Development of front contact grid for GaP/Si solar cells

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Abstract. A scalable technology for applying metallization to GaP/Si photovoltaic structures for mass production was explored. The study of Ag-based contacts, which are obtained by screen-printing of silver paste followed by subsequent annealing, are presented in this paper. Contact resistance measurements are done using the TLM method. The developed contacts have demonstrated excellent performance even in comparison with the vacuum deposition technology, which is the basis for using the developed technology of forming contacts in industry.

1. Introduction

In recent years, the task has been set to search, develop and improve photovoltaic semiconductor structures with a small quantity of optical and electrical losses, providing the highest efficiency of solar energy conversion. A perspective way to reach the lowest optical losses is to use the wide band gap emitter layers, in particular a growth of GaP on Si substrate could provide several advantage compared to conversional Si based solar cells design [1].

The mismatch of lattice constants between GaP and Si is 0.37% [2], as a result epitaxial growth of GaP/Si structures with low defect concentration at the interface is possible [3]. At the same time, the thermal stability of such structures is improved compared to that based on heterojunction between amorphous semiconductors and crystalline Si [4]. However, there is still an important task for solar cell fabrication being to find the optimal material and technology for the front contacts to GaP/Si structures, which should exhibit the lowest level of losses due to contact resistance and can be applied for mass production.

In the current work, the properties of the contacts to n-GaP obtained by screen-printing and vacuum deposition metallization technologies are explored. In addition, it is necessary to pay attention to the electrical resistivity of the contacts and evaluate the effect of the temperature on the GaP/Si structure properties during the thermal processing.

2. Experimental conditions, materials and results

GaP/Si heterojunctions were grown by plasma-enhanced atomic layer deposition method at 380°C. During the growth, phosphine (PH₃) was decomposed in RF plasma to supply the growing surface by phosphorus atoms, while trimethylgallium (TMG) was thermally decomposed at the next step being a source of gallium atoms. Hydrogen was used as carrier gas to provide a flow of TMG. For more details refer to [5].

The next stage was the metallization of the grown structure. Two types of different metallization technology were compared. The contacts of the first series of the samples were formed by screen-
printing using conductive paste based on Ag and subsequent annealing. Samples with contacts formed by vacuum deposition of Ag/Ti were also considered. Samples made using screen-printing technology with a set of contact pads measuring 2.85×0.85 mm were annealed in N\textsubscript{2} atmosphere using the Jipelec JetFirst 100 rapid thermal annealing setup at a temperature of 700-800°C for 1 minute. Alternatively, Ti/Ag non-alloyed ohmic contacts (area of 1.5×0.2 mm) were formed on the top of GaP/Si structures using lithography and vacuum evaporation (Boc Edwards Auto 500).

![Figure 1. a) Contact grids of the screen-printed sample (b) Contacts grids of the sample with vacuum deposition](image)

During the experiment, the specific contact resistance \( \rho_c \) of the samples was determined. The transmission line method (TLM) was used, which considers the dependence of the total resistance \( R_T \) between two contacts as a function of the distance between them.

![Figure 2. a) TLM contacts of the screen-printed sample (b) TLM contacts of the sample with vacuum deposition](image)

The total resistance between two contacts consists of the series resistance of a metal \((R_M)\), a semiconductor \((R_{\text{semi}})\), and the resistance of a metal-semiconductor interface \((R_C)\).

\[
R_T = 2R_M + 2R_C + R_{\text{semi}}
\]

Notice, that the resistance at the interface is many times higher than the resistance of the metal, so the latter isn’t taken into account.

The semiconductor resistance depends on the length of the current flow \((L)\) and the width \((W)\):

\[
R_{\text{semi}} = R_s \frac{L}{W}
\]

Where \(R_s\) — semiconductor volume resistance.

To determine the resistance under the contact, it is necessary to take into account that current density reduces with distance along the contacts exponentially. For these tasks we use transfer length \((L_T)\):
\[ L_T = \sqrt{\frac{\rho_C}{R_S}} \]  

(3)

As a result we can determine the contact resistance:

\[ R_C = \frac{\rho_C}{L_TW} = \frac{R_S L_T}{W} \]

(4)

During the measurements a set of distances \( L \) was used and for each position of the measuring contacts a current-voltage (I-V) characteristics were measured, which determined the total resistance. We varied voltage from -1V to 1V with a step of 0.1 V. The limit value for the current is 0.305A. Figure 3 (a,b) presents examples of obtained dependencies.

![Figure 3(a, b). (a) Total resistance of the screen-printed sample (b) Total resistance of the sample with vacuum deposition](image)

The specified dependence is approximated by a straight line [6]:

\[ R_T = \frac{R_S}{W}L + 2R_C = \frac{R_S}{W}(L + 2L_T) \]

(5)

These parameters can be derived from experimental data. By them, we can determine the value of the specific contact resistance:

\[ \rho_C = R_C L_TW \]

(6)

For Ag/GaP/Si samples obtained by screen-printing method and annealed at \( T=700°C \) and \( 800°C \), the specific contact resistance values are \( 4.2\cdot10^{-3} \) Ohm·cm\(^2\) and \( 1.8\cdot10^{-5} \) Ohm·cm\(^2\) respectively. For the Ag/Ti/GaP/Si sample obtained by vacuum deposition technology, the specific contact resistance value is 0.18 Ohm·cm\(^2\).

Thus, we can conclude that for the samples with metallization formed by screen printing, the specific contact resistance is several orders of magnitude lower than for the samples with vacuum metallization. This allows to reduce ohmic losses and improve the operational properties of the samples.

Nonetheless, for samples which were formed by screen-printing, the problem of GaP surface erosion was detected after annealing. It turned out that for Ag/GaP/Si samples annealed at \( T=700°C \) and \( 750°C \) surface erosion is not so ruinous. But it has such a strong effect on samples annealed at a temperature of \( 800°C \) (figure 4 (a)). These samples have the best electrical characteristics so what is why it is necessary to find a solution to this difficulty.
Figure 4(a, b). (a) GaP surface and (b) GaP surface covered by Si$_3$N$_4$ after annealing at 800°C.

This problem can be avoided by deposition of Si$_3$N$_4$ layer (50 nm) on the GaP surface with Ag paste pattern (figure 4(b)). However, deposition of Si$_3$N$_4$ layer on the conductive Ag paste leads to a high resistivity of Ag fingers after annealing. This could be explained by the fact that grains of silver do not sinter under a Si$_3$N$_4$ layer. One of the possible solutions of this problem is a coating of conductive Ag paste on the thin Si$_3$N$_4$ layer deposited on GaP surface, which will melt it during subsequent annealing. Another solution is a usage of GaN layer on GaP.

3. Conclusion

For samples with metallization formed by screen-printing, the specific contact resistance is several orders of magnitude lower than for samples with vacuum metallization. This allows one to reduce ohmic losses and improve the efficiency of the solar cells. Screen-printing method of forming contacts is scalable and can be released for mass production. It is necessary to take into account the increase in resistivity of Ag grid caused by the deposited nitride layer in order to avoid GaP erosion.

Acknowledgments

The reported study was partially supported by RFBR research project #20-08-00870.

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