# Investigation of Photo-Stimulated Diffusion Processes in III-V Semiconductors

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***Abstract**:*

*The paper presents the results of investigation of photo-stimulated diffusion (PSD) processes from continuous source in the GaAs, GaAlAs and GaP during formation of ohmic contacts, p-n junctions, $p^+$ and $n^+$ areas and insulation regions. It is shown, that along during PSD with the temperature the role of the ionization factor is very significantly. It is suggested, that in III-V compounds group III atoms should be more mobile during pulse-photon irradiation and probability of vacancy generation in these points should be higher in compared to group V atoms points.*

***Keywords**: photo-stimulate diffusion, pulse-photon irradiation.*

It is well-known that a decrease in the time and temperature of technological processes of semiconductor device production improve device characteristics. Limited possibilities of the traditional technology do not enable us to solve these problems. Photo-stimulated processes allow us to remove such undesirable factors as a creation of special media and a long-term high-temperature heating. This fact is particularly important for III-V compounds.

In the present work the results of the investigation of photo-stimulated diffusion (PSD) processes in the GaAs, GaAlAs and GaP are given. The photo-stimulated diffusion from continuous source was investigated in processes of formation of ohmic contacts, p-n junctions, $p^+$ and $n^+$ areas and insulation regions (Table 1).

Pulse-photon irradiation (PPI) was carried out in the air on a specially designed PPI system by pulses of nonmonochromatic light from tungsten halogen lamps with duration $\tau=0.1\div90$s and radiation power $P=10\div300$ W·cm$^{-2}$. The structures were irradiated from metal composition side (face side) or the semiconductor side (back side). The wafer temperature was estimated using a chromel-alumel low-inertial thermocouple (of a thickness of 0.1 mm).

The optimal regimes for creation of different areas and optimal values of their control parameters after PSD are given in Table 1. The last column illustrates regimes of traditional thermal treatment for comparison. As is seen from table 1, formation of one and the same areas, proceeds in easy conditions (without especial medium - in air, small times, relatively less temperatures). It will be noted, that in all processes given in Table 1 a number of general regularities are observed:

- In the same PPI conditions better results were obtained under irradiation from the back side. For example, in formation of ohmic contacts to GaAs by PPI ($P=90$ Wcm$^{-2}$ and $\tau=1.9$ s) irradiation from the face side gives average values of $R_c=0.9$ Ohm.mm$^{-1}$, while after irradiation from the back side - $R_c=0.7$ Ohm.mm$^{-1}$; in this case the structure temperature $T\leq700$K. Thermal burning-in in the furnace gives $R_c=1.0$ Ohm·mm$^{-1}$.

- The irradiation intensity is very important - If the structures are irradiated with less powerful but longer pulses ($P=30$W·cm$^{-2}$, $\tau=10$s) at which the same temperatures as in the above example, are achieved, the contacts remain rectifying.

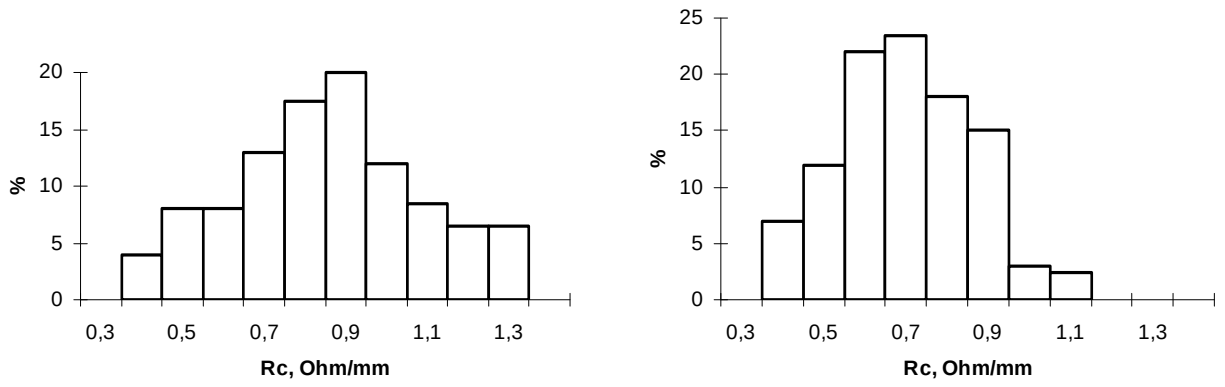
- After thermal burning-in the contact surface is coarse-grained, with signs of melting on all the structures, while after PPT it remains mirror-smooth and uniform distribution of electrophysical parameters throughout the surface is increased (fig. 1).

It is impossible to account for the obtained results, as well as a number of experiments [1-4], like pulse thermal heating only, as is regarded by majority of researchers [5]. It is necessary, along with temperature, to take in to account the role of the ionization factor - the change in the quantum

state of the crystal electron subsystem [1-4]. Indeed, as is seen from the foregoing experiments, at higher intensity (while the temperature is the same and pulse duration is markedly small) diffusion processes proceed more actively. The mere fact, that diffusion from the metal multilayer is more intensive when irradiation occurs from back side must be due to the absorption photons with the energy lower than the band gap, passing through the semiconductor, directly in the defect near-contact semiconductor-metal interface. In this region breaking of chemical bonds takes place -jump of an electrons from the bonding orbitals on the antibonding orbitals [2,6], which favours solid phase photostimulated diffusion providing the mirror-smooth surface. The very important role of the ionization factor in photo-stimulated processes in for IV group semiconductors in paper [2] is shown. Unlike Group IV semiconductors, binary semiconductor compounds have the structure with two different atoms in the unit cell and bonding forces are partially covalent and partially ionic. The bonding electron density is nonuniformly distributed between atoms and the electron density decreases in interstials. Besides, the electron cloud around the element with a lower number of valence electrons is somewhat smaller than it is necessary for total positive charge compensation and on the contrary, around the elements with a higher number of valence electrons it is as much bigger than it is necessary for compensation.

It is shown in ref.[7] that a probability of defect formation according to Frenkel depends on the antibonding particle concentration $\sim n^3$, and the diffusion coefficient is proportional to $\sim n^5$ [8]. Hence, the probability of defect formation is higher in the crystal points with lower bonding electron density. The atoms in such points should also have a higher selfdiffusion coefficient (which is borne out by the experiments [9]) . Here it should be also taken into account that almost in all binary semiconductor compounds the mass of antibonding electrons is lower than that of the holes and antibonding electrons appear more often in the points, where a positive nuclear charge is not fully compensated by electrons. Thus in III-V compounds group III atoms should be more mobile and probability of generation vacancy in this points should be higher in comparison with group V atoms points.

From these considerations it will be easily understood the role of irradiation intensity in PSD processes. During PPI in group III atoms sublattice vacancies are intensively generated, where the substitution of displaced atoms by diffuser atoms. As a result diffusion actively proceeds in small times and at relatively less temperatures.




a) b)

Fig.1. Histograms of Rc parameter distribution over the wafers:
a) after burning-in in the furnace (T=745K, t=1min.),
b) after PPI (P=90 $W.cm^{-2}$, $\tau$= 1.9 sec.).

Table 1.DATA ON EXPERIMENTS OF PHOTOSTIMULATED DIFFUSION IN III - V COMPOUNDS.
THE LAST COLUMN ILLUSTRATED REGIMES OF TRADITIONAL THERMAL TREATMENT FOR COMPARISON.

| FORMATION OF | SEMICOND. | IMPURITY CONCENTR. $CM^{-3}$ | METAL COMPOSITION | PULSE PHOTON IRRADIATION ON THE AIR | | | MEASURED CONTROL PARAMETERS | REGIMES OF TRADITIONAL THERMAL TREATMENT |
|---|---|---|---|---|---|---|---|---|
| | | | | PULSE POW.$CM^{-2}$ | PULSE DURATION, SEC | PULSE NUMBER | | |
| Ohmic contact | epitaxial structure GaAs, i - $n^-$ - n | $1.5x10^{17}$ | Au/Ge/Ni | 90 | 1.9 | 1 | contact resistance $R_c$ =0.7 Ohm.$cm^{-2}$ | vacuum, 745 K, 1 min |
| Ohmic contact | light emission. structure GaAlAs: n-GaAlAs, p-GaAs | $10^{18}$<br>$3\div20x10^{18}$ | Pd/Ni/Au/Sn<br>Pd/Ni/Au/Sn | 40<br>40 | 1.8<br>1.8 | 1<br>1 | forward voltage $U_{for}$ =1.6 V, at $I_{forr}$ =10 A. | vacuum, 720 K, 10 min<br>720 K 10 min |
| $p^+$ - area Ohmic contact | light emission. structure GaP: p – GaP, $p^+$- GaP n - GaP | $5x10^{17}$<br>$\sim10^{19}$<br>$5x10^{17}$ | Zn<br>Al<br>Pd/Ni/Au/Sn | 90<br>80<br>80 | 1.6<br>1.3<br>1.3 | 1<br>1<br>1 | forward voltage $U_{for}$=2.1 V, at $I_{for}$ =10 mA | vacuum, 1000 K, 15 min<br>720 K, 10 min<br>720 K, 10 min |
| $n^+$- area | n - GaAs | $1.7x10^{16}$ | Ge | 70-90 | 1-3 | 1-3 | surface resistance decrease $10^3$ fold | [10], $Si_3N_4$ mask >673K, >15 min |
| $p^+$- area | p - GaAs | $7x10^{16}$ | Zn | 40-90 | 1-3 | 1-7 | surface resistance decrease $10^3$ fold | [10], $Si_3N_4$ mask >673K, >15 min |
| n-p junction | n - GaAs | $7x10^{16}$ | Zn | 50-90 | 1.5-3 | 1-5 | $U_{for}$=0.4-0.6 V and $U_{inv}$=6-8 V at I =$10^{-4}$ mcA | [10], $Si_3N_4$ mask >973K, >15 min |
| i - area (with $SiO_2$ mask) | epitaxial structure GaAs, i - $n^-$ - n | $1.5x10^{17}$ | Cr | 55-90 | 2-5 | 1-20 | current between test cells I =35-40 mcA, at U =10 V | — |

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