1. INTRODUCTION

Studies of the properties of porous-silicon structures with deposited metal particles demonstrate that the development of new composite materials possessing catalytic and sensor properties and high biological activity is promising [1].

It has been noted that the passivation of nanoporous silicon with iron enhances and stabilizes the photoluminescence (PL) from this material [2–4]. A study of the electrical properties of structures based on iron-passivated mesoporous silicon SiMP:Fe has shown that the conductivity and barrier properties in Al–SiMP:Fe–p-Si–Al structures ambiguously depend on the iron concentration. In the case of a sample with space-charge-limited currents (SCLCs), the charge-transport mechanism in the Al–SiMP:Fe–p-Si–Al heterostructure changes under illumination from the SCLC type to the barrier type. Passivation with 0.1–0.2 at % iron stabilizes not only the electrical, but also the photoelectric and photovoltaic properties of the structures. A further increase in the Fe concentration gives rise to new traps caused by the appearance of iron and silicon oxides, which leads to instability of the properties. The structures exhibit high sensitivity under low-level illumination. The open-circuit voltage is 16 mV under AM-1 irradiation (~2 mW/cm²).

2. SAMPLES AND MEASUREMENT PROCEDURE

Mesoporous silicon layers were produced by the method of electroless etching (EE) of silicon, which consists in the removal of silicon atoms through the reduction of silver ions, Ag⁺ → Ag⁰, in an aqueous solution of AgNO₃ (0.02 M) and hydrofluoric acid (5 M) at a temperature of 20°C over the course of 1 h. To remove silver, the samples were etched in concentrated nitric acid for 1 h. The absence of silver was confirmed by elemental analysis data facilitated by scanning microscopy. As substrates served single-crystal p-Si (100) wafers (KDB-4.5, p-Si:B with a resistivity of 4.5 Ω cm). A part of the substrate surface remained protected from exposure to the solution. The resulting structures had a columnar–porous morphology previously described as an “array of nanowires” and illustrated by Fig. 1a in [5]. The mesoporous silicon layers were passivated in an etching (HF : C₂H₅OH : H₂O = 1 : 1 : 1) or aqueous solution of Fe(NO₃)₃ with a concentration of 0.1–0.5 M. The passivation duration was varied from 5–10 min to 24 h. Upon being passivated, the samples were washed in ethanol and then dried in air. Previously performed microanalysis showed [7] that iron is present in the samples at a concentration of 0.1–0.2 at % upon passivation in an aqueous solution of 0.1–0.3 M Fe(NO₃)₃ for 5–10 min and at a concentration of ~1 at % after a sample was kept in a 0.5 M Fe(NO₃)₃ : H₂O solution for 24 h. Al–SiMP:Fe–p-Si–Al heterostructures were fabricated from the passi-
Fe in an aqueous solution of $\text{Fe(NO}_3\text{)}_3$, which is of the heating of the sample to 120°C for 30 min to clean its (Fig. 1). The forward barrier type in the dark, remains so under illumination.

The open-circuit voltage steps in the range 0–10 V. The currents measured in the dark current upon illumination, $I_V$ (curves 1–3) illumination to the initial $I_V$ with the $\mu_e \tau_n$ product increases from the initial value of $2 \times 10^{-5}$ cm$^2$ V$^{-1}$ to $8 \times 10^{-5}$ cm$^2$ V$^{-1}$. At a Fe content of $\approx 0.1$ at %, $\mu_e \tau_n$ decreases to $1.6 \times 10^{-5}$ cm$^2$ V$^{-1}$, which is close to the value before passivation with Fe.

—The photocurrent mainly varies with voltage in the reverse $I–V$ characteristic (Fig. 1). The photocurrent gain $G$ at voltages in the range 0.1–0.5 V upon passivation with 0.1–0.2 at % iron (curves 2–2') decreases by a factor of $\approx 1.5$ compared with the initial iron-free sample (curves 1–1') and becomes 40–50. This is possibly due to the simultaneous increase in the dark current upon passivation with Fe [7]. Raising the concentration of iron further leads to a sharp fall in the gain coefficient $I_{ph}/I_d$ (curves 3–3').

—At an iron content of 0.1–0.2 at %, both the forward and reverse currents return after illumination is terminated to their initial values within 5–20 s at voltages in the range 0.1–5 V.

With the iron content increasing to 1 at %, there appears a high residual photoconductivity (PPC) equal to the ratio of the difference of the dark currents after ($I_{ph}$) and before ($I_d$) illumination to the initial dark current $I_d$. This ratio is 1.4–10, depending on the applied voltage (Fig. 2, curve 2). In addition, some samples show oscillations of the photocurrent $I_{ph}$ and the dark current upon illumination, $I_{dph}$, at applied voltages of 0.05–0.5 V (Fig. 3). With increasing voltage ($V> 1$ V), the amplitude of the current oscillations and the residual photoconductivity decrease. The current decay times are from several seconds to tens of seconds. These processes are associated with the capture of photogenerated carriers and their release from deep traps created by the passivation of SiMP with iron.

—The energy position $E$ of the traps affecting the photoprocesses can be estimated from the photocurrent in the saturation region under reverse bias. Provided that the photocurrent is similar to the quasi-

3. RESULTS AND DISCUSSION

Our study made it possible to determine the following.

—Photoelectric and photovoltaic characteristics of structures SiMP:Fe depend on the concentration of iron administration ambiguously.

—The $I–V$ characteristic of the Al–SiMP:Fe–p-Si–Al heterostructure produced by passivation with Fe in an aqueous solution of $\text{Fe(NO}_3\text{)}_3$, which is of the barrier type in the dark, remains so under illumination (Fig. 1). The forward $I–V$ characteristic has a negative current portion at low voltages of 0.01–0.2 V (see inset of Fig. 1). This means that there appears a positive charge and corresponding photovoltage to the SiMP:Fe–p–Si heterojunction, which causes a current directed oppositely to the forward current. This current is compensated for by an increase in the applied forward voltage due to the injection of minority carriers from the Al–SiMP:Fe Schottky barrier and corresponds to the open-circuit voltage $V_{oc}$. The value of $V_{oc}$ depends on the concentration of the introduced iron creating additional surface states.

The value found for $\mu_e \tau_n$ are in the range ($10^{-7}$–$10^{-4}$) cm$^2$ V$^{-1}$, depending on the concentration of introduced iron. For example, at a Fe concentration in the sample of 0.1–0.2 at % and a voltage of 1 V the $\mu_e \tau_n$ product increases from the initial value of $2 \times 10^{-5}$ cm$^2$ V$^{-1}$ to $8 \times 10^{-5}$ cm$^2$ V$^{-1}$. At a Fe content of $\approx 0.1$ at %, $\mu_e \tau_n$ decreases to $1.6 \times 10^{-5}$ cm$^2$ V$^{-1}$, which is close to the value before passivation with Fe.