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Acoustostimulated Diffusion of Gold Atoms into Highly Doped N^+-Layers of Silicon

Abdumalik Gaibullayevich Gaibov, KutbiddinIlovidinovich Vakhobov

Ph.D., Associate Professor of General Physics of Tashkent State Technical University, Uzbekistan,
Old lecturer of the Department of General Physics of Tashkent State Technical University, Uzbekistan

ABSTRACT: In the present work the research of processes of penetration of gold through alloyed by phosphorus n^+ -silicon layers under the influence of ultrasonic waves by frequency f = 1÷25 MHz and power (intensity) of I* ≤ 0,4 ÷ 0,5 W/cm^2 is conducted. It is shown that under the influence of the I ultrasonic waves I* ≤ 0,4÷ 0,5 W/cm^2 at times of ultrasonic processing of t <30 min. gives improvement of functional (spectral) characteristics of Si-receivers of radiation and reduction of speed of a superficial recombination. Ultrasound suppresses recombination centers in thin near-surface layers of the "input" window, (dead layers), which makes an additional contribution to the efficiency of collecting non-equilibrium charge carriers. Increased ultrasonic processing time (t > 30min) results in deeper penetration of gold into the sensitive (active) region of Si receivers. As a result, Au- defects occur and the performance of Si radiation receivers is degraded.

KEY WORDS: Ultrasoun; Si radiation receivers; gold atoms; diffusion

I.INTRODUCTION

When manufacturing semiconductor radiation receivers on the surface of the "input window" of the Si radiation receivers, a thin layer of gold with thickness "d" to 300Å is applied, used as a front contact, and ultrasonic treatment of the Si receivers takes place on the side of the "input window," and therefore it is of clear interest to study the effect of ultrasonic waves on the gold contact. Similar studies on the effect of ultrasonic free on silicon with aluminium, copper and nickel contacts were carried out in works [1, 2, 3], where the acoustostimulated adhesion effect was studied.

In the present work the research of processes of penetration of gold through alloyed by phosphorus n^+ - silicon layers under the influence of ultrasonic waves by frequency f =1÷25 MHz and power (intensity) of I* ≥ 0,4 W/cm^2. is conducted. As is known, gold is widely used in semiconductor technology for various purposes and forms deep levels in silicon [4, 5, 6]. Therefore, the scope of this work does not include a detailed study of the behavior of this element and its ability to change silicon parameters.

II. SIGNIFICANCE OF THE SYSTEM

The article focuses on the study of gold penetration processes through phosphorus-doped silicon n + layers under the influence of ultrasonic waves with a frequency of f =1÷25 MHz and a power (intensity) of I * ≥ 0.4 W/cm^2. The study of literature survey is presented in section III, Methodology is explained in section IV, section V covers the experimental results of the study, and section VI discusses the future study and Conclusion.

III. LITERATURE SURVEY

In recent years, in connection with the intensive development of a new direction in semiconductor physics, "Acoustic Phenomena" in semiconductors, the question of conducting detailed studies of the physical mechanisms of these phenomena has arisen. The study of these phenomena opens up access to a deeper understanding of the properties of semiconductors and allows us to create a new "acoustic technology" for purposefully changing their physical properties. A very impressive list of new acoustic phenomena and effects, as well as their implementation in practical semiconductor electronics, which can provide much useful for its development. The problem of using the acoustic

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properties of semiconductors has not yet led to the creation of a stable semiconductor "acoustic technology" and requires a wide range of scientific research.

Research on Si- and Ge-receivers of nuclear and electromagnetic radiation detectors (γ-кванты, X-rays) at low temperatures at Physical and Technical Institutes of Russia and Uzbekistan has opened new ways to create high-efficiency radiation receivers. Above these works, the existence of local inhomogeneities with a concentration of $N < 10^{10}$ cm^{-3} in "ultra-pure" semiconductor materials that do not allow achieving the ultimate functional characteristics of radiation receivers was first demonstrated. Intensive scientific searches have led to the discovery of the decay of some local inhomogeneities in ultrasound fields.

For the first time in world practice, this phenomenon was discovered at the Physics and Technology Institute of the Academy of Sciences of Uzbekistan under the leadership of Academician R.A. Muminov in 1983. As new information appears about acoustic phenomena in semiconductors and about the achievements of semiconductor electronics, one after the other there are problems associated with the detection of physical mechanisms of acousto effects and the existence of defects in the structure of semiconductor devices; the elimination of which by traditional methods is in principle impossible (for example, the problem of thermal defects).

IV. METHODOLOGY

For production of Radiation Si-receivers (Si-PI) ingots of single-crystal silicon of p-type with a specific resistance of $\rho=(10\div14)\cdot10^3\Omega$cm and lifetime of nonbasic carriers of a charge of $\tau=450\div650\mu$s, as well as more low-impedance ingots p-Si with $\rho\le(2\div5)\cdot10^3\Omega$cm and $\tau=800\div1000\mu$s were used. Oxygen concentration was No_2 not more than $10^{16}cm^{-3}$and dislocation density $N_D\sim10^4cm^{-2}$. The ingots, which were in the shape of a cylinder, were cut into plates up to 0.5mm thick. The plates had an S area of 0.25 cm^2 to 2.0cm^2. The Si plates were ground on both sides with abrasive powder M15. After the corresponding chemical treatment on one of the parties of Si-plates aluminum (Al) deposited thickness of $l\approx0{,}45\mu m\div 0{,}5\mu m$, at this technological procedure of edge a Si-plate were protected by a mask. A solution of phosphorus pentoxide was then applied to the other side of the Si plate P_2O_5 and the coating was dried. The next step was to diffuse phosphorus into the Si plates. Samples located in quartz ampoule were placed in a diffusion furnace. Diffusion of phosphorus was carried out at temperature T = 1073 K in inert gas flow for time t = 60 minutes. The temperature then slowly decreased to room temperature. The aluminum besieged on a Si-plate is alloyed with it at T≈820 K and then, diffusing from fusion in Si-plate volume, forms heavy doping p^+- a silicon layer. After cooling, the Si-plate undergoes a number of chemical-processing operations to clean and remove phosphorus silicate glass on the n^+-layer obtained by diffusion of phosphorus. Before production of back metal contact to a Si-substrate on n^+ - a layer of test n^+ - p-diode structure at a temperature T = 300 K deposited a layer of gold 300 Ǻ thick then heat treatment of structures at was carried outT = 400 K during t =10s ÷ 10min. The concentration of N_{Au} gold measured by method of the neutron and activation analysis made an order of $N_{Au}\approx (4\div5)10^{10}cm^{-3}$.

The second group of gold layer test structures on the n layer was not subjected to similar heat treatment. The electrophysical characteristics of the groups were investigated, and it was found that the second group of radiation receivers (not heat treated), which had the designation Si-PI-W, had better characteristics than the group of heat treated receivers designated Si-PI-P.

V. EXPERIMENTAL RESULTS

It has been shown that the cause of deterioration of characteristics and the occurrence of polarization effects is related to the existence of local clusters of impurity atoms in the active region of Si-receivers of radiation. The nature of these clusters, as shown by the analysis of the amplitude characteristics of Si receivers, is apparently related to the presence of gold. Figure 1 shows the spectral lines and charge pulse shapes for two groups of Si-n-p receivers subjected to Si-PI-P and non-Si-PI-W heat treatment at T = 400 K for 10s. The observed difference (the appearance of doublets and longer charge pulse fronts) is believed to be due to the diffusion of gold into the sensitive region of Si radiation receivers from the gold contact at the input window. After measurement of spectral and electrophysical characteristics a number of ultrasonic treatment (UT) of samples of the Si groups - PI - P and Si-PI-W in the frequency range of f=0,8÷15 MHz and power of the $I^*=0\div5W/cm^2$ was carried out at a temperatureT = 300K.

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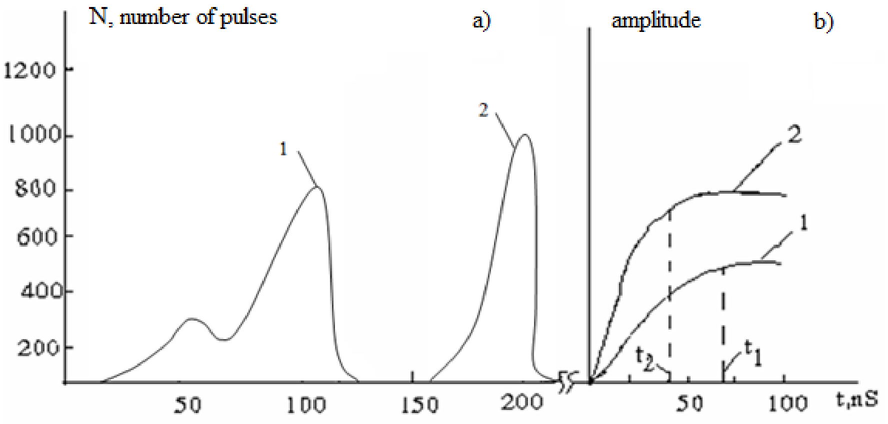

Fig. 1. Forms of spectral α-lines from isotope ^{241}Am (a) and charge pulses (b) of Si-n-p detectors of two groups: T = 300K, E = 500 V/cm.

Group 1 (Si- PI-P detectors). The detector structures were heat treated during manufacture (curves 1);

Group 2 (Si - PI -W detectors). The detector structures were not heat treated. The spectral line of the 1st group detector has a doublet, a small amplitude and a longer time-up t1 than the Si-PI-W detector of the second group.

The ultrasonic wave fell on the Au layer. Each of the Si-PI-R and Si-PI-W groups was divided into two batches, one of which was control. Spectral lines, signal amplitude of Si-receivers and change of gold concentration N_{Au} in n^+-layers of Si control samples were measured by X-ray analysis of thin layers [7].At the same time X-ray microanalyser of "JOEL" brand JSM 5910 LV-Japan was used, which allowed to determine component composition of studied thin semiconductor layers. Characteristic radiations of Au were excited by sources of soft γ - radiations of ^{109}Cd, x-ray radiation ^{241}Am and were registered the semiconductor detector which had the size of power permission of R = 300 eV.

The difference in characteristics is due to the presence of gold in the sensitive region of the Si-PI-P detector and the absence of Au in the sensitive region of the Si-PI-W. The N_{Au} concentration was measured before and after the UT in the n^+-layers of the samples at a time interval of t = 60 minutes and the results of the experiment are shown in Figure 2. The signal amplitude was also measured after ultrasonic processing and the spectral line shapes were analyzed, then the process of UT, receiver characteristics measurement and N_{Au} concentration distribution were repeated.

It was revealed that:

•Concentration of N_{Au} in n^+ - layers after ultrasonic influence increases in all samples Si-PI-P, which were previously subjected to heat treatment at T=400 K in depth of n^+ - a layer and exceeds initial $N_{Au} \approx 4{,}5 \cdot 10^{11} cm^{-3}$ value on several orders (Fig. 2.);
• In all samples of Si-PI-P group previously subjected to heat treatment, deterioration of spectral line shapes, reduction of signal amplitude and occurrence of polarization effects was observed after UP (Fig. 3). The control samples of the Si-PI-P group that were not sonicated had higher functional characteristics and no polarization effect occurred.

Scanning collimated by α- particle bunch on an entrance window of sensitive area, allowed to find in not control samples large-scale heterogeneity which were not earlier.

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Vol. 7, Issue 7 , July 2020

• No heat treatment operations were performed on the Si-PI-W samples. After passing of UP through them with a power of $I^* \leq 2$ W/cm^2 and f = 15 MHz during t = 30 min observed improvement of their functional characteristics on average of ≈5%÷7%..

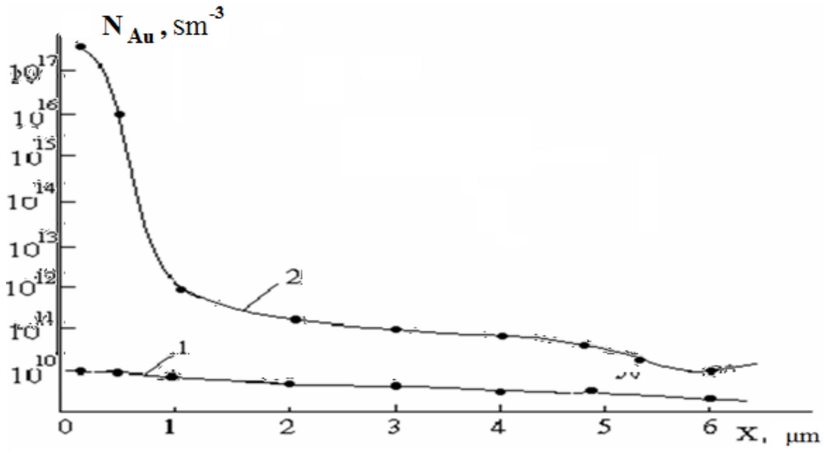

Fig. 2. Curve - 1-distribution of gold concentration in the control Si- sample. Curve 2-distribution of gold concentration in - Si-in depth after treatment with ultrasonic waves with intensity I * = 5W/cm^2 and frequency f = 15MHz, for t = 12 hours.

No increase in N_{Au} concentration in n^+-layers was observed. At ultrasonic treatment times t for more than 3 hours and constant parameters, the characteristics of the receivers began to deteriorate and the concentration of N_{Au} began to increase in the n^+-layers

Thus, the analysis of experimental data leads to the following conclusions:

• Under the action of ultrasonic waves there is acoustostimulated diffusion of gold from the surface into the depth of Si-receivers.

• Heat treatment results in gold enrichment at the surface n^+-layer near the sample surface. This thin, gold-enriched layer is a "launching pad" for the initiation of acoustostimulated Au diffusion into the depth of the n^+-layer of silicon;

• Samples without heat treatment do not have such an Au layer and the diffusion of Au deep into the n^+-layer under the action of UP is slow, as Au atoms need to overcome the obstacle in the form of thin oxide layers and potential barriers created by surface states;

• Gold forms complexes with phosphorus P and also sharply reduces τ of carriers that will be coordinated with literary data [4.5, 6]. The arising new defects in the form of the Au_2P_3complexes and single Au atoms lead to deterioration in functional characteristics of Si-PI and emergence of effects of polarization [8];

•Improvement of functional characteristics of receivers at times of UPt<30 min is connected with disintegration of local congestions of impurity atoms as well with increase in adhesion of a film of gold to a Si-surface in the ultrasonic field due to effect of acoustostimulated diffusion of gold from the surface of silicon in its volume.

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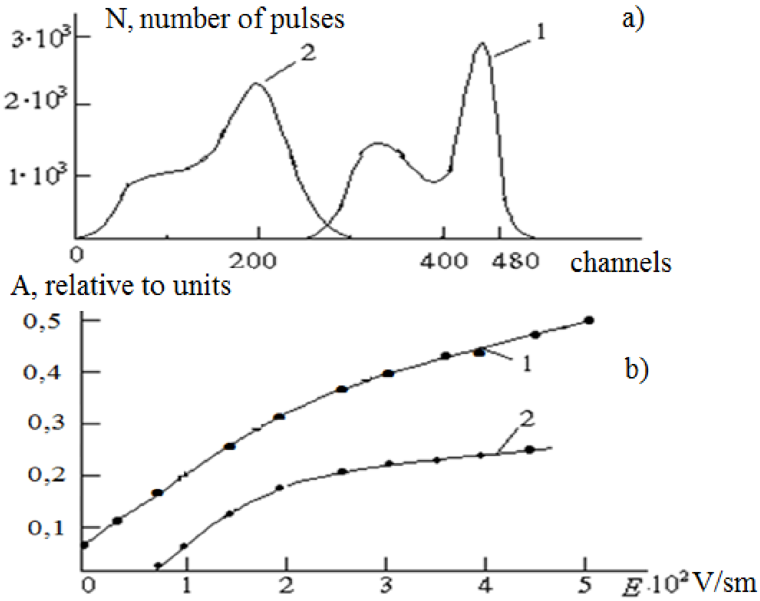

Fig. 3. Spectral line shapes (a) and signal amplitude Athe detector Si-PI-№6 (d=50μm), measured to (curves 1) and later(curves 2) impact of ultrasonic waves with intensityI * = 0.5W/cm^2, frequency f = 15MHz, during t = 12h, at T = 300K.Spectral lines are measured at E = 450V/cm.

At the same time mechanical and electrical properties of Au-contact to silicon are improved, which is reflected on noise characteristics of Si-receivers of radiation, resulting in reduction of noise value at increased displacement voltages. This is an important factor because it is one of the main requirements for the quality of Si-receiver contacts. The current characteristics discussed above and the volt-noise characteristic of one of the Si radiation receivers demonstrate a reduction in the noise level after ultrasonic processing the last (fig. 4.). The electrical and strength characteristics of the metal-semiconductor contact can be improved by irradiating it with ultrasound, as studied in [1] in the case of acoustostimulated adhesion of copper films to Si.

Increased ultrasonic processing time (t > 30min) results in deeper penetration of gold into the sensitive (active) region of Si receivers. As a result, these Au defects and deterioration of the characteristics of the Si radiation receivers (spectral line shape, noise, etc.) occur. It is also necessary to note still that improvement of functional (spectral) characteristics of Si-receivers of radiation is influenced also by reduction of speed of a superficial recombination under the influence of the I ultrasonic waves I* ≤ 0,4 ÷ 0,5 W/cm^{2}at times of ultrasonic processing of t <30 min. Ultrasound suppresses recombination centers in thin near-surface layers of the "input" window, (dead layers), which makes an additional contribution to the efficiency of collecting non-equilibrium charge carriers.

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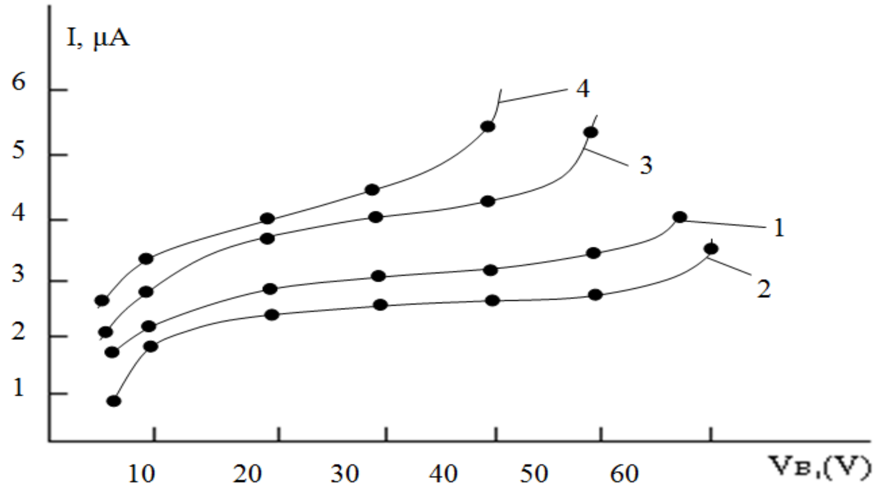

Fig. 4.Voltamp characteristics of Si-n-p receiver of Si-PI-W- -№8 radiation before and after ultrasonic treatment at I * = 0.4W/cm^2, f = 15MHz and T = 300K. curve 1-to-ultrasonic treatment; curve 2-processing time t = 20min; curve 3 t=120min; curve 4- t = 240min. The curves measured at T=300K. The decrease in current (curve 2) is due to the improvement in the structure of the sensitive region and the adhesion strength of the Au-contact at the "input" window.

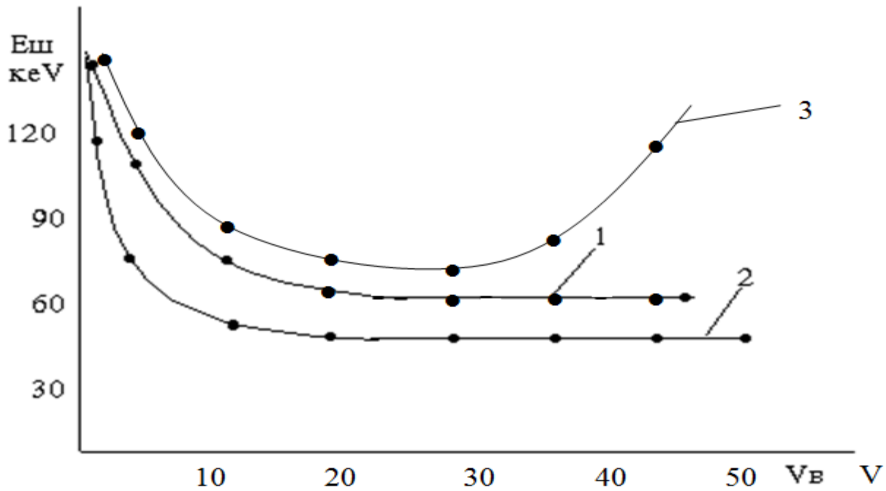

Fig. 5. Noise dependence of Si-n-p-receiver of Si-PI-W -№8 radiation on bias voltage at T = 300K.Krey 1-to, curve 2- after ultrasound irradiation with intensity I*=0,4W/cm^2, f = 15MHz during t = 25min. curve 3- after ultrasound irradiation I*=0,4W/cm^2,, f = 15MHz during t=120min

It should also be noted that the effect of suppression of surface recombination centers by ultrasound was observed earlier in both p-Si monocrystals and polycrystalline silicon [9]. As is known, the effects of surface recombination in polycrystalline silicon are mainly due to physical processes occurring at the intergranular boundaries of individual crystals. These experiments [9, 10] confirm our conclusion that in single crystal Si there is suppression of the recombination and hole capture centers, both in the volume and in the near-surface layers of the active element of Si radiation receivers.

This effect is first found by us in the n$^+$-layers of Si-monocrystals in the study of Si-n-p-structures and is associated with the formation of electrically inactive complexes from donors and acceptors protruding to ultra- Sound processing as capture centers,

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Vol. 7, Issue 7 , July 2020

recombination of non-equilibrium holes and electrons. Formation of such complexes takes place due to the mechanism of acoustostimulated diffusion of impurity atoms, which was theoretically considered for lithium atoms [11] and experimentally investigated relative to phosphorus atoms in [12] when studying the effect of ultrasound on the optical spectrum of reflection of Si - n - p - structures.

VI.CONCLUSION AND FUTURE WORK

Penetration of gold into active area of Si-receivers of radiation under the influence of the I ultrasound $I^* \geq 0{,}4\div0{,}5 W/cm^2$ for a long time as it was noted above, leads to deterioration in their characteristics. This is because the introduction of centres with deep levels (gold) leads to a reduction in the lifetime of charge carriers. Studies by various authors show that gold atoms in silicon can be in three charge states once negative, positively charged, and neutral. The donor gold level lies at a distance of $E_1 = 0{,}35eV$ from the valence zone, and acceptor level at a distance of $E_2 = 0{,}54eV$ from the bottom of the conduction zone [4.5.6]. The levels due to the introduction of gold are concentrated near the n-p transition of the Si radiation receiver and this will lead to an increase in current (Fig. 4) and, accordingly, an increase in noise level (Fig. 5 curve3). The effect of gold on the characteristics of Si thyristors produced by thermal diffusion of the latter was found in [13], where an increase in leakage currents was noted in particular.

In such a way that under the influence of the I ultrasonic waves $I^* \leq 0{,}4\div 0{,}5 W/cm^2$ at times of ultrasonic processing of t <30 min. gives improvement of functional (spectral) characteristics of Si-receivers of radiation and reduction of speed of a superficial recombination. Ultrasound suppresses recombination centers in thin near-surface layers of the "input" window, (dead layers), which makes an additional contribution to the efficiency of collecting non-equilibrium charge carriers.

Increased ultrasonic processing time (t > 30min) results in deeper penetration of gold into the sensitive (active) region of Si receivers. As a result, Au defects occur and the performance of Si radiation receivers is degraded.

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