FIZIKA VOLUME 10 SUPPLEMENT 2, 1978
Proceedings of the VI Yugoslav Symposium of the Physics of Condensed Matter, Kruševac, September, 18-22, 1978

SOLUBILITY AND DIFFUSION OF SODIUM IN GALLIUM ARSENIDE

M. Stojić, V. Spirić and D. Kostoski
"Boris Kidrič" Institute of Nuclear Sciences, Vinča, Belgrade

Abstract: The solubility and diffusion of sodium in p-type and n-type GaAs are studied by means of radioactive tracer method at temperatures below the decomposition temperature which is $637^{o}C$. It is established that solubility and diffusion of sodium in GaAs are strongly dependent on the kind and concentration of impurities introduced into material during crystal growth. Two diffusion components are observed. The slower one has been considered in terms of Arhenius relation being for p-type/$3x10^{17}$ cm^{-3}/ GaAs, $D = 4.1x10^{4} \exp(-2.59\ eV/kT)\ cm^{2}s^{-1}$ and for n-type/$2x10^{17}$ cm^{-3}/ GaAs, $D = 1.22 \exp(-1.65\ eV/kT)\ cm^{2}s^{-1}$. It is also established that sodium in the specimens depth where the the slower component is dominant acts as an acceptor. The results about behaviour of sodium in GaAs are compared with those for Si and Ge.

1. Introduction

From alkali metals only the behaviour of lithium as impurity in Si, Ge and partly in GaAs have been studied systematically. Far less is known about the other alkali metals, so that even for sodium there are only a few papers concerning the solubility, diffusion and the electrical properties of sodium in Si[1,2,3] and Ge[4,5,6]. As far as we know, the data about the properties of sodium in GaAs do not exist.

The aim of the present work is the study of solubility, diffusion and electrical behaviour of sodium in GaAs. For the sake of comparison the obtained results are presented together with those treating the properties of sodium in Si and Ge that have already been published.

2. Experiment

In this experiment we used the same procedure as we did in the study of solubility and diffusion of sodium in Ge[6]. The specimens of n-type($2x10^{17}$ cm^{-3}) GaAs and p-type($3x10^{17}$ cm^{-3} and $2x10^{16}$ cm^{-3}) GaAs of rectangular shape/20x10x1 mm^3/ were used. Metalic sodium as source of diffusing impurity was a well defined mixture of Na^{23} and Na^{24} obtained in Vinča reactor by the exposure of natural sodium to the known thermal neutron flux. Having the vapour of sodium as a constant source of impurity, diffusion has been performed during 2 houres at temperatures below 637°C which is the decomposition temperature of GaAs. Under this temperature, the evaporation is congruent and vapour has the same composition as the solid phase[7].

The method of determining the distribution of diffusing species in the diffused region was essentially reduced to measuring the radioactivity of thin layers after their successive removal parallel to the original specimen surface. Sectioning of specimens was done carefully by means of an aqueous solution of 8 gr NaOH and 20 ml 30% H_2O_2 in 100 ml of water.

3. Results and discussion

Plotting the concentration of sodium in a layer against the diffusion depth, the distribution curve is obtained as it is shown in Fig. 1.

Extrapolating the concentration to zero depth, the surface concentration of sodium in GaAs was determined. According to the conditions of this experiment, the surface concentration was assumed as the solid dolubility of sodium. The solubility as function of temperature is shown in Fig. 2. It is obvious that solubility, which increases with temperature increasing, is an order of magnitude larger in p-type GaAs (curve 1) than in n-type GaAs (curve 2).

The similar dependence was established for the solubility of sodium in Ge[6].

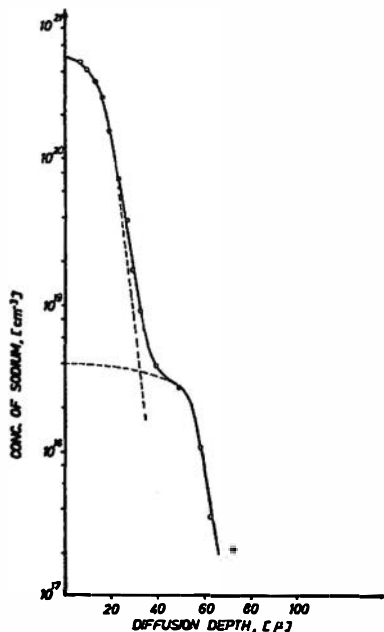

Fig. 1. The concentration of sodium as a function of diffusion depth.

As it can be seen from Fig. 1 the distribution of sodium indicates two diffusion components, the slower and the faster one.

For diffusion from vapour phase into semi-infinite specimen the distribution of sodium as a function of diffusing time (sec) and distance (cm) from original specimen surface is simply described by well known error function.

This formalism has been used in determining the diffusion coefficients of slower component considered here separately from the faster component. Results obtained in this way could be correct enough to be compared with those for Si and Ge indicating the behaviour of sodium in Si, Ge and GaAs.

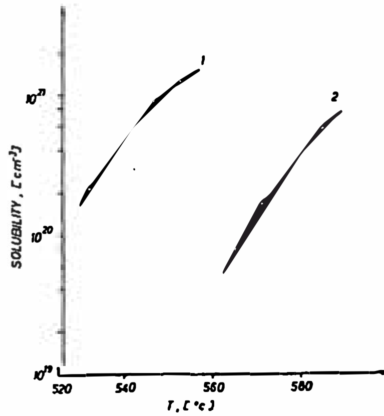

Fig. 2. The solubility of sodium as a function of temperature:
1 - in p-type GaAs; 2 - in n-type GaAs.

The diffusion coefficient as a function of temperature shown in Fig. 3 is expressed by the following relations:

$D = 4.1 \times 10^{4} \exp(-2.59\ eV/kT)\ cm^{2} sec^{-1}$, for p-type($3 \times 10^{17}\ cm^{-3}$) GaAs

$D = 1.22 \exp(-1.65\ eV/kT)\ cm^{2} sec^{-1}$, for n-type($2 \times 10^{17}\ cm^{-3}$) GaAs,

where k is Boltzmans constant and T temperature in K.

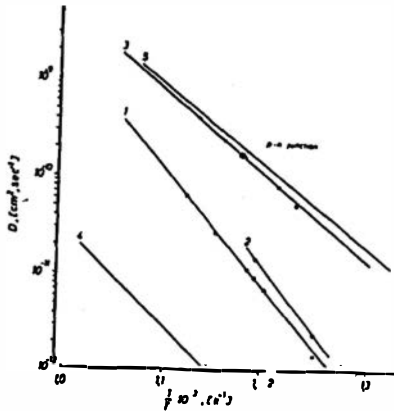

Fig. 3. Diffusion coefficient as a function of absolute temperature: 1 - p-type($3 \times 10^{17}\ cm^{-3}$) GaAs; 2 - p-type ($2 \times 10^{16}\ cm^{-3}$) GaAs; 3 - n-type($2 \times 10^{17}\ cm^{-3}$) GaAs; 4 - p-type($1 \times 10^{14}\ cm^{-3}$) Ge; 5 - n-type($2 \times 10^{14}\ cm^{-3}$)GaAs

Fig. 3 also consists of the results of sodium diffusion in p-type Ge (curve 4) and in n-type Ge (curve 5) we have obtained earlier[6].

Like in Ge, diffusion of sodium in GaAs is strongly dependent on the kind and concentration of impurities in crystals being much faster in n-type than in p-type GaAs. This effect unexpectedly large could be understood on the basis of different interactions of sodium with donors and acceptors, particularly with the lattice defects created at diffusion temperatures. Namely, it is assumed that sodium diffuses in semiconductors as singly positive ion, so that its Coulombic interactions with acceptors, donors and lattice defects will be different in n- and p-type materials having the different influence on the diffusion process resulting in different frequency factors and activation energies. The final explanation of this effect requires the additional work in which both diffusion components should be treated simultaneously through the model of vacancy-interstitial diffusion mechanism or in some other appropriate way.

In Table I the properties of sodium in Si, Ge and GaAs are shown for the sake of comparison. Diffusion of sodium in Si occures via interstitial mechanism where it acts as a donor[3]. On the contrary, in Ge the diffusion of sodium is described by vacancy mechanism, being much faster in n-type than in p-type Ge[6]. Sodium in Ge is an acceptor[6]. In GaAs two components of diffusion are observed. Concerning the slow component the behaviour of sodium in GaAs is similar to the one in Ge.

Table I. The behaviour of Sodium in Si,Ge and GaAs

material		Electrical activity	Solubility $/cm^{-3}/$	Diffusion coefficient D, $/cm^2.sec^{-1}/$	References
	Si	donor (-)	9×10^{18} (1200°C)	$1.65 \times 10^{-3} \exp - \frac{0.69\ eV}{kT}$	/3/
Ge	p	acceptor (+)	8.7×10^{17} (800°C)	$0.395 \exp - \frac{2.0\ eV}{kT}$	/6/
	n	acceptor (+)	2.7×10^{17} (900°C)	$0.185 \exp - \frac{1.51\ eV}{kT}$	
GaAs	p	acceptor (+)	1.3×10^{21} (560°C)	$4.1 \times 10^{4} \exp - \frac{2.59\ eV}{kT}$	Present work
	n	acceptor (+)	5.8×10^{19} (560°C)	$1.22 \exp - \frac{1.65\ eV}{kT}$	

References

1) J. O. McCaldin, M. J. Little and E. A. Widmer, J. Phys. Chem. Solids 26, 1119 (1965).

2) L. Švob, Phys. stat. sol. 7, K1 (1964).

3) J. Švob, Solid-State Electronics, Pergamon Press 10, 991-996 (1967).

4) A. L. Goncharov and G. N. Clevleishvili, Inorg. Materials 10, 540 (1974).

5) V. Spirić and M. Stojić, Phys. stat. sol. A10, K119-20 (1972).

6) M. Stojić, V. Spirić and D. Kostoski, Rad. Effects in Semiconductors, Dubrovnik, 1976. Inst. Phys. Conf. Ser. No. 31, chapter 3, pp. 304 (1977).

7) H. C. Casey, Ir. Diffusion in the III-V Compound Semiconductors, Atomic Diffusion in Semiconductors, edited by D. Shaw (p 360), Plenum Press, London and New York, 1973.