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THE CALCULATION OF RANGE DISTRIBUTION OF IMPLANTED DOPANTS IN GaAs AND GaP

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Abstract. Starting from the experimentally stated fact that the distribution of implanted ions is gaussian, the formalism for the calculation of the projected range R_p and projected range standard deviation ΔR_p has been presented in this paper using the well-known LSS theory[1)]. It has also been assumed that the compound semiconductor stopping power is governed by Brag's additivity rule. In this paper, the numerical results for the implantation of GaAs by ^{28}Si, ^{32}S, ^{64}Zn, ^{80}Se and ^{130}Te ions, and GaP by ^{32}S, ^{64}Zn, ^{80}Se, ^{119}Sn and ^{130}Te in the energy range of 10-350 keV have been presented and discussed.

1. Introduction

Ion implantation is a process by which controlled quantities of certain impurities are introduced into solid material surface layers in the form of an accelerated ion beam of energies of several keV to several hundred keV, which corresponds to penetration depths from several tenths of Å to 1 μm. As a technique, it has been widely applied in a number of scientific fields, especially in the solid state physics, due to the fact that electrical, magnetic, optical, superconductive and mechanical properties of solid materials are very sensitive even at the presence of slight quantities of impurities. In the last several years numerous investigations have been undertaken in the field of ion implantation applications in semiconductor compounds of the type III-V and II-VI. The results obtained until now, the most important of which are successful fabrication of LED diodes, semiconductor lasers, IMPATT diodes, FET integrated circuits, light guides, IR detectors and electroluminiscent diodes, show that the real possibilities of ion implantation are considerable.

The basic problem in the application of the ion implantation in semiconductor compounds is the determination of the depth concentration distribution of implanted ions in materials. The collision details between accelerated ions and solid target atoms are random variables, and therefore the depth concentration is gaussian, i.e.

$$N(x) = N_{max} \exp \{- \frac{(x - R_p)^2}{2 \Delta R_p^2}\} \tag{1}$$

where, $N(x)$ is the number of implanted ions of the unit volume, N_{max} the maximal concentration value, R_p the depth which corresponds to N_{max} (so called projected range) and ΔR_p the projected range standard deviation. Due to the fact that N_{max} is directly connected to the implanted dose, which is during the implantation process precisely electrically measured, the problem of the determination (1) is reduced to the calculation of the quantities R_p and ΔR_p. In the well-known LSS theory$^{1)}$, in the aim of the calculation of these quantities, the integrodifferential equation is formed, which governs the transport of ion beams through penetrating medium.

2. Problem formulation, its solving and results

In this work the integrodifferential equations for suitably chosen distribution functions of implanted ions have been formed. Further on, they have been transformed into integral equations for the distribution function moments (so called moment equations) which have been further approximated into ordinary differential equations of the first order being analytically integrable. As an example, the expression for the projected range obtained by the above said procedure is given

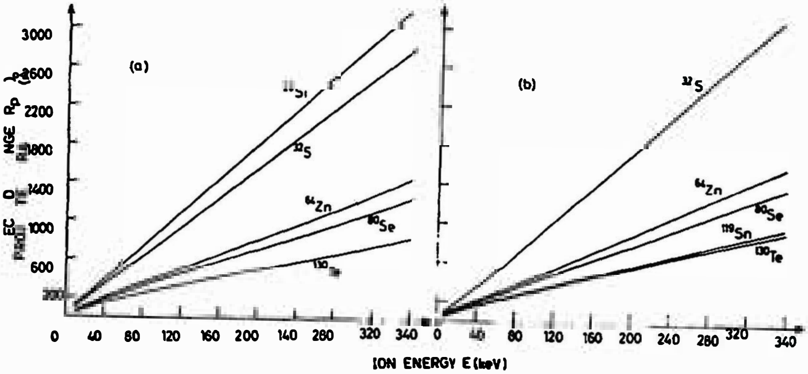

Fig.1. Projected range R_p versus ion energy E for ions (a) ^{28}Si, ^{32}S, ^{64}Zn, ^{80}Se and ^{130}Te implanted into GaAs, and (b) ^{32}S, ^{64}Zn, ^{80}Se, ^{119}Sn and ^{130}Te implanted into GaP.

[14] M.M. Tošić, Fig. 2

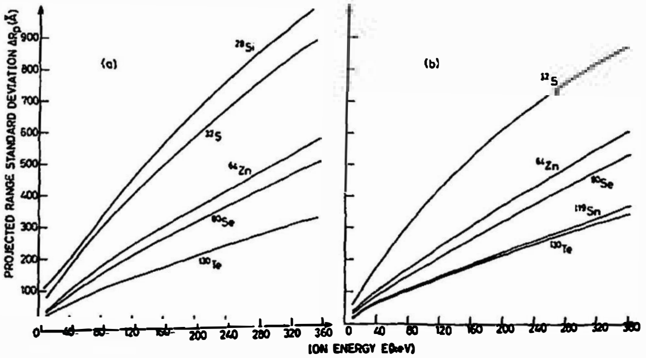

Fig.2. Projected range standard deviation ΔR_p versus ion energy for ions (a) ^{28}Si, ^{32}S, ^{64}Zn, ^{80}Se and ^{130}Te implanted into GaAs, and (b) ^{32}S, ^{64}Zn, ^{80}Se, ^{119}Sn and ^{130}Te implanted into GaP.

$$R_p(E) = \int_0^E \frac{dy}{N|Sn(y)+Se(y)-\mu\Omega n^2(y)/2y|} \times \exp\left\{-\int_0^E \frac{\mu\, Sn(x)/2x}{Sn(x)+Se(x)-\mu\Omega n^2(x)/2x}\, dx\right\} \qquad (2)$$

where E is the incoming ion energy, N target atom concentration, Sn(E) and Se(E) stopping cross sections for collisions of ions with target nuclei and electrons (assuming they are separable) respectively, $\Omega n^2(E)$ energy square fluctuation and μ target atom through ion mass ratio. Projected range standard deviation R_p is calculated from the following definition

$$\Delta R_p(E) = \{<R_p{}^2(E)> - <R_p(E)>^2\}^{1/2} \tag{3}$$

For the variable $<R_p{}^2(E)>$, the solution is found in the same manner as for (2), and it depends on the variables Sn(E), Se(E) and $\Omega n^2(E)$. The calculation of variables Sn(E), Se(E) and $\Omega n^2(E)$ has been solved in Lindhard et al.$^{2)}$ where, starting from the Thomas-Fermi model and introduced LSS dimensionless units for the energy, $\varepsilon=C_E E$ and length $\rho=C_R R$ (C_E and C_R are the functions of incident ion and target properties), it has been found that Se(E) is proportional to $E^{1/2}$, while the functions for Sn(E) and $\Omega n^2(E)$ have been given in tabular form.

As the base for the application of the previously described formalism in semiconductor compound implantation the Brag´s additivity rule is used

$$<\Delta E> = \Sigma_i N^i \Delta x \ S^i(E) . \tag{4}$$

It claims that the solid compound stopping power is equal to the sum of the weighted stopping powers of the compound constituents. In the (4), N^i and $S^i(E)$ represent atomic concentrations and stopping powers of the type i constituent, respectively.

Numerical execution of the formalism has been performed on the CDC 3600 computer system. As incoming data, the ion parameters (Z_1, M_1) and target parameters $(Z_2, M_2, N)^i$ (i=1,2) are read. The values for the projected range R_p, projected range standard deviation ΔR_p, total range R, total range standard deviation ΔR, nuclear NSn(E) and electronic stopping power N Se(E) are printed for each ion energy from the set (10, 20, ..., 350) keV.

Using the above described formalism and having in mind the fact that the galium semiconductor compounds, especially GaAs and GaP are very interesting, the ion implanted depth distribution parameters have been found for ^{28}Si, ^{32}S, ^{64}Zn, ^{80}Se and ^{130}Te in GaAs and ^{32}S, ^{64}Zn, ^{80}Se, ^{119}Sn and ^{130}Te in GaP. The projected range energy dependence $R_p(E)$ for the above given implantations is shown in Fig.1, whereas the projected range standard deviation $\Delta R_p(E)$ is shown in Fig.2.

The following conclusions can be drawn immediately from Figs. 1 and 2: (i) Projected ranges of implanted ions are somewhat smaller for GaAs, what is caused by the fact that its stopping power is somewhat higher than that of GaP, (ii) Projected range is almost a linear function of the energy, what is caused by the fact that the total stopping power of GaAs and GaP for given ions is almost constant in the chosen energy interval and the disagreement of linearity occurs at lower energies when the electron stopping power is dominant; (iii) the relation $\Delta R_p(E)/R_p(E)$ increases slowly with the incident ion mass due to the fact that $\{(M_1+M_2)/2(M_1M_2)^{1/2}\}\ \Delta R_p/R_p$ is almost constant in the observed energy range.

References:

1) J.Lindhard, M.Scharff and H.E.Schiøtt, Mat.Fys.Medd.Dan. Vid.Selsk. 33 (1963), no 14.
2) J.Lindhard, V.Nielsen and M.Scharff, Mat.Fys.Medd.Vid. Selsk. 36 (1968), no 10.