Subcontact layers of p-InGaAs with minimal resistance for photodetectors of high-power laser radiation

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Abstract. It is necessary to minimize the resistance of electrical contacts to reduce heat losses in photovoltaic converters of laser radiation. The paper describes ways to reduce the resistance of electrical contacts for p-InP by choosing the composition of the subcontact layer based on p-InGaAs. For this purpose, layers of p-InGaAs with different compositions and bandgaps were grown by the MOCVD method. AgMn/Ni/Au contact metallization was deposited on samples to compare the characteristics of electrical contacts. The minimum specific contact resistance was $7 \times 10^{-5} \, \Omega \cdot \text{cm}^2$ for the layer with $E_g = 0.51$ eV.

1. Introduction

Special photovoltaic devices are needed to convert laser radiation with power up to 10 kW. Which characterized by minimal energy losses for heating. Most energy losses occur in a pn-junction and a metal-semiconductor junction. It is necessary to choose materials of surface layers to reduce the resistance of the metal-semiconductor junction. It is also necessary to define the structure of contact metallization and heat treatment processes.

Powerful lasers that are capable to transmit energy in the atmosphere usually operate at a 1.06 μm wavelength. It means that the photovoltaic converter should be made of materials that have an energy bandgap of about 1.17 eV. This energy bandgap might be obtained in the $\text{In}_{0.82}\text{Ga}_{0.18}\text{As}_{0.4}\text{P}_{0.6}$ solution. This material is commonly grown on an InP substrate [1]. Indium phosphide is a material with a wider bandgap than $\text{In}_{0.82}\text{Ga}_{0.18}\text{As}_{0.4}\text{P}_{0.6}$, and it does not absorb radiation at 1.06 μm. This property makes it possible for radiation to enter the structure through the substrate surface.

Thus, it is necessary to obtain electric ohmic contacts with minimum resistance to p- and n-type InP. Production of electrical contacts to n-InP has been described in numerous studies. The specific contact resistance of these contacts is low, close to $10^{-6} \, \Omega \cdot \text{cm}^2$ [2,3]. Production of electrical contacts to p-InP presents some difficulties, and the minimum value of the specific contact resistance is about $10^{-6} \, \Omega \cdot \text{cm}^2$ [3-5]. It should be noted that electrical contacts to p-InP in most cases include alloys or layers of zinc. Zinc is difficult to deposit in alloys due to the high vapor pressure and a relatively low melting point, and Zn also contaminates the vapor deposition apparatus. This is the reason why, in many cases, the InGaAs layer was grown on the p-InP surface. This layer has a lower bandgap. For the frequently used composition $\text{Ga}_{0.47}\text{In}_{0.53}\text{As}$, it is possible to obtain electrical contacts with a resistance of about $2 \times 10^{-8} \, \Omega \cdot \text{cm}^2$[6].

The main purpose of this work is to determine the composition of InGaAs, at which the applied contacts will have minimum resistance. It was decided to use a multilayer electric contact...
AgMn/Ni/Au deposited by thermal vacuum evaporation. The AgMn/Ni/Au contact was used in [8,9] to produce ohmic contacts to concentration solar cells, and the specific contact resistance was about $4 \cdot 10^{-6} \, \Omega \cdot \text{cm}^2$ [9].

2. Experimental
Epitaxial layers of p-InGaAs were grown on n- and p-type InP substrates by MOCVD. The energy bandgap of the grown layers has a value from 0.35 to 0.78 eV. InP substrates were doped with Sn for n-type with a concentration of $3 \cdot 10^{18} \, \text{cm}^{-3}$, and p-type InP substrates were doped with Zn with a concentration of $4 \cdot 10^{18} \, \text{cm}^{-3}$. Epitaxial grown layers were doped with Zn with a concentration of $1 \cdot 10^{18} \, \text{cm}^{-3}$. The thickness of the grown layers was 1 μm.

The surface of some grown samples was examined with a scanning electron microscope (SEM) to determine the influence of lattice mismatch on surface quality.

Further, AgMn/Ni/Au contacts with a thickness of 800/600/1000 Å were deposited on the samples by vacuum thermal evaporation. After deposition, the contacts were annealed in a hydrogen atmosphere at 380°C for 20 seconds.

Then, the resistance between the contact pads was measured at different length across the pads. The contact resistance was measured by the two-probe method. Dependences of specific contact resistance from $E_g$ were obtained.

3. Results
Images of the surface of some samples obtained by a scanning electron microscope are presented below.

**Figure 1.** Image of the surface obtained by SEM for the layer of InGaAs with $E_g = 0.78$ eV.

**Figure 2.** Image of the surface obtained by SEM for the layer of InGaAs with $E_g = 0.39$ eV.
These images show that quality of the surface degrades with increasing lattice mismatch. However, the surface quality of this layer will not affect the properties of the device when radiation enters from the substrate.

The specific contact resistances for different grown layers were obtained from the results of measurements.

It was suggested that as the band gap width decreases, the specific contact resistance also decreases. The $r_c(E_g)$ dependence is shown in figure 3.

![Figure 3](image_url)

**Figure 3.** Dependence of specific contact resistance on the energy bandgap of the grown layers. The line is a polynomial curve of the 2nd grade.

It can be seen that the minimum specific contact resistance is $7 \cdot 10^{-5} \Omega \cdot \text{cm}^2$ for the sample with an energy bandgap of about 0.5 eV. The polynomial curve has a minimum resistance at $E_g = 0.42$ eV.

**4. Conclusions**

A p-InGaAs layer with a minimum specific contact resistance was successfully obtained during the work process for AgMn/Ni/Au contact metallization. The obtained minimal value of specific contact resistance was $4 \cdot 10^{-5} \Omega \cdot \text{cm}^2$ for the sample with an energy bandgap of about 0.5 eV.

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