USAGE OF ELECTRON ACCELERATORS IN MATERIAL RESEARCH STUDIES

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Abstract

The process of silicon doping by phosphorus and boron by means of electron beam treatment in air is described. The electron beam with energy 1.2-2 MeV and current density of 0.01-0.1 mA/cm^2 was generated by pulse linear accelerator ILU-6.

Comparison of diode structures formed by thermal (traditional) and radiation-thermal treatment have shown similarity of their electric parameters but the temperature and duration of radiation-thermal process are much lower than that of traditional one.

The ferrite compositions are also synthesized under electron beam. This process has some advantages over traditional pure thermal technology.

1 INTRODUCTION

One of the ways to intensify the processes of solid phase interaction is the irradiation of reagents. The effectiveness of treatment sufficiently depends on the type and power of ionizing radiation, on physical and mechanical properties of irradiated materials and on irradiation conditions. As the result of research works of last years have shown the use of powerful electron beam (energy of 1.5-2.5 MeV, power of up to 40 kW) as radiation agent permits to sufficiently broaden the limits of the observed effects of intensification of solid state processes and realize the process of obtaining the pure chemical materials.

2 DOPING OF SILICON UNDER BEAM

The silicon plates were irradiated by electron beam in air at normal conditions. Beam density in irradiation zone was 0.01-0.1 mA/cm^2, energy was 1.2-2.0 MeV. The right energy choice permits to realize irradiation highly homogeneous in depth. Standard silicon plates and liquid diffusants containing various combinations of boron and phosphorous were used.

The plates with applied diffusant were placed under extraction window of ILU-6 accelerator [1] on the heat insulator usually one over another, working surfaces one to other. The temperature was monitored by thermocouple located under the plates. There is an unambiguous relation between beam current, temperature of sample and irradiation dose power at known parameters of electron beam and value of heat flux from plate, so it is possible to precisely control the process by variation of beam energy, temperature of plate and duration of treatment.

As a result of the electron beam treatment at described conditions the temperature of the plates rises up to 600-1300° C for the time of less than 1 minute. Then the temperature is controlled with high accuracy. Truly this treatment ought to be assumed as thermal-radiation.

It is experimentally proved that thermal-radiation treatment of silicon at temperature of 1000°C during 10 minutes does not lead to the apparition of the additional electrically active defects in comparison with the thermal treatment.

The masking of the surface diffusant by the layer of SiO_2 having width of 0.5 mkm permits to form semiconductor structures at temperature of 1140-1150°C during 0.5-50 minutes. The greater treatment time leads to diffusion of boron and phosphorous in silicon as it can be noticed from the value of the surface resistance of plates.

Radiation stimulated diffusion can help to resolve the technological contradictions because it reduces duration and temperature of treatment [2] or even get rid of thermal operations. But technological processes using this physical phenomenon are still not mastered by microelectronics industry.

The treatment of silicon with surface diffusant during 5 minutes gives the following distribution of dopant concentration along the depth:

for phosphorous-

$1.5*10^{18}$ atoms/cm^3 in near-surface layer and $1.5*10^{15}$ atoms/cm^3 at depth of 1.2 mkm, temperature of treatment is 1100°C;

$2*10^{17}$ atoms/cm^3 in near-surface layer and $2*10^{15}$ atoms/cm^3 at depth of 0.4 mkm, temperature of treatment is 900°C;

for boron -

$4*10^{18}$ atoms/cm^3 in near-surface layer and $1.5*10^{15}$ atoms/cm^3 at depth of 0.7 mkm, temperature of treatment is 1250°C.

At temperature of treatment of 1000°C a thickness of silicon layer saturated by boron (determined by the decrease of concentration in 1000 times) are 1 mkm after treatment during 15 minutes and 2.7 mkm after treatment during 50 minutes.

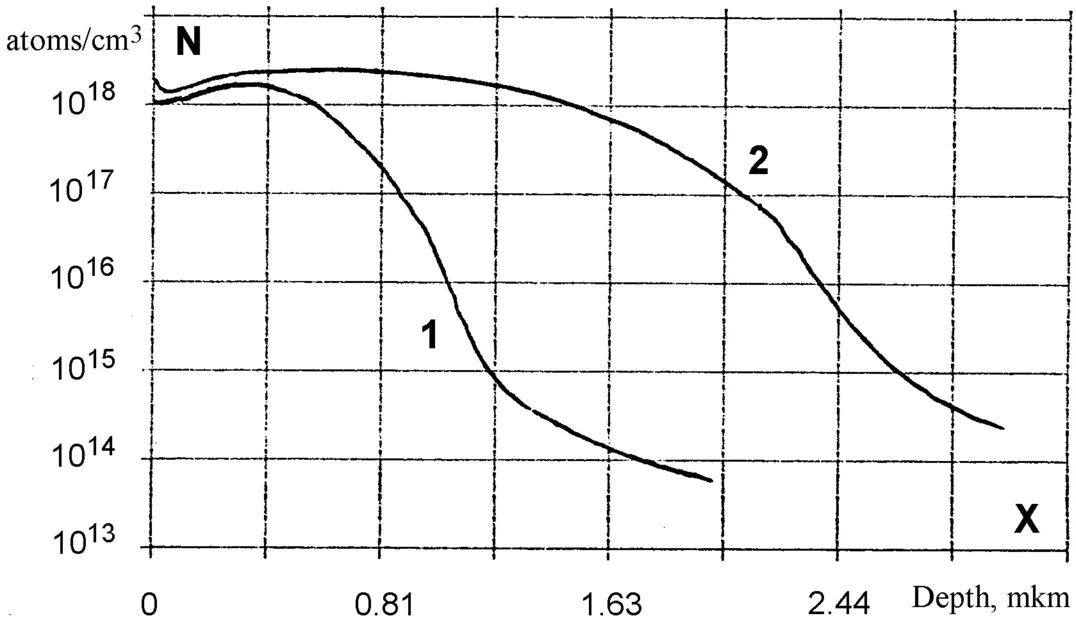

Figure 1. Profiles of boron distribution in silicon at electron energy of 1.7 MeV. 1 - duration of treatment is 5 minutes, 2 - duration of treatment is 50 minutes

Figure 1 shows the profiles of boron distribution in silicon after thermal-radiation treatment at electron energy of 1.7 MeV during 15 and 50 minutes. The profiles of distribution were obtained by the method of secondary-ion mass-spectroscopy.

Table 1 presents the values of slope of volt-ampere characteristics and of breakdown voltage of the p-n transitions formed by these two technologies and by their combinations. Comparison of electric properties of diode p-n structures formed by thermal-radiation and pure thermal technologies proves their similarity, but temperature and formation time of p-n transitions in thermal-radiation technology are sufficiently less than the same parameters in pure thermal technology.

Table 1. Parameters of p-n transitions formed by different technological processes.

N	*Drive-in*	*Diffusion*	*Annealing*	*Slope of volt-ampere characteristics*	*Breakdown voltage*
1	Thermal, 1000°C, 30 minutes	Thermal, 1000°C, 30 minutes	No	0.5-0.6 mA/V	25 V
2-1	Thermal, 1000°C, 30 minutes	Thermal-radiation 600°C, 10 minutes	No	2 mA/V	25 V
2-2	Thermal, 1000°C, 30 minutes	Thermal-radiation 600°C, 10 minutes	Thermal, 1000°C, 10 minutes	2 mA/V	100-130 V
3-1	Thermal, 1000°C, 30 minutes	Thermal-radiation 1000°C, 5 minutes	No	3 mA/V	40-50 V
3-2	Thermal, 1000°C, 30 minutes	Thermal-radiation 1000°C, 5 minutes	Thermal, 1000°C, 10 minutes	3 mA/V	40-60 V
4-1	Thermal-radiation drive-in and diffusion in one cycle, 600°C, 10 minutes		No	2-2.5 mA/V	20-30 V
4-2	Thermal-radiation drive-in and diffusion in one cycle, 1000°C, 5 minutes		Thermal-radiation 1000°C, 10 minutes	2-2.2 mA/V	40-55 V

3 USE OF ELECTRON BEAM IN HIGH TEMPERATURE SOLID PHASE SYNTHESIS

The modern industrial electron accelerators are the perspective sources of heating for realization of the high-temperature inorganic synthesis processes. The powerful electron beam as a heater has a number of advantages in comparison with traditional ones: high power transformation efficiency, homogeneous and quick heating of volume of treated material, active change of the thermal treatment regimes, chemical purity of beam, possibility to organize the synthesis in the slag lining regime.

Besides these the powerful beam of accelerated electrons intensifies the processes of diffusion mass transfer in the treated reaction mixtures [3] so its use can be very helpful in realization of numerous high temperature solid state processes.

Synthesis of combinations in system $BeO-Fe_2O_3$ is going through the formation of a set of intermediate combinations, and phase balance is achieved very slowly in this system due to kinetics, thus requiring the prolonged high temperature annealing, in some cases the duration can be up to 1000 hours. The duration of such synthesis in thermal-radiation conditions reduces up to 15 - 60 minutes depending on the mole ratio of reaction mixture components.

The stage of a preliminary thermal treatment (ferritizing annealing) is used in the production of the goods made of magnetic-soft materials such as lithium-titanium ferrites. This stage implies 4 operations and the total duration is about 20 hours. The use of electron beam reduces the number of operations to 1 and the duration of it is no more than 5 minutes.

The powerful electron beam is capable to provide very high heating rate of the treated materials. So the synthesis of the combinations comprising volatile at high temperature elements (for example, MoO_3, WO_3, etc.) is accomplishing so fast that violation of final products stoichiometry is negligibly little and does not influence on their properties. The traditional technology requires prolonged multistage thermal treatment according the complicated regime. The purity of the products obtained by thermal-radiation synthesis is higher than that of the products obtained by the traditional technologies. In principle new high effective technologies of inorganic combinations' synthesis can be created with use of industrial electron accelerators.

4 CONCLUSION

It is ascertained that the intensification of the mass transfer process at high temperature takes place in the diverse systems with ion and metal types of chemical bonds. A vacancy diffusion mechanism is realized in all cases. The absence of intensification effect in the case of interstitial diffusion is underlining the role of the point defects having radiation origin. One may note that diffusion characteristics in our work have the meanings of the effective values. The exact differentiation between thermal and radiation components can be determined for each case only with the help of the complicated mathematical apparatus concerning the interaction of all factors influencing on creation and destruction of radiation defects in crystal lattice and their participation in the mass transfer.

The combined influence of temperature and parameters of electron beam on the kinetics of development of the level of structural defects is studied by us in the work [4]. The necessity to consider not only the average values but also the pulse parameters of electron beam was shown on the example of the diffusion mechanism with consideration of the relaxation processes.

5 REFERENCES

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