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Photovoltaic Effect In Silicon With Schottky Micro-Barriers Created On The Basis Of Nickel Impurity Atoms And Spectral Characteristics

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ABSTRACT.

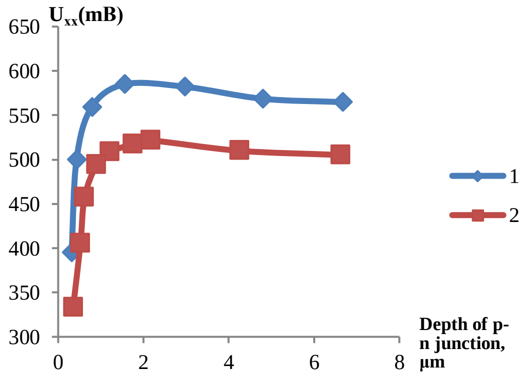
The paper shows the possibility of self-organization of microparticles of impurity nickel atoms in silicon under certain thermodynamic conditions. It was found that the concentration of microparticles in the volume is distributed almost uniformly. It was found that upon additional annealing, self-ordering of microparticles of impurity atoms in the silicon bulk and the formation of Schottky micro-barriers occur. The study of the I – V characteristics of these samples showed that at the points where the microscopy of nickel atoms formed, it has a diode character. The obtained experimental data show the possibility of creating photocells (PV) based on compensated silicon by the impurity of nickel atoms. To study the fundamental electrophysical parameters of photocells, modern methods and instruments were used, such as an MIC-5 infrared analysis microscope, Oxford Instruments ZEISS EVOMA 10 REM analysis, XIA-200 atomic force microscope, and X'PertPowder diffractometer. Micro- and nanoclusters found in silicon are explained by the accumulation of concentration of nickel atom clusters. It has been established that the overgrown clusters of impurity nickel atoms lead to an improvement in the electrophysical parameters of photocells.

Key words: cluster, impurity atoms, nickel, semiconductor, doping, supersaturation coefficient, solubility, low-temperature annealing, short circuit current, idle voltage, coefficient of performance.

1 INTRODUCTION

The study was carried out in photocells made on the basis of the initial silicon grade(silicon hole doped with boron atoms with a specific resistance of -0.5 Ohms×cm) KDB-0.5 and (silicon electron doped with phosphorus atoms with a specific resistance of - 4.5 Ohms×cm) KEF-4.5, in which the no-load voltage(Ui.v.) and short-circuit current(Is.c.) reach the highest values. It was determined that the volt-ampere characteristics (VAC) and FF-fill factor of photocells obtained on the basis of KDB-10 and KEF-40 silicon were low [1, 2].
The conducted experiments showed, that the value of the short–circuit current and the idle voltage of photocells (Fig. 1) depend on the depth of the p–n junction, and at the depth of the p-n junction of 0.8–1 microns, the short-circuit current of solar cells reaches the maximum value. With an increase in the depth of the p–n junction to 6 microns, the change in the short-

circuit current was insignificant. The results obtained allow us to determine in advance a sharp drop in the short-circuit current. In the initial samples with low resistivity, the degree of reduction of Is.c was higher than in the samples with a high value of Is.c. to achieve high values of Ui.v. andIs.c., p–n junctions with a depth of at least 0.5 microns should be obtained, which is explained by the influence of surface events at low depths of the p-n junction that go away from Is.c.[3,4]. During the temperature treatment of photocells, oxide layers of different thickness were obtained on the surface, depending on the temperature.



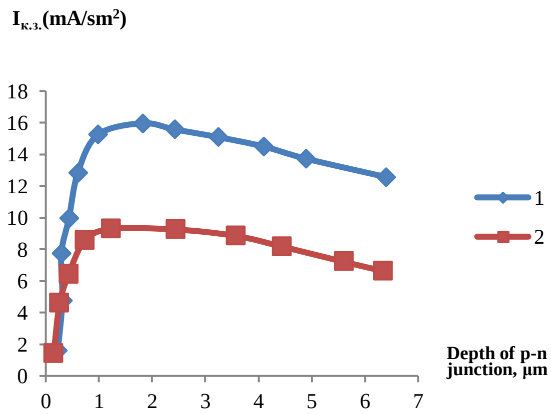


Fig. 1. Dependence of idle voltage and shortcircuit current on depth of p-junction: *a - dependence of Ui.v.- idle voltage of solar cell on depth of p-n-transition;б – dependence of short circuit current Is.c. of solar cell from depth of p-n-junction:1 – SHB-0.5; 2 – SEP-4.5, T=300 K.*

When using semiconductor materials of the SEP-4,5 and SHB-10 grades, the internal resistances of the solar cells were equal as when connected in series, a large resistance (Rs) is obtained, as a result, a decrease in Is.c. isobserved.h when introduced into samples in a small amount of concentrations of impurity Nickel atoms by doping. This, in turn, reduces the Ui.v. voltage several times. The photocells made on the original silicon of the SEP-40 brand have small currents of Is.c.

For fig. 2 the dependence of the resistance of silicon with a p–n transition on the temperature and time of diffusion is given, while figure 2a,- shows the diffusion of phosphorus on a p-type substrate, and figure 2b,- shows the diffusion of boron on an n-type substrate [5,6].

When doping silicon samples in a certain temperature range, the ordering of cluster structures of impurity Nickel atoms is established. The study of their electrophysical parameters led to the production of a VAC with a similar characteristic of the Schottky diode type.

Photovoltaic cells with Ni impurities were heat treated at different temperatures, then the current-voltage characteristics were measured. Based on the analysis of the experimental data obtained at different annealing temperatures, the distribution and mutual coupling of cluster Nickel atoms in silicon are determined.

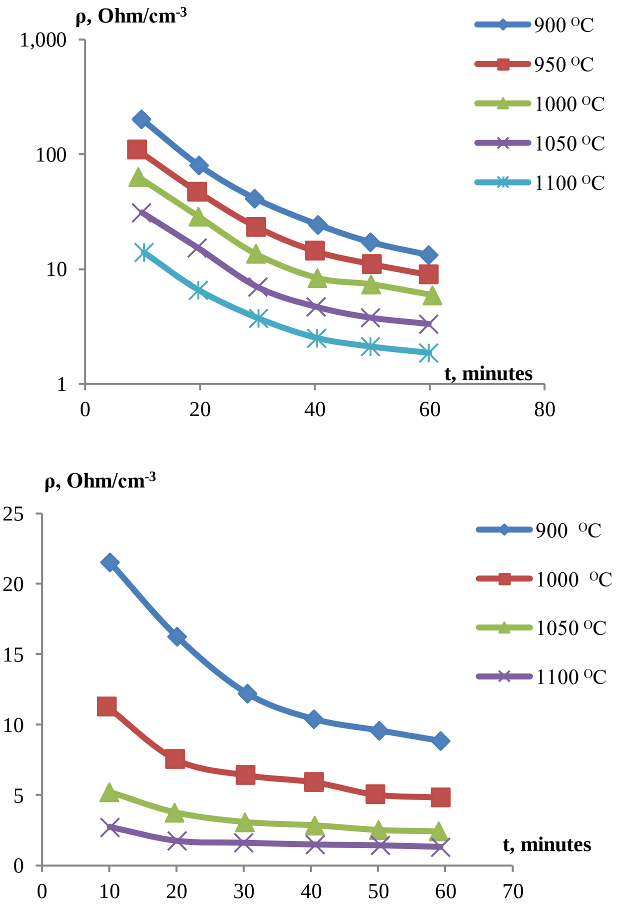


Fig. 2. Dependence of surface resistance on diffusion temperature and time: *a - phosphorus diffusion is carried out on p-type substrate; B - boron diffusion is carried out on n-type substrate.*

2. MAIN BODY

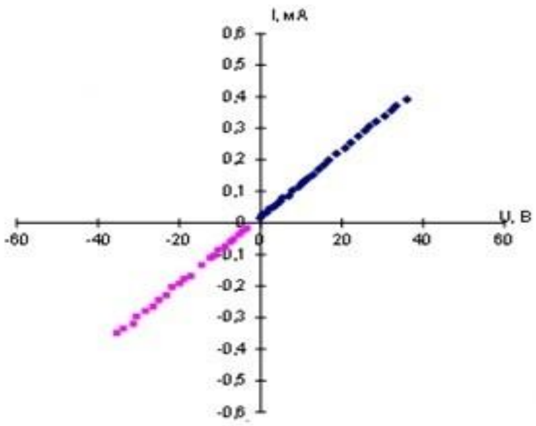
2.1 Theoretical analysis

When determining the VAC on the entire surface of the solar cells, two types of contacts were taken: in the first, a probe made of tungsten (W-probe) wire was used in the front side, and in the second, a smooth aluminum surface (Al-layer) was used. On the surface of the studied photocells, the probe moved freely along the x-y axes [7, 8]. One end of the tungsten wire probe in the micron dimension has the form of a trigonal pyramid, the tip of the second end is attached to the spring contact.

When changing the developed installation of the VAC of silicon-based solar cells with clusters of impurity Nickel atoms, at least at three points, the average value was taken, which was recorded as the result. The light-sensitive surface was determined using a probe on the sample surface [9, 10].

To remove the oxide layer of the plate surface,the photocells were treated in hydrofluoric acid (HF). Under vacuum conditions at a pressure of $8\pm0.5\times10^{-5}$ torr, a metallic layer of Nickel (Ni) was deposited on the samples by sputtering [11, 12]. To control the thickness of the resulting metal layer, one point of the photocell was selected. The evaporation method is used to obtain a layer evenly distributed over the entire surface, the thickness at the selected point is assumed to be equal to the thickness of the layer on the entire surface of the solar cells. To clean the plate from invisible blockages before spraying Ni atoms, the surface of the photoelements was heated in the temperature range T=50÷300 ^{o}C.

When measuring the VAC of solar cells, the tungsten probe was connected to the negative voltage, and the polished aluminum disk to the positive voltage. When receiving the VAC of solar cells, a voltage from -3 to +3 Volts was applied. The VAC values of the tungsten probe and the aluminum disk together with the silicon substrate are shown in Fig. 3.
After additional processing at high temperatures of 600-1100 ^{o}C of solar cells, Ni clusters formed structures of the Schottkymicrobarrier type both on the surface and in the volume. After additional temperature treatment on the surface, an increase in the size of clusters of Ni atoms and the values of the short-circuit current is observed [13, 14].



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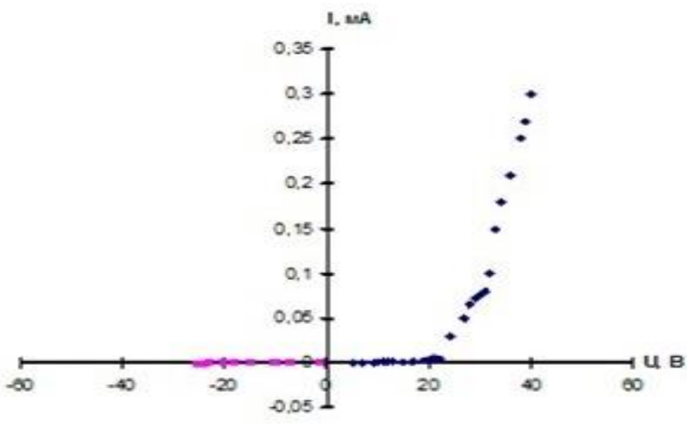
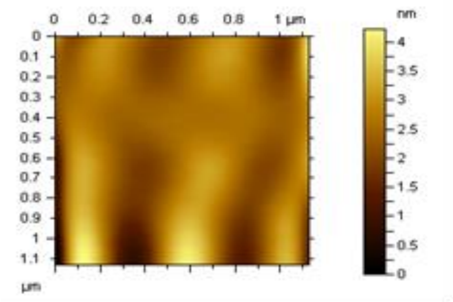


b)

Fig. 3. VAC of photovoltaic cells with micro - and nanocluster Schottky micro-barriers determined by the microprobe method (T = 300 K): *a - VAC of solar cell without clusters; b - VAC of solar*

cell with nickel micro- and nanoclusters.

The experimental study of the VAC on the surface of solar cells at some points revealed a sudden increase in current and a decrease in it at some other points, which were explained by binding to the distribution of micro - and nanocluster structures of impurity Nickel atoms in the form of Schottkymicrobarriers over the surface volumes of solar cells. With additional temperature treatment of solar cells for 2 and 3 hours, a difference in VAC was observed.



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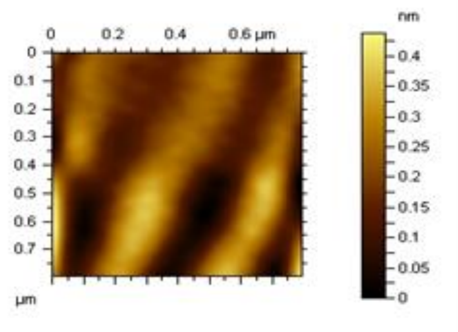

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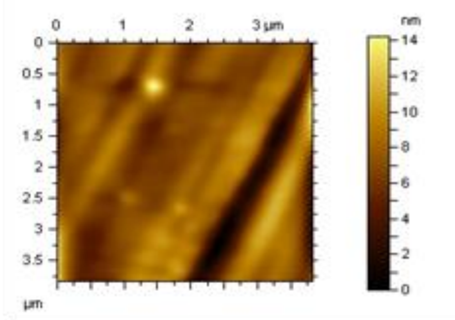

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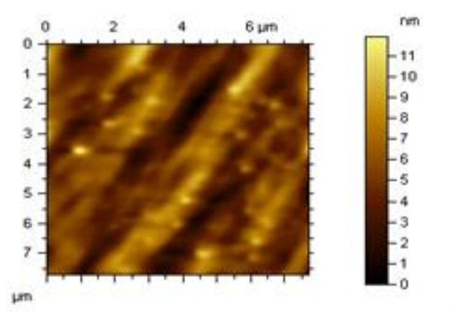


g)

Fig. 4. Microstructure patterns of solar cell surface under AFM with clusters of impurity Ni atoms at T = 300 K: *a - temperature untreated surface layer; b - after temperature*

treatment t = 1 hour; c - after temperature treatment t = 2hours; g - after temperature treatment t = 3 hours.

Research of solar cells after temperature treatment for 3 hours, a sharp increase in the current of the VAC was observed compared to the VAC of solar cells that were subjected to temperature treatment for 2 hours. The number of nanostructures based on Nickel atoms from the volume in the surface was 0.5 %. After temperature treatment of photovoltaic cells, it was determined that the longer the heat treatment time, the higher the height of the Schottky barrier and the current value will be. After additional temperature treatment, the formation of system structures of clusters of Nickel atoms on the surface and in the volume of solar cells was observed [15, 16].
Figure 4 shows an image of the surface of solar cells with Ni clusters obtained using an atomic force microscope (AFM).
Figure 5 shows the spectral dependences obtained in solar cells treated at temperatures of 600, 800, 900, 1100, 1220 0C and containing clusters of Nickel atoms. The results of the study of the spectral dependence for the initial initial solar cells subjected to heat treatment under the same conditions but containing no impurity Nickel atoms are also presented [17,18].

2.3. The results and discussion

Research under the influence of x-rays was carried out in various nodes of directed rays on the surface of solar cells. When x-rays were directed at the same angles, the spectral peaks of solar cells exposed to different annealing temperatures and having clusters of Nickel atoms were compared. For comparison, the spectral peaks of the above-mentioned solar cells were studied at angles from 20^0 to 80^0. Figure 5 shows comparisons of the spectral peaks of solar cell samples obtained at angles of 26^0-30^0.
Based on the analysis of the experimental data obtained, the cluster–silicon structure can be considered as a metal-semiconductor structure. The spectral peaks obtained on the diffractometer are shifted by a certain angle in comparison with the control samples of solar cells that do not contain clusters of Nickel atoms, and the spectra of samples of solar cells heated at a temperature of 900 and 1100 ^{0}C, which indicates the appearance of a diode character based on the Schottky barrier in solar cells with the formation of micro-and nanoclusters based on impurity Nickel atoms[19-32].

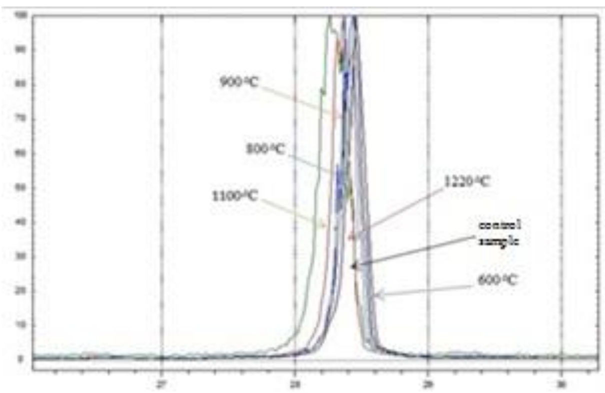
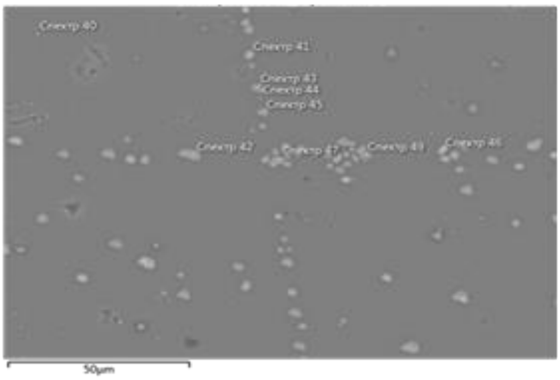


Fig. 5. Spectral dependences of solar cellsobtained by heat treatment at different temperatures and x-ray radiation at angles of 26^0–30^0.

Using an EVOMA-10 electron microscope, the surface of polished solar cells was examined under certain temperature conditions. Figure 6 shows a structural analysis of solar cell plates with impurity Nickel atoms, which were obtained using an Oxford Instruments ZEISS EVOMA-10 electron microscope.

The results obtained prove that in solar cells there are clusters of impurity Nickel atoms in the range of 9÷15%, while the experimental error was within the error range of σ=0,1÷0,2%.



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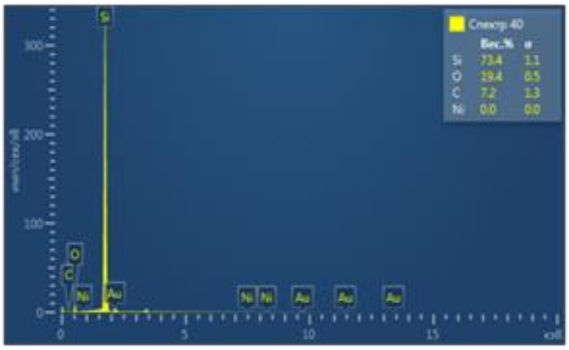

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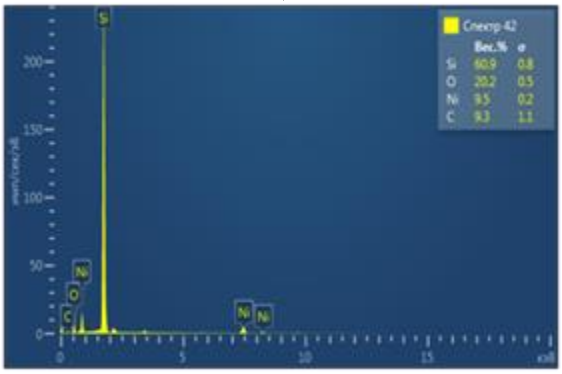

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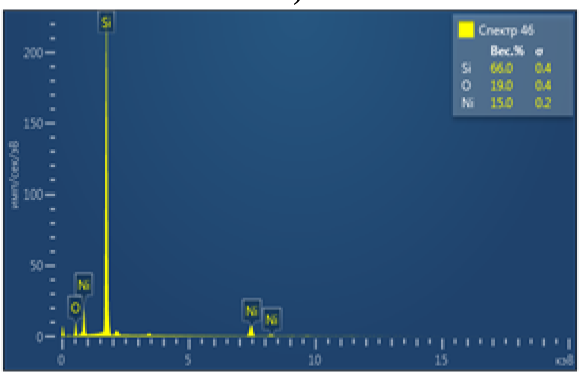

g)

Fig. 6. Pictures of the microstructure of the compositions of the surface of the solar cells with clusters of Nickel (REM): *a - distribution of cluster point zones; b - without cluster zones; c - with cluster zones at Ni = 9.5%; g - with cluster zones at Ni = 15%.*

3. EQUATIONS AND MATHEMATICS

Analysis of the results showed that solar cells containing impurity Nickel atoms in the volume can be considered as a metal-semiconductor structure. The spectral peaks obtained on a diffractometer and compared with control solar cells that do not contain clusters of Nickel atoms, as well as the peaks of the spectra of solar cells subjected to heat treatment at a temperature of 900 and 1100 ^{0}C, are shifted by a certain angle, which indicates the appearance of Schottky diodes in the volume and surface of solar cells, due to the formation of micro-and nanoclusters of impurity Nickel atoms.

After the formation of the Schottky barrier, a decrease in the value of the electrophysical parameters of additionally heat-treated solar cells was observed. If the heat treatment time was longer, this led to a sharp decrease in the initial values of Ui.v. andIs.c.

Tables 1 provide information on changes in the no-load voltage and short-circuit current from heat treatment for 1 hour. Table 1 shows information about solar cells developed on the basis of SHB – 0.5 silicon.

Table 1
Electrophysical parameters of solar cells made on the basis of silicon grade SHB - 0.5.

(SHB-0,5)The temperature of the heat treatment of solar cells °C	The average size of clusters, mkm	Uiv(mV)	I_{sc}(mA/cm^2)
1100	0,5 – 1	480	20,9
1000	1 – 1,5	482	21,4
900	1,5 – 2,5	498	45,7
800	2,5 – 3	506	28,1
Controlsample	0,5 – 1	507	20,5

Analysis of the results shows that the introduction of impurity Nickel atoms into the initial p –type silicon leads to an increase in the lifetime of non-basic charge carriers.In the new re-processed text of the article, we explained the role of the lifetime of non-basic charge carriers in solar cells, which plays an important role in improving the efficiency (efficiency coefficients) of solar cells.

In samples of the initial n – type silicon, when doped with Nickel atoms, an inverse relationship is observed, that is, a decrease in the lifetime of non-basic charge carriers. With additional processing of solar cells, it becomes stable. It was found that additional doping of SEB samples with Nickel atoms leads to a decrease in the lifetime of non-basic charge carriers.

Table 2
The spectral sensitivity of solar cells made on the basis of the initial silicon of the SEB-0,5 after the formation of clusters of nickel atoms.

№	Wavelength, mkm	I, mkA/mW
1.	0,45	562,9
2.	0,6	991,2
3.	0,9	751,4
4.	1	231,8
5.	1,2	4,3
6.	1,42	0,6
7.	1,85	0,6
8.	2,25	0,99
9.	2,65	4,4
10.	3,05	16,74
11.	3,45	13,25
12.	3,85	11,6

As can be seen from the results obtained, the spectral sensitivity of solar cells after the formation of clusters of impurity Nickel atoms increases from 1 mkm to 4 mkm, shifting in the IR region of the radiation spectrum.

4. CONCLUSIONS

The maximum electrophysical parameters of the manufactured solar cells are observed at the optimal temperature of additional thermal ignition at 900 ºC based on the formation of internal structures of clusters of impurity Nickel atoms. The no – load voltage of photovoltaic cells made on the basis of SEB-0.5 silicon after the formation of clusters of Nickel atoms with optimal heat treatment is less than that of control samples, but their short-circuit current exceeds the short-circuit current of control samples by more than two times.

The creation of silicon-based solar cells with clusters of impurity Nickel atoms makes it possible to replace expensive multi-stage solar cells based on $A^{III}B^{V}$ and $A^{II}B^{VI}$ compounds obtained using high technology. Our solar cells, compared to existing multi-stage solar cells, have a fairly wide spectral range of photosensitivity, practically covering a large area of the Solar radiation spectrum, which leads to increased efficiency. Solar cells differ in manufacturing technology, as well as simplicity and cheapness of manufacturing, which do not require expensive and complex technological equipment.

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