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Optimization of the contact grid for the GaP/Si solar cells

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Abstract. In this paper, the calculation of electrical properties for (n)GaP—p(Si) solar cells was performed for different contact grid design. The influence of annealing temperature on the current-voltage curves of solar cells was shown via the Hall measurements and the simulation respectively. For calculations 20 μm and 200 μm width contact bars were used. First group corresponds to lithography. The second one could be appropriate for mass-scalable screen-printing metallization technique. The distance between contacts was varied in the range from 50 μm to 4000 μm in case for 20 μm contact width and in the range from 200 μm to 4000 μm in case for 200 μm contact width. According to the results of calculation, the thermal annealing at 600—700 °C is optimal for 20 μm configuration of contact grid. The predicted conversion efficiency is approximately 21.5%. Relative to contact grid with 200 μm width of bars, the optimal annealing temperature is 700 °C. These conditions lead to 19% conversion efficiency.

Keywords: solar cells, heterojunction GaP/Si, screen-printing, contact grid

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Оптимизация контактной сетки для солнечных элементов на основе GaP/Si

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Аннотация. В данной работе проведен расчет электрических свойств солнечных элементов (n)GaP—p(Si) для различных конфигураций контактной сетки. Было показано влияние температуры отжига на вольтамперные характеристики солнечных элементов при помощи измерений методом Холла и моделирования. Для расчетов использовались ширина контактов 20 мкм и 200 мкм. Первая группа соответствует нанесению контактов при помощи литографии. Вторая группа может подойти для масштабируемого метода трафаретной печати. Расстояние между контактами варьировалось в диапазоне от 50 мкм до 4000 мкм при ширине контакта 20 мкм и в диапазоне от 200 мкм до 4000 мкм при ширине контакта 200 мкм. По результатам расчетов термический отжиг при 600—700 °С оптимален для конфигурации контактной сетки 20 мкм. Прогнозируемый КПД преобразования составляет приблизительно 21.5%. При ширине контактов

200 мкм оптимальная температура отжига составляет 700 °C. Эти условия соответствуют эффективности преобразования 19%.

Ключевые слова: солнечные элементы, гетеропереход GaP/Si, трафаретная печать, контактная сетка

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Introduction

The formation of contact systems is an important technological process in the design of solar cells. Materials, structure, and geometry of contacts affect the distribution of currents [1–2].

Depending on the contact position relative to the propagation of light (front or rear), they have different requirements. In the front contact system, an optimum must be observed between the shading effect and the contact resistance losses [3–4]. If the contact grid area is small, then the optical losses associated with shading will decrease, but the electrical resistance will increase. Therefore, in industrial solar cells, one can often find a configuration of mutually perpendicular current-carrying bars and strips. It is the optimal ratio between light and electrical losses.

In this work, we will calculate contact systems for the (n)GaP/(p)Si structure, we will search for the optimal distance between contacts at fixed annealing temperatures.

Materials and Methods

In our simulations, we varied the distance between contact bars and estimated its influence on the conversion efficiency. We calculated the electrical properties of GaP/Si solar cells using Silvaco software. For calculation we used spectra in the wavelength range from 0.3 μm to 1.2 μm, the spectral density distribution corresponds to the AM1.5G standard. For numerical calculations, we divided this range into 50 bands of equal width. The radiation propagated along the normal on the sample, while we considered the condition of complete bleaching with GaP (there is no reflection at the interface with GaP). For electrical calculation the Shockley-Read-Hall model was used.

The influence of the thermal annealing on electrical properties was analyzed using experimental data obtained for (n)GaP/(p)Si structures. Various annealing temperature was applied in range from 500 °C to 800 °C. Via the Hall method, we measured the concentration and the mobility of charge carriers in the (n)GaP layer and inversion layer at the (n)GaP/(p)cSi interface. Using the database [5] the lifetime was taken as a parameter for further calculations. Further, the influence of annealing temperature and the searching of the optimal distance between the contacts was considered.

Results and Discussion

The Hall measurements results are shown below.

Table 1

The electrical properties of inversion layer

Annealing temperature, °C	Without	500	600	700	750	800
Concentration, cm^{-3}	$8 \cdot 10^{17}$	$1 \cdot 10^{19}$	$8 \cdot 10^{19}$	$5 \cdot 10^{20}$	$3 \cdot 10^{21}$	$7 \cdot 10^{22}$
Mobility, $cm^2 \cdot V^{-1} \cdot s^{-1}$	108	25	29	26	30	0.5
Lifetime, s	$5 \cdot 10^{-5}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-9}$	$1 \cdot 10^{-9}$

The thicknesses and electrical properties of the remaining layers are given in the table below. The GaP-Si junction is designed to generate and spatially separate electron-hole pairs and the BSF (back surface field) is used to reduce the surface recombination of charge carriers.

Table 2

Electrical properties of layers in GaP/Si solar cell

Parameter	(n)GaP	(p)c-Si	BSF
Thickness, μm	0.05	300	1
Concentration, cm^{-3}	10^{18}	10^{16}	10^{19}
Mobility, $cm^2 \cdot V^{-1} \cdot s^{-1}$	1	holes: 300; electrons: 1000	holes: 300; electrons: 1000
Lifetime, s	10^{-6}	10^{-4}	10^{-4}

The calculated conversion efficiency dependency for 20 μm is shown in Fig. 1. This width of contact provides higher efficiency. However, the lithography of contact grid deposition is more complicated in comparison with the screen-printing method

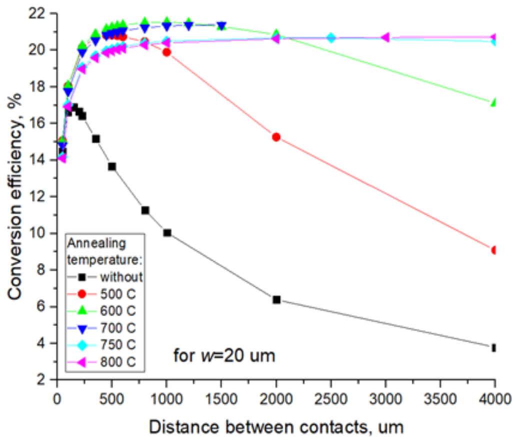

Fig. 1. Dependence of the simulated conversion efficiency of a solar cell on the distance between the contacts for a contact width of 20 μm for GaP/Si structures annealed at different temperatures

Based on the data obtained, we can notice that in the absence of annealing, the conversion efficiency is lower by several percent, which can be associated with a low concentration of charge carriers. For annealing temperature of 500 °C an increase in efficiency is noticed. However, at a distance between contacts of 1 μm a significant decrease is observed. From a practical point of view, this is not convenient since the implementation of the possibility of reducing shadow losses is limited.

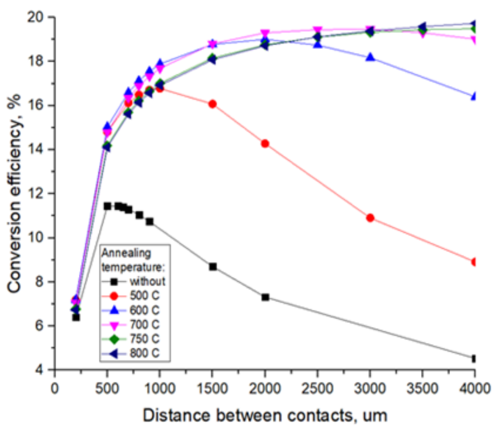

Fig. 2. Dependence of the simulated conversion efficiency of a solar cell on the distance between the contacts for a contact width of 200 μm for GaP/Si structures annealed at different temperatures

The simulation results show that at an annealing temperature of 600–700 °C the solar cell has high and stable conversion efficiency values of about 21.5%. This can be related to the fact that there is an optimum between the values of the concentration and the carrier lifetime. For annealing temperature of 800 °C, the experiment shows a low mobility of the inversion layer (an order of magnitude lower than at other temperatures). This may be due to the large number of capture traps caused by phosphorus diffusion. However, the simulation shows an increase in efficiency with saturation as the distance between the contacts increases. Here there is a discrepancy between the computer model and experiment.

Now we will focus on the contact widths of 200 μm, which is preferred for screen printing technology (Fig. 2).

For a contact width of 200 μm, a similar nature of the dependences is observed except that the maximum efficiency under these conditions is about 19%. Of particular note are the results that correspond to an annealing temperature of 700 °C. In this case, with lengths between contacts from 2 to 3.5 mm, it is possible to maintain an efficiency of 19%. This allows to use the screen printing taking into account inhomogeneities in the application of contacts.

Conclusion

In case for 20 μm width of contacts, the calculated conversion efficiency could exceed 21% under the annealing temperatures 600–700 °C with distance between contacts in range 0.7–1.5 mm (Fig. 1). The maximum efficiency for the optimal conditions in 200 μm configuration is about 19%. These results correspond to an annealing temperature of 700 °C with lengths between contacts in range from 2 to 3.5 mm, which is an appropriate condition for the using the screen-printing method.

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