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CVC STRUCTURE OF PtSi - Si<Pt>-M IN A WIDE RANGE OF TEMPERATURES

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In this work the mechanism of current flow during illumination with $h\nu \geq E_g$ in the temperature range of 77÷300 K is considered. It is established that in the PtSi – Si<Pt>-M structure in the temperature range of 77÷270 K the regime of space charge limited currents (SCLC) is realized. The current-voltage characteristics of the structures show areas of linear and quadratic dependences of current on voltage, as well as areas of a sharp increase in current. These features of the current-voltage characteristic are explained by the presence of deep level structures and sticking levels for charge carriers in the base region. From the temperature dependence of the SCLC, the concentration of adhesion levels was determined to be equal to (1.8÷3) 10^{15} cm^{-3} and the adhesion factor to be equal to $6.32 \cdot 10^{-2}$. In the temperature range 77÷115 K at voltages 0.2÷1 V, the current-voltage characteristic obeys the law $J \sim U^n$(n=3÷4), and above U – the law $J \sim U^6$, followed by a transition to the quadratic law.

Key words: *Structure; Diffusion; Concentration; Level of Adhesion; Photoconductivity; Trap; Injection; Silicide; Silicon; Platinum*
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INTRODUCTION

Currently, complex theoretical and practical work is being carried out on the research of optical and electro-optical properties of various wide bandgap materials [1-3].

The world's leading research institutes are studying the physical processes occurring in the bulk of monocrystalline silicon after doping with impurities, creating deep levels [4-9]. In such crystals, the surface layer with a thickness of 150-200 microns were considered to be damaged and of no practical interest.

However, for an in-depth study of the process of diffusion doping of silicon with metals and atoms of rare earth elements [10,11], it is relevant to consider such important issues as the physics of the formation of a heavily doped surface and near-surface region, the nature of the formation of metal silicides, which are very different from the metal and semiconductor, as well as the mechanism of current flow through the near-surface region and the bulk part of the crystal [12,13].

Therefore, in this work, the current-voltage characteristics (CVC) were studied through a structure consisting of a near-surface and bulk part of diffusion-doped silicon with platinum atoms.

EXPERIMENTAL PART

To dope silicon with platinum, single-crystal silicon ingots of p-type KDB-10 grade, grown by the Czochralski method, were used. Their initial parameters are as follows: for p-type silicon, resistivity ρ = 10 Ohm·cm, hole mobility μ_p = 430 cm^2 / V·s, hole concentration $n_p = 1.5 \cdot 10^{15}$ cm^{-3}, oxygen concentration $\leq 1 \cdot 10^{15}$ cm^{-3}.

Samples in the form of a parallelepiped with dimensions of 1.5×5×12 mm^3 were cut from single-crystal silicon ingots using a diamond disk. The samples were ground using silicon carbide micropowder M-5, M-10. In order to remove the surface layer damaged during grinding, the samples were degreased in toluene at a temperature 40-50 °C and subjected to chemical etching in a solution of 1HF:5HNO$_3$ for 1÷2 minutes, washed in deionized water and dried at a temperature of no more than 100 °C. Silicon samples were placed in quantities of 3 in quartz ampoules, previously washed in a solution of HNO$_3$÷3HCl and boiled in distilled water [14].

Metal powder of 99.999 purity in an amount of 3÷5 mg was placed into the ampoule. Ampoules with samples and diffusant were evacuated to a vacuum of ~10^{-3} mm Hg ($1.33 \cdot 10^{-1}$ Pa) and sealed. Then the ampoules were placed in a horizontal oven and annealed at a temperature of 950÷1000 °C for 50 minutes up to 2 hours. Temperature fluctuations in the working area of the furnace did not exceed ±5 °C. After annealing, the samples were quenched by cooling at a rate of 100-150 degrees/s by dropping the ampoules into water and kept to a crystal temperature of T = 15-20 °C. After opening the ampoules, the surface of the samples had p-type conductivity.

Due to the fact that the samples had a surface layer with high conductivity, to eliminate its shunting effect, the samples were ground off on three sides to a depth of about 40-50 μm. Electrical contacts were connected to two opposing

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unpolished highlanders, and measurements were taken on the unpolished surface lying between them while successively removing thin layers. It turned out that the conductivity profiles have two sections: the near-surface area with increased conductivity and the volume area with conductivity close to its own. Parallel measurements of conductivity and the Hall effect [15] at temperatures T=77÷300 K showed that the near-surface layer has p-type conductivity, with a carrier concentration of ~10^{20}÷10^{21} cm^{-3} and Hall mobility μ_H=2÷6 cm^2/V·s and volumetric – i-type conductivity, with carrier concentration 10^{10}÷10^{12} cm^{-3} and mobility μ_H=300÷400 cm^2/V·s.

The measurement results showed that the near-surface anomalous layer has a carrier concentration of ~10^{20}÷10^{21} cm^{-3} and a Hall mobility of 1÷17 cm^2/V·s. Calculations have shown that the surface layers of Si<Pt> with a thickness of 1÷5 μm have a specific conductivity of (1.6÷9.9)·10^3 (Ohm·cm)$^{-1}$.

RESULTS AND DISCUSSION

PtSi-Si<Pt>-M structures were fabricated based on diffusion-doped silicon with platinum. The blocking contact was created by applying NiGa or AlGa alloys to the side surface of the base area of the structures or by pressing a metal contact on the same surface. When this structure is formed, the Longini-Green mechanism occurs, which consists in the fact that the base region becomes highly resistive. Therefore, at low temperatures, when the level of thermal generation is low, an analogue of the structure is a dielectric diode.

The current-voltage characteristics of the structure were studied at different temperatures. Carriers injected from the contacts will fill stationary charged centers (SCCs) in the space charge region (SCR) [12]. From the solution of the equation, it follows that the length of the SCR is proportional to $\sqrt{N_{SCC}}$, i.e. with a decrease in the concentration of immobile charged centers (N_{SCC}), the length of the SCR increases and, ultimately, the length of the high-resistivity region W decreases. At sufficiently small W, when the base is considered thin, the regime of space charge limited currents (SCLC) will be realized in the structure.

The dark current-voltage characteristic of structures at T = 300 K is linear (Ohm's law is satisfied) throughout the entire range of applied voltage. However, when the temperature of the samples is lowered to T = 77 K in the dark at biases U > 10 V, the value of the dark current decreases to 10÷12 A, which makes it impossible to measure the current-voltage characteristic [13-16]. Therefore, in order to study the injecting properties of contacts, current-voltage characteristics were measured by photoexcitation with hν = 1.4 eV both in the near-contact and in the middle parts of the base region of the structures. In this case, the power of the incident local radiation did not exceed 1÷2 mW.

Figure 1 (curve 1) shows the direct current-voltage characteristic curve and curves 2–5 show a family of reverse current-voltage characteristics in the temperature range T=77÷145 K, and Figure 2 shows the direct current-voltage characteristic (curve 1) and the reverse one (curve 2–6) in the temperature range from 160 K to 300 K. As can be seen from the curves above, at U = 10 V the photocurrent increases with decreasing temperature.

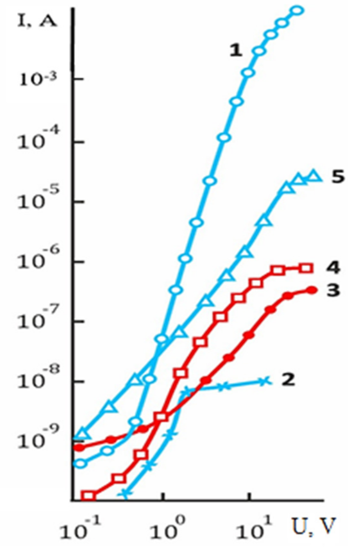

Figure 1. Current-voltage characteristics of the PtSi – Si<Pt>-M structure in the temperature range 77÷145 K. 1 - 77÷145 K, "plus" voltage on PtSi, 2 – 77 K; 3-115 K; 4-125 K; 5-145 K; 2÷5 – "Plus" voltage on the metal

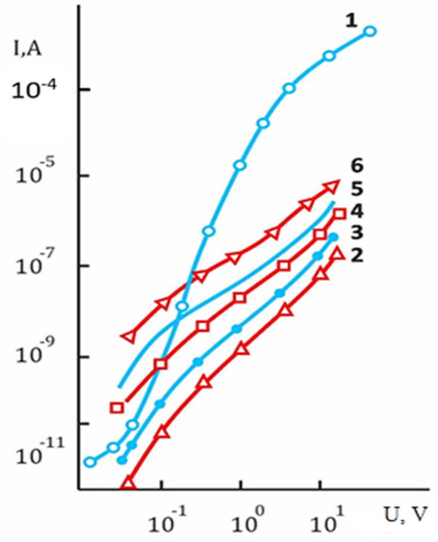

Figure 2. Current-voltage characteristics of the PtSi – Si<Pt>-M structure in the temperature range 160÷300 K. 1 - 160÷300 K, "Plus" voltage on PtSi, 2 – 160 K, 3 – 180 K, 4 – 250 K, 5 - 270 K, 6 – 300 K

Starting from a temperature of 250 K and below, a change in the course of the current-voltage characteristic curves is observed: for the curve at T = 250 K, a section J ~ $V^{3.3}$ is observed, followed by a section with a quadratic dependence, and for temperatures below 180 K on the current-voltage characteristic there are sections of a sharp increase in current and quadratic dependence of current on applied voltage. The transition voltage, starting from which the section of sharp increase in current turns into a quadratic section, does not depend on the temperature in the region T = 77÷250 K.

The current-voltage characteristics at $T=300$ K were almost symmetrical and linear. Under illumination with $h\nu>1.2$ eV, an increase in the photocurrent by 5–6 times relative to the dark current is observed in the case when a positive bias is applied to the silicide contact, and approximately 2 times with reverse polarity.

At low temperatures, a current-voltage characteristic characteristic of an SCLC with ohmic, quadratic sections and sections of a sharp increase in current is observed, followed by a transition again to quadratic sections. Another proof of the SCLC mode in such structures is that the electric field with a physical base length of 45 μm (determined from capacitance measurements) at biases of 10÷15 V has a value characteristic of this mode of $\sim 10^3$ V/cm.

The presence of a vertical section preceding the quadratic section gives grounds to believe that there are monoenergetic levels of attachment for holes located significantly below the quasi-Fermi level F, i.e. condition is met $(F-E_t)/kT>>1$, because up to the voltage of completely filled traps (U_{CFT}), all attachment levels for holes are occupied by electrons. In hole high-resistivity silicon, levels below the equilibrium Fermi level are occupied by electrons, i.e. "empty" for holes, so $P_{t,o}=N_t$.

In this case, the concentration of adhesion levels is equal to $(1.8\div3)\cdot10^{15}$ cm^{-3}, the adhesion factor is equal to $6.32\cdot10^{-2}$. Traps are sticking levels for holes, and the presence of such sticking levels is evidenced by the fact that long-term relaxation of photoconductivity and residual conductivity, as well as thermally stimulated conductivity, are observed in these structures.o dope silicon with platinum, single-crystal silicon ingots of p-type KDB-10 grade, grown by the Czochralski method, were used. Their initial parameters are as follows: for p-type silicon, resistivity $\rho = 10$ Ohm·cm, hole mobility $\mu_p = 430$ cm^2 / V·s, hole concentration $n_p = 1.5\cdot10^{15}$ cm^{-3}, oxygen concentration $\leq 1\cdot10^{15}$ cm^{-3}.

CONCLUSION

As a result of the scientific research, we came to the following important scientific conclusions:

1. The current-voltage characteristics of PtSi – Si<Pt>-M structures in the temperature range 77÷300 K were studied.
2. In the range $T = 125\div160$ K in the voltage range above 1 V, $J \sim U^6$ is observed.
3. In the range $T=160 \div 250$ K, the power-law dependence $J \sim U^6$ turns into $J \sim U^3$ in the voltage range 0.1 – 1 V; in this case, $U > 1$ V, the quadratic dependence remains.
4. Above 250 K, the direct and reverse branches of the current-voltage characteristic transition to a linear law.

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СТРУКТУРА ВАХ PtSi - Si<Pt>-M В ШИРОКОМУ ДІАПАЗОНІ ТЕМПЕРАТУР

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У роботі розглянуто механізм протікання струму при освітленні з hν≥Eg в інтервалі температур 77÷300 К. Встановлено, що в структурі PtSi – Si<Pt>-M в інтервалі температур 77÷270 К реалізується режим обмежених струмів об'ємного заряду (СКЗ). На вольт-амперних характеристиках конструкцій спостерігаються ділянки лінійної та квадратичної залежності струму від напруги, а також області різкого зростання струму. Ці особливості вольт-амперної характеристики пояснюються наявністю структур глибокого рівня та рівнів прилипання носіїв заряду в базовій області. За температурною залежністю СКЛК визначено концентрацію рівнів адгезії (1,8÷3) ·1015 см-3 і коефіцієнт адгезії 6,32·10-2. В інтервалі температур 77÷115 К при напругах 0,2÷1 В вольт-амперна характеристика підкоряється закону J ~ Un(n=3÷4), а вище U – закону J ~ U6 з наступним переходом до квадратичний закон.

Ключові слова: *структура; дифузія; концентрація; рівень адгезії; фотопровідність; пастка; ін'єкція; силіцид; кремній; платина*