for blocking of electron injection from the silicon into the Si_3N_4 ıat charge storage in the control MNOS devices having an aluminum electrode is absent.

Following polarization, a negative voltage was applied to the metal electrode and the :ics of the holes draining onto the metal electrode at different field tensions and tem- tures was studied (Fig. 1, IIIc).

An analysis similar to that made for stored charge scattering was made of the kinetics epolarizing positively charged MNOS devices (Fig. 2). In keeping with the experimental (Figs. 2, 4) the kinetics of hole and electron transport agree within the limits of er- for a given Si_3N_4 fabrication technique, i.e.,

$$\Phi_t^e = \Phi_t^h, \quad \nu^e = \nu^h. \qquad (7)$$

atisfied.

THE MODEL FOR DEEP CENTERS

We will isolate the basic properties of trapping centers: a) the symmetry of the hole electron traps parameters: the relations $\Phi_t^e = \Phi_t^h$, $\nu^e = \nu^h$; b) activation energy as

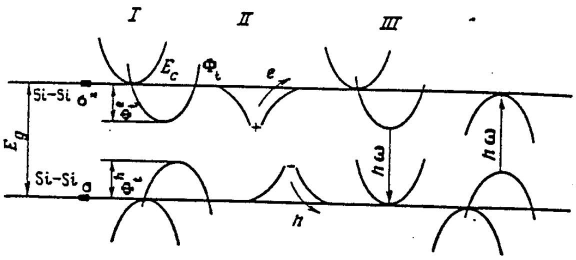

Fig. 6. A polaron model for carrier trapping in Si_3N_4 at a neutral ≡Si—Si≡ defect. The configuration diagrams illustrate multiphonon trapping and the recombination of local carriers with free carriers of opposite sign: I) multiphonon capture; II) emission; III) trapping and recombination; E_g = 4.6 eV.

functions of electric field intensity (the Frenkel—Poole effect) and the large trappi tion $\sigma_t^e = \sigma_t^h = 5\cdot10^{-13}$ cm² [12] attest to the far-reaching nature of the voltage (a distances, ~1 nm, the voltage is near a Coulomb voltage), and; c) the large recombina tions for holes and electrons that were observed experimentally in the Si_3N_4: σ_r = 3 cm² in [7] and $\sigma_r = 5\cdot10^{-14}$ cm² in [13].

The model for a compensated semiconductor [3], in particular the volt—ampere cha istics of the defects [14], may explain the first two properties, however, they do no plain the large recombination sections.

It is possible that the properties observed can be explained by a polaron model l the hypothesis that neural Si_3N_4 defects exist in the ≡Si—Si≡ [15, 16]. The bonding (antibonding σ*- orbitals in such a defect coincide with the edges of the E_v and E_c in (Fig. 6). Localizing holes and electrons proceeds via multiphonon transition into a s having negative energy Φ_t'. The gain in energy due to polarizing the lattice during t trapping on a defect of radius R_0 can be estimated by Mott's formula:

$$\Phi_t \simeq -q^2/\varepsilon_p R_0;\quad \varepsilon_p^{-1} = \varepsilon_\infty^{-1} - \varepsilon^{-1}.$$

In Si_3N_4 ε_∞ = 4, ε = 7, and the value Φ_t = 1.5 eV corresponds to R_0 = 0.1 nm. The la ping section in this model is qualitatively explained by the fact that the wave functi the σ- and σ*- orbitals are very delocalized. The large recombination section is expl by Coulomb attraction of local carriers to free carriers having opposite sign. Parame that depend on the sign of the charge carrier (e.g., m*) do not appear in Eq. (8), the the polaron model explains the equality $\Phi_t^e = \Phi_t^h$. The ≡Si—Si≡ defects model explains absence of diamagnetic centers in unpolarized Si_3N_4 [15]. Equation (8) is inwardly cc dictory, because the macroscopic parameter ε_p appears along with the microscopic para R_0 at characteristic dimensions of which the ε concept in the problem loses strict mea Also, the individual properties of the defect at which the polaron was trapped do not in Eq. (8).

DISCUSSION OF RESULTS

The principal result of this work is experimental proof that the parameters of ho electron traps in the body of the Si_3N_4 are equal. From this fact and the injective n of conduction in the Si_3N_4 [18] we can draw the general conclusion that the sign of the carrier in the Si_3N_4 is determined by the barrier, which assures a high level of carri jection for a given polarity.

The potential barrier for electrons at the Al—Si_3N_4 interface is Φ_0^e = 2.0-2.1 eV the corresponding barrier for holes lies in the Φ_0^h = 2.5-3.0 eV range [19]. Even whe ative voltage is applied to the metal (Al) in MNOS devices having a thin SiO_2 layer, h jection from the Al into the Si_3N_4 is negligible in comparison with holes injection fr silicon [4]. From here it follows that holes injection from the Al into the Si_3N_4 is r less likely at a positive voltage in comparison with electrons injection at another vo (because $\Phi_0^h > \Phi_0^e$). Thus, from the barrier parameters at the contacts point of view can conclude that when a positive voltage is applied to the metal, electrons are the m contributors to conduction in MNOS devices. In other words, an MNOS device having an aluminum electrode is well described by model A. However, the possibility of realizing model B is not excluded. This variant of conduction apparently occurs in devices having gold or partially silicon electrodes (when V > 0) or with a negative bias on the metals with little work at the output. Bipolar injection was observed experimentally in a nonstationary mode in [20] and was analyzed theoretically in [6, 21].

The results of this work do not clarify the nature of the unusually small value of the frequency factor ν. Note that values of $\nu = 1.2 \cdot 10^{8}$ sec^{-1} were observed in [22] and $\nu = 5 \times 10^{8}$ sec^{-1} in [23].

CONCLUSIONS

1. A method of determining the parameters Φ_t and ν for hole trapping centers was proposed and realized experimentally.

2. It was experimentally established that the parameters of deep electron and holes centers are

$$\Phi_t^e = \Phi_t^h, \quad \nu^e = \nu^h$$

for all three Si_3N_4 fabrication techniques.

3. A numerical analysis of the kinetics of depolarizing a negative charge was made. Charge scattering is accompanied by intense retrapping. Nevertheless, the experiment is satisfactorily described by the simplified model, not considered trapping.

4. A polaron model of holes and electrons trapping on a neutral ≡Si—Si≡ defect in Si_3N_4 was proposed. In keeping with this model, electrons (holes) were initially trapped in the antibonding (bonding) orbitals of an Si—Si defect that coincide with the E_c and E_v zone edges in the Si_3N_4. Carriers were localized by the subsequent multiphonon transition. The model explains the basic experimental data for the transport of holes and electrons in Si_3N_4 qualitatively.

5. The equality of the parameters for deep centers and the relationship of potential barriers for injecting holes and electrons in MNOS devices support using the two-zone monopolar model to describe conduction in the Si_3N_4, i.e., by electrons when a positive voltage is applied to the aluminum and by holes when a negative voltage is applied — not by the hole model proposed in [6, 7].

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FRENKEL-LIMITED MONOPOLAR CONDUCTIVITY OF MNOS STRUCTURES

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The reduction in the thickness of Si_3N_4 films associated with increasing integration of MNOS memory matrices has stimulated research on the physical mechanisms of charge transfer in dielectrics. There is no unique interpretation of the experimental data. In particular, two models are used to explain the conductivity of MNOS structures:

1. The monopolar two-band model [1, 2], according to which for both polarities of the potential V_g applied to a metallic contact (Al) charge transfer is realized by carriers injected from the silicon.

2. The hole model, according to which for $V_g < 0$ transfer is realized by holes injected from the silicon, while for $V_g > 0$ it is realized by holes injected from the Al electrode [3, 4].

The numerous experiments on stationary currents in the state of nonequilibrium depletion or MNOS structures [1, 5] and on the separation of the electronic and hole components of the current in MNOS transistors [2, 4, 6] do not permit choosing unequivocally one or the other model.

The first theoretical studies of the transition from the nonstationary to the stationary state, carried out in [7] and independently in [8], demonstrated the determining effect of spece charge on current flow in both states. However, a number of questions have remained unresolved.

The purpose of this work is a) to clarify the limiting factors of charge-carrier transfer in the nonstationary and stationary states under conditions of polarization of the structure and b) to make a quantitative comparison of the experimental results on the conductivity of MNOS structures with Si_3N_4 layers of different thickness over a wide range of fields and temperatures with numerical calculations based on the monopolar, one-level model.

EXPERIMENT

The experimental data were obtained on MNOS structures with an SiO_2 film thin enough (20 Å) to permit tunneling. The thickness of the Si_3N_4 layer in different structures equaled d_N = 390, 740, 1350, and 2500 Å. The silicon nitride layers were obtained from SiH_4 and NH_3 in a low-pressure reactor, T_{syn} = 850°C, and SiH_4/NH_3 = 1:30. The metallic contact consisted of an Al electrode with an area of $S = 5\cdot10^{-3}$ cm². Silicon nitride prepared in this manner is characterized by the existence of trapping centers with energy ≈1.4 eV, which is convenient for the experimental study of the conductivity because of the insignificant relaxation of the current when a constant voltage is applied. Since the main evolution is over ≈1 sec after the external voltage is applied, after which long-time current relaxation with an insignificant change in the magnitude of the current (≈10%) occurs, the current measured 3 min after the onset of polarization was adopted arbitrarily as the quasistationary value of the current.

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