Spectral characteristics of InP photocathode with a surface grid electrode

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Abstract. Results of indium phosphide structures research, showing the possibility of using it in the near inferred range (NIR) photocathodes of InP / InGaAs, are represented. An optimal method of obtaining the atomically clean indium phosphide surface was suggested. The activation process of indium phosphide was shown and its spectral characteristics were given. Researches of the photoemission dependence of the structure with surface grid electrode upon different bias voltages were carried out.

1. Introduction
The creation of a photocathode, which operates in the NIR range, also known as the transferred electron photocathode, was proposed by Bell [1]. Such photocathodes can move the long-wavelength threshold of photoemission by increasing the internal energy of the photoelectrons. Their structure has been realized on the basis of heteropair indium phosphide – solid solution of indium – gallium arsenide. The InGaAs forbidden band is narrow enough to detect near-infrared range. However, this narrow–band material ("absorber") cannot provide by itself the negative electron affinity (NEA) on the surface, which is a determinant factor for obtaining high quantum efficiency for such structures. However, InGaAs can be perfectly matched to the InP crystal lattice, which is a conductor of electrons (emitter) generated in the absorber. The indium phosphide is an A₃B₅ semiconductor which allows getting on its surface the effective state of the NEA. Semiconductor photocathodes activated to negative electron affinity (NEA) serve as electron beam sources for many applications. InP photocathode is an emitter with InP/InGaAs heterostructure. These heterostructures allows getting greater quantum efficiency as compared to other semiconductor materials in case of detection reflective laser beam in near infrared range [2]. That is why the purpose of the work is to study the indium phosphide purification methods to obtain the high efficiency photocathode, and a study of its persistence.

2. Purifying of InP surface
The structures based on the indium phosphide are characterized by low thermal resistance and heating over with the temperature of 593 K lead to the degradation of these structures, so that the typical cleaning methods for metals and thermally stable materials cannot be used. Sulfur passivation leads to stable surface termination, but the chemisorbed sulfur atoms cannot be removed completely by thermal annealing at temperatures below the decomposition temperature of InP. Process of obtaining a clean InP surface is rather difficult, especially pre–vacuum chemical cleaning step. The treatment with HCl-C₃H₅O and subsequent vacuum annealing is useful method for obtaining the atomically clean GaAs
surfaces, another semiconductor of the \text{A}_3\text{B}_5 group [3]. However, etching with these chemical compounds is ineffective for InP surfaces.

Therefore, we use the efficient three-step method of chemical etching combined with a thermal cleaning in vacuum to obtain the atomic clean surface of InP [4, 5]. Samples of InP (111): Zn, with concentration \(p=1\cdot10^{18}\ \text{cm}^{-3}\) were used for studies. Sample of InP structure with surface grid is shown in figure 1.

![InP structure with surface grid](image)

**Figure 1.** InP structure with surface grid

Etching time was increased, as compared to [4], and the mode was adjusted to increase in rate of the removing of a thick natural oxide layer by the use of ultrasound in the etching process. Besides that the intermediate etching step was added: a weak solution of sulfuric acid was used. Strong acid solutions with HCl or \(\text{H}_2\text{SO}_4\), which are used in third step of chemical cleaning, are able to remove the surface oxide and leave the InP surface passivated with elemental P which is, in turn, terminated with H [4]. This yields a hydrophobic surface and allows using lower temperatures during annealing. All steps of chemical cleaning are shown in table 1:

| Solution | Concentration |
|----------|---------------|
| 1 \(\text{H}_2\text{SO}_4:\text{H}_2\text{O}:\text{H}_2\text{O}\) | 4:1:100 |
| 2 \(\text{H}_2\text{SO}_4:\text{H}_2\text{O}\) | 1:10 |
| 3 \(\text{H}_2\text{SO}_4:\text{H}_2\text{O}\) | 1:1 |

Protective layer formed on InP surface are also allows to carry etched structures from chemical laboratory bench to vacuum installation in atmosphere. This is an important achievement in terms of surface oxidation and uncontrolled contamination of surfaces. We studied the effect of etching on the titanium grid and the possibility of etching agents use without degradation of the grid structure. As a result, we found that etching is equally effective for two different acid solutions HCl and \(\text{H}_2\text{SO}_4\), however, in case of HCl titanium grid is exposed to chemical degradation.

3. Activation of InP structures
The ultra-high vacuum installation was used to conduct the research in a vacuum, which could reach the level of \(1\cdot10^9\ \text{Pa}\). Structural diagram of installation is shown in figure 2.
As a result of the etching process the hydrophobic surface InP structure was obtained [4]. After heating in a vacuum chamber at a temperature of about 573 K, the net InP atomic surface was received, that’s ready for the activation with Cs and O$_2$, which allows to form effective state of NEA on InP photocathode surface.

The method of the activation structure called «yo-yo» [6], based on a continuous simultaneous supply of cesium and oxygen was used. The process for obtaining the maximum photoemission current was about 90 minutes. The progress of activation is presented in figure 3.

Research was conducted on InP structures which etched by solutions of C$_3$H$_8$O+Br, C$_3$H$_8$O+HCl and our new three stage method of chemical cleaning with solutions of H$_2$SO$_4$. After graphical analysis, we found that with new method of chemical cleaning the photoemission current increase in 6 times as compared to previous experiments. In addition to pure samples were also studied samples with the grid electrode, used to create the photocathode with the transferred field. The dependence of the photoemission current on the applied bias voltage is shown in figure 4.
Figure 4. The dependence of photoemission current on the applied bias voltage

Measurements were carried out in range of 500 to 950 nm. Based on figure 3, quantum efficiency (QE) is calculated using the ratio:

\[
QE = \frac{I \cdot h \cdot c}{P \cdot e \cdot \lambda} \cdot 100\%
\]

where \( I \) — the photoemission current, \( P \) — the monochromator radiation power at wavelength \( \lambda \), \( h \) — the Planck’s constant, \( c \) — the speed of light \( e \) — the elementary charge.

Calculation of the dependence between QE and \( \lambda \) using (1) are represented in figure 5.

Figure 5. Spectral characteristics of InP:Zn (111) photocathodes, \( p=1\cdot10^{18} \text{cm}^{-3} \). 1 — without grid; 2 — with grid on \( U_r=0 \text{ V} \); 3 — with grid on \( U_r=1.2 \)
The analysis of the obtained experimental results on figure 5 allows us to make the following conclusions. The quantum efficiency is greater than 10% at a wavelength of 630 nm, and more than 1% for 900 nm on indium phosphide. In [5] the QE at 632 nm was in the range 9-12% and spectral characteristics were not present. The photolithographic grid stamped on of InP, has demonstrated not only the overall photoemission gain increase, but also provided the greater sensitivity at longer wavelengths when a voltage was applied to the grid with the help of the pressure contact. For example at the wavelength of 650 nm the QE increases by 46%, and by 177% at 900 nm. The resulting dark current was small (less than 0.05 nA at \(U_r=3V\)), but at the applied voltage exceeding 2V the photoemission current has saturation, which makes the voltage increase weakly effective.

As the result of our experiments we got that spectral sensitivity of InP samples, which was etched by solutions of \(C_3H_8O+Br\) and \(C_3H_8O+HCl\), was lower than 1% at the wavelengths from 500 to 700 nm. Another important fact is that the value of quantum efficiency of structures was irregularly on the surface of InP. The difference of quantum efficiency between various points, which was illuminated with monochromator radiation beam, was more than 100%. This indicates that surface of the InP structure is not purified. For structures etched by our method, difference of quantum efficiency in various points is on the level of 10-15%.

Persistence of InP photocathode is determined by the vacuum level in the activation chamber. QE of the structure is decreases by 50% in 24 hours on the vacuum lower than \(1x10^{-8}\) Pa, however it can be recovered by inclusion of the cesium source.

4. Conclusion

Obtained results of the researches confirm the validity of the usage of our method for purifying InP structures. Based on the experimental results analysis, further ways of improvements current technologies for obtaining photocathode on the basis of InP/InGaAs heterostructure were provided. These heterostructures work in near infrared range and could be used in devices for special purposes, where high processing speed of detection reflected radiation from the object is needed. At present time solid-state analogs of these devices cannot provide the same processing speed.

5. References

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