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Electrical and Physical Properties of Structures with *p–n* Transition Produced from Silicon Obtained by Fivefold Meltdown of Metallurgical Silicon in a Solar Oven

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Abstract—The results of studying electrical and physical properties of *n–p* structures produced from silicon obtained by fivefold open-air meltdown of metallurgical silicon of KR3 silicon in a solar oven are presented. It is shown that the current and voltage generated during the heating of structures with plain ohmic contacts start to fall at around 120°C, while in structures with *n–p* transition these characteristics continue to increase at up to 250°C. It has been discovered that structures with *n–p* transition display rectifying properties in a temperature range of 30–150°C.

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Since silicon remains the basic material used in semiconductor electronics and for the production of photoelectric cells in particular, interest in obtaining this material with new methods remains unabated because the current method of purifying metallurgical silicon to obtain a material of the necessary purity required in instrumental applications is energy intensive and environmentally harmful. In this respect, interest in other approaches to purifying metallurgical silicon and materials thus produced is quite natural. In recent years, several works have been written in which the properties of silicon obtained from KR3 metallurgical silicon using a new chloride-free method—multifold open-air meltdown in a solar oven—have been studied. In particular, fivefold meltdown of this silicon allowed it to be purified 98.77 wt %. Concurrently, the resulting material appeared to have several unique characteristics. A sample with plain ohmic contacts made from this material turned to a current and/or voltage generator under minor thermal pressure (just above room temperature) [1]. At the same time, the material appeared to have spectral voltage sensibility in the infrared region [2], which is typical neither of single-crystal nor of polycrystal or noncrystalline silicon. It is therefore natural that the next stage in studying this material will be to analyze the properties of *n–p* structures based on this silicon, which is precisely the objective of this work.

The source material was common industrial KR3 silicon (according to the specifications, it consisted of Si (96 wt %), Al (1.5 wt %), Fe (1.5 wt %), Ca (1 wt %), etc.). After the fivefold open-air meltdown in a solar oven the material underwent an X-ray structural analysis as a result of which silicon appeared to contain the following weight rates of Si, Fe, Al, Se, Ca, Pb, P, Mn, Cu, and Ag: 98.77, 0.41, 0.0163, 0.015, 0.2185, 0.0007, 0.11, 0.047, 0.0185, and 0.00041 wt %, respectively. The atomic composition of the material included Si, Fe, S, Al, Se, Ca, P, Mn, Cu, Pb, and Ag (99.1, 0.21, 0.79, 0.01, 0.0053, 0.15, 0.10, 0.02, 0.008, 0.0001, and 0.00011 at %, respectively). Thus, silicon with purity of 99.1 at % was obtained, its samples were coarse-grained with variously oriented grains of ~1 × 2 mm^2 (80–85%), contained no shunt metallic impurities, and displayed *n*-type conductivity without preliminary alloying.

Plates with a thickness of ~500 μm and a diameter of 40 mm were cut out of the resulting bars of polycrystal silicon with purity of 99.1 at %. Then those plates were ground on one side and polished on the reverse, similarly to what is described in [3]. At 1100°C, boron was diffused to the polished side through borite plates. In carrying out the vacuum sputtering described in [4], an ohmic contact was coated on the ground side while an ohmic contact in the form of a nickel titanium grid was coated on the polished side. Thus, a semiconductor *n–p* structure was produced.

The current–voltage characteristic (CVC) of the resulting *n–p* structure were analyzed at the different temperatures given in Fig. 1.

In Fig. 2, the CVC of an R_{ohm}-*n*-R_{ohm} structure produced from metallurgical silicon that had been remelted five times and the corresponding CVC of the *n–p* structure at identical temperatures are compared.

It is seen that, at room temperature, the structure with ohmic contacts displays practically no rectifying properties, while the structure with *n–p* transition shows fairly good rectification, which improves as the

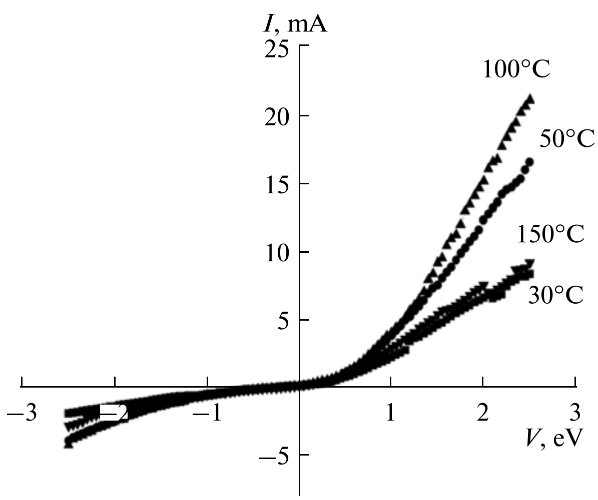

Fig. 1. Current–voltage characteristics of the *n–p* structure produced by diffusion of boron and based on silicon remelted five times at different temperatures.

temperature grows to 100°C. Figure 2d clearly shows that, at 150°C, there is a sharp downfall of current in the structure with an *n–p* transition, while, in the structure with a plain ohmic contact, an increase in current is observed.

The temperature effect on the resulting *n–p* structure was studied as well. It appeared that, similarly to the structure with plain ohmic contacts, the *n–p* structure started to generate current and/or voltage at low temperatures. For the results of studies, see Figs. 3a and 3b.

According to comparative analysis of curves *1* and *2* in Fig. 3b, dependences *V*(*T*) of both structures behave identically within a region of 30–160°C, but then the voltage in the plain structure starts to decrease, while the voltage in the structure with an *n–p* transition starts to rise and reaches 1.03 mV at 250°C. As for variations in current during the rise in temperature, it follows from curves *1* and *2* in Fig. 17a that, up until 140°C, the current in the structures with plain ohmic contacts is approximately twice as high as in the structures with *n–p* transition and only at temperatures

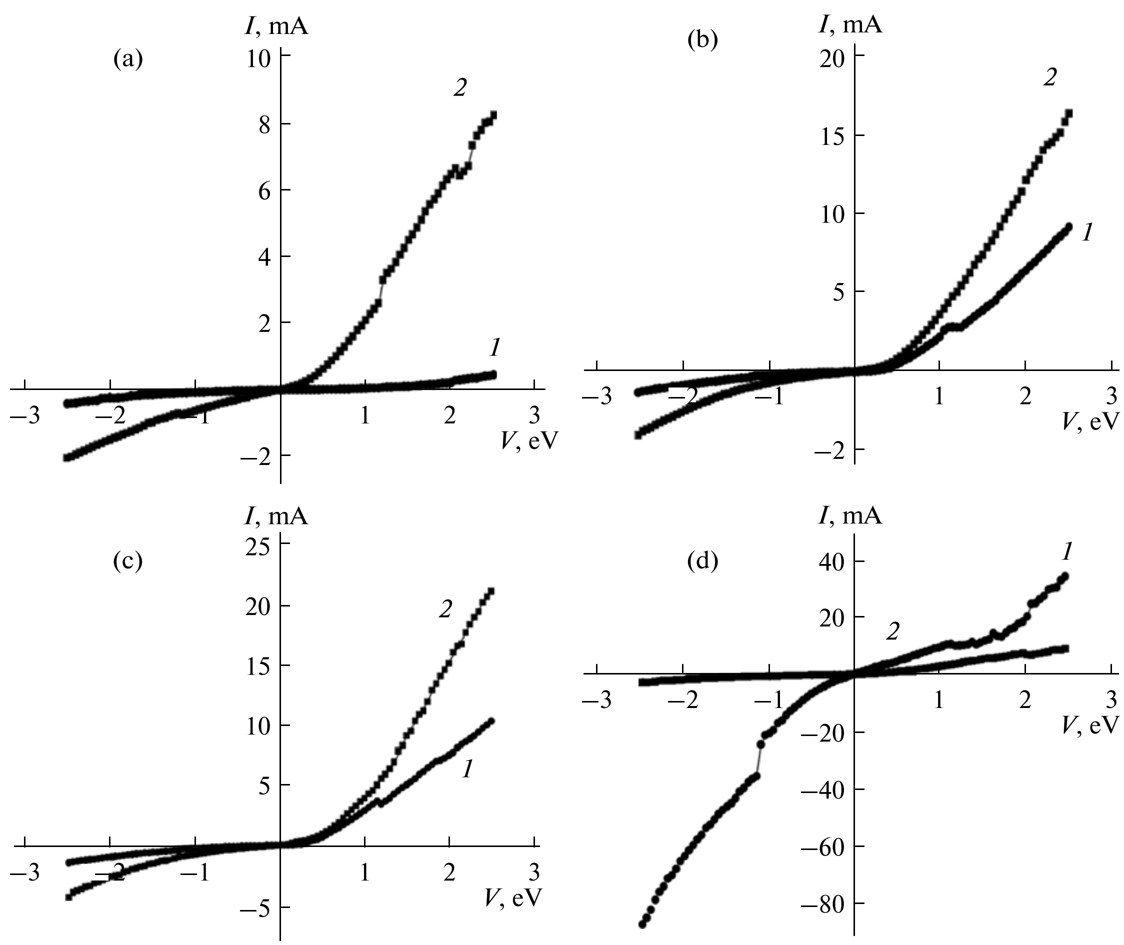

Fig. 2. The CVC of an R_{ohm}-*n*-R_{ohm} structure produced from metallurgical silicon remelted five times (curves *1*) compared with the corresponding CVC of the *n–p* structure (curves *2*) at 30, 50, 100, and 150°C (a, b, c, and d, respectively).

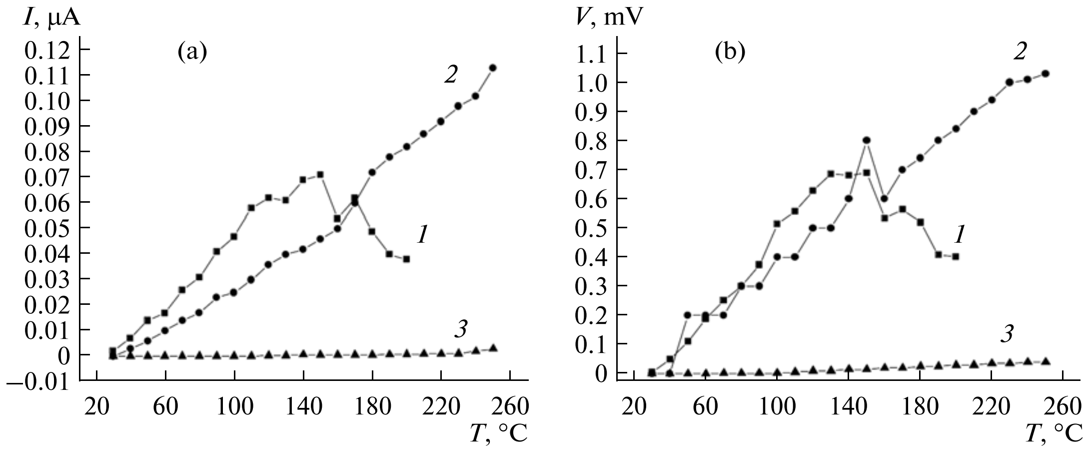

Fig. 3. Temperature dependences of (a) current and (b) voltage in the *n–p*-Si structure produced by diffusion of boron and based on metallurgical silicon remelted five times (curves *2*) and the same dependences for the structure with plain ohmic contacts, produced from metallurgical silicon remelted five times (curves *1*) and for the standard n-polysilicon photoelectric cell (curves *3*). The dependences were obtained solely under a thermal effect.

higher than 140°C does the current start to fall. Unlike in the common photoelectric cells, in which the produced current does not exceed 10^{-4} μA and the voltage is about 10^{-4} mV, the current in the structures with *n–p* transition rises up to 0.11 μA at 250°C.

It should be especially emphasized that, according to Fig. 1, the resulting *n–p* transition rectifies current even at 150°C, while it is well known that the common silicon transition stops working at about 120°C.

Thus, it has been proved for the first time ever that it is possible to produce an *n–p* transition from industrial silicon purified in a solar oven to 98.7 wt % using a chloride-free method.

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