Investigation of Small Dose Radiation Stimulated Processes in Semiconductor Materials and Structures

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***Abstract**:*
The paper presents the results of investigations of influence of radiation-thermal treatment (RTT) on the properties of semiconductors and structures based on them (Si,GaAs,GaAlAs,GaP). After RTT the crystal is cleaned of native (″genetic″) defects, the degree of homogeneity of lattice increases and electrophysical and optical properties of the semiconductor materials and structures improve (″small dose effect″). The processes taking place during the RTT are discussed and the perspectivity of the method in practice is shown.

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As early as 1970's, in investigation of the radiation influence on semiconductors and structures it was revealed that after irradiation with relatively small radiation doses (accelerated electrons, γ-quantum) followed by thermal annealing return radiation degradation effect takes place: lifetime, mobility and concentration of free carriers, crystal lattice homogeneity are increased, parameters of semiconductor devices are improved ("small dose effect")[1-5]. However, this effect is poorly investigated since it depends on many factors, such as type, energy and intensity of irradiating particles, irradiation and annealing temperature, initial defectivity of a semiconductor, etc.

This paper presents the results of experimental investigations of radiation-thermal treatment (RTT) influence on the properties of semiconductors and structures based on them (Si,GaAs,GaAlAs,GaP). Irradiation by 2÷4 MeV electrons was carried out at room temperature, the fluence being $10^{12}\div10^{14}cm^{-2}$. The irradiated samples were annealed thermally (T=400÷670 K).

For studying the influence of "small dose effect" on silicon epitaxial structures used in semiconductor electronics (КЭФ-0.7) the maps of sheet resistivity distribution throughout the surface before and after RTT were taken (33 points). The sheet resistivity value across the area on the starting wafer varied within the range 0.56÷0.80 Ohm.cm, i.e.0.68±0.12 Ohm.cm which means deviation from the average value by 18%. After the RTT process was carried out, there occurred value equalization of the given parameter across the wafer and the deviation from the average value was ~ 5% (0.64±0.03 Ohm.cm).

On the basis of this investigation the regimes of the RTT process were determined for epitaxial Si and tested in the production of a pilot lot of various types of integrated circuits (ICs) of the K555/533 series (STTL). The RTT application resulted in an increase of ICs percentage yield by 4÷6 % (then the factual ICs percentage yield under production conditions depending on type was 35 ÷ 55%).

The cause of the positive influence of RTT was clearly shown during the visual observation on the dislocation wells on the surface of the wafer epitaxial structures Si and GaAs (thickness 10÷16μm). As is seen from Fig. 1a, before RTT areas with strong accumulation of different size disturbances are revealed on the surface of the GaAs wafer. After RTT most of the disturbances disappear. Exclusion make big disturbances only which might be drains for simple defects forming small disturbances. Fig.1a,b show a trend toward cleaning of the epitaxial layer surface from defects which is verified by parameter improvement at RTT. Similar picture is obtain in Si [5].

The RTT influence on the parameters of light-emitting structures (LES) based on III-V semiconductor compounds (GaAlAs<Zn>, GaP<N> and GaP<N,Zn,O> - red, green and yellow, respectively) was also studied. The I-V characteristics (IVC), electroluminescent spectrum and luminous intensity at a given value of direct forward current (10mA) of light-emitting diodes {LED's} made of this structures have been measured before and after irradiation and after consequent annealing. Two groups of each chip type (20-25 diodes), the first with an luminous intensity twice the second were selected. .

The investigations have shown that after RTT only the band intensity changed. Its shape and position (or location) on the spectrum remain unchanged.. The IVC''s are also unchanged i.e. injection coefficients. A marked increase in the luminous intensity is observed directly after irradiation (Table 1). Here this effect is more pronounced in the first group of samples. The Table lists the optimal annealing temperatures, further increase of which decreases the luminous intensity.

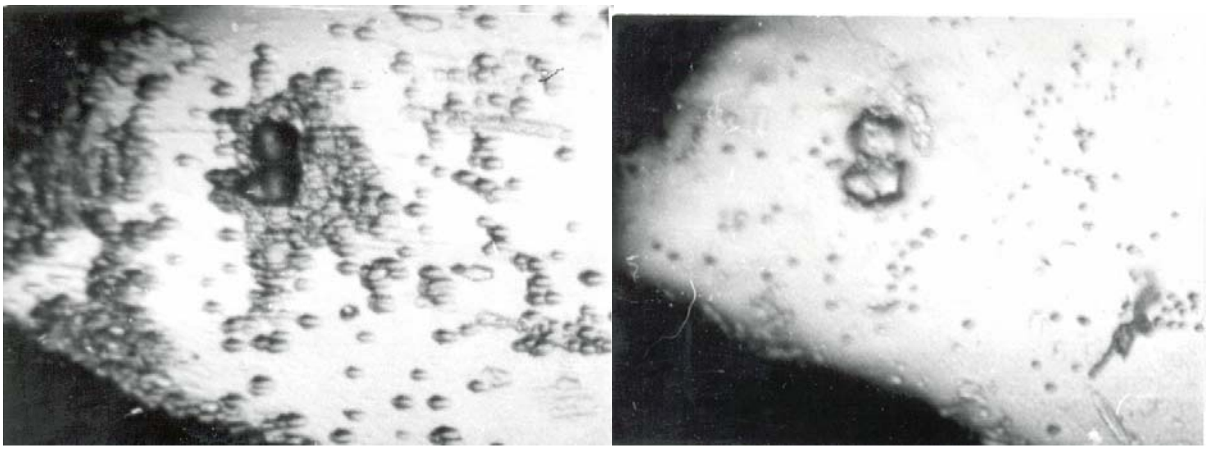
To explain the above-mentioned experiments we will deal with light-emission mechanisms in particular structures: red emission in GaAlAs<Zn> is a result of electrons transition from the conduction band on the valence band and level of zinc. GaP<N> green emission is formed during the exciton annihilation which is created on the nitrogen isoelectronic captures (N_P), but yellow emission in GaP<N,Zn,O> is formed by definite proportion blend of green and red emission ,where the red emission is result of the exciton annihilation on the captured the isoelectronic molecules (Zn_{Ga}-O_p). The concentration of emission recombination centers in active sections of LED's is ~ 10^{18} cm^{-3} [6]. If one even assumes that radiation defects (RD) play a role of emission centers, the integrated fluxes and thus the RD concentrations are so small that they are incapable to change significantly the concentration of emission recombination centers of the crystals under investigation. Hence, it could be suggested that the effect observed is due to a decrease of the concentration of nonemission recombination centers. It is well-known [6] that the nonemission or infrared emission recombination centers with deep-levels in the structures under investigation (dislocations, precipitates of impurity atoms, complexes involving vacancies) have capture sections that exceed the section of main emission centers with shallow-levels by several orders of magnitude. Therefore low integral radiation fluxes turned out to be effective..

Under irradiation of the crystal with high-energy particles two processes take place: accumulation of RD (the crystal transfer into more inequilibrium state) and a stimulation of the reaction of healing the native ("genetic") defects (the crystal tend to equilibrium). At the beginning of small-dose irradiation when the concentration of created radiation defects is small and interaction with native defects prevails over the interaction with each other healing crystal native defects takes place. At RTT this process proceeds in two stages: the first stage takes place during irradiation when the mobile components of Frenkel pairs, in the radiation stimulated diffusion process meeting and healing of native defects of the crystal. The second stage occurs at subsequent annealing when diffusion takes place and simultaneously with healing (annihilation) the accumulation of elementary defects forming native disturbances takes place on the drains. Since temperatures at RTT ($T \leq 670K$) are much lower than those in the crystal growth technology, the crystal remains in a more ordered state after RTT.

Thus, we have shown that by relatively low temperature radiation stimulated processes the homogeneity of crystal lattice can be increased and successfully applied in the technology of semiconductor materials, devices and ICs.

Table 1. The results of the investigation of the RTT effect on LED's
I_0,I_Φ,I_T are LED emission intensities before irradiation, after irradiation and after annealing, respectively.

Crystal type	I_0,mcd	Φ,cm^{-2}	$\Delta I_\Phi/I_0$,%	T,K	$\Delta I_T/I_0$, %
GaAlAs<Zn>	0,6	4.10^{12}	43	420	30
	0,7	8.10^{12}	15	520	55
(RED)	1,2	4.10^{12}	12	520	37
	1,3	1.10^{13}	-10	420	0
GaP<N>	0,15	4.10^{12}	50	420	70
	0,15	1.10^{13}	15	420	7
(GREEN)	0,30	4.10^{12}	10	420	33
	0,30	8.10^{13}	-30	420	-20
GaP<N,Zn,O>	0,15	4.10^{12}	42	420	65
	0,15	1.10^{13}	20	420	0
(YELLOW)	0,30	4.10^{12}	10	420	35
	0,30	8.10^{13}	-25	420	-20



a) b)

Fig 1. A view of the surface area of epitaxial GaAs before (a) and after (b) radiation-thermal treatment (scale:1cm -100μm)

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