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METHOD FOR DETERMINING THE COORDINATE DISTRIBUTION OF LOCAL INHOMOGENEITIES IN THE BULK OF A SEMICONDUCTOR

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Abstract

A method has been developed for determining the two-coordinate (x and y) distribution of localized impurity atom clusters within the bulk of semiconductor materials. The developed method is used in the preliminary selection of homogeneous materials for the production of semiconductor devices.

Keywords: *semiconductor material, n-p junction, impedance, local inhomogeneities, grid ohmic contacts*

1. Introduction

Semiconductor device technology is a critical component of rapidly developing nanotechnology, one of the key aspects of which is the development of methods for studying localized impurity atom clusters within the bulk of semiconductor materials.

Known methods for quality control of semiconductor materials include electron microscopy (Fedina, L.I., 2012), probe resistivity measurements (Smirnov, V.I., 2012), and chemical selective etching and decoration (Azimov S. A., Muminov R. A., et al., 1981). These methods provide information strictly on the surface. Their use for studying the bulk properties of semiconductors involves the sequential destruction of the single crystal (e.g., by continuous etching or grinding), making them unsuitable for rejecting material used in device fabrication.

The traditional approach to studying the influence of a given concentration of various point imperfections in the crystal structure (impurity levels, dislocations, point adhesion centers) on the physical processes in semiconductor devices is insufficient to meet the modern requirements of semiconductor instrumentation. Research is needed to identify fluctuations in their distribution within the bulk of the semiconductor, determine local inhomogeneities in such distributions, and study the role of such local inhomogeneities on the properties of modern semiconductor devices.

2. Material and Method

A method for identifying local inhomogeneities in a semiconductor material based on the frequency dependence of the impedance of structures (Azimov S. A., Muminov R. A., et al., 1981) is proposed. The essence of this method is to fabricate an n-p junction on the semiconductor material, measure the frequency dependence of the n-p junction impedance over a wide frequency range, and, based on linear diagrams, determine the integral value of local inhomogeneities in the form of high-resistance layers throughout the entire volume of the sample.

This method cannot determine the coordinate distribution of local inhomogeneities. A new method is proposed for determining the coordinate distribution of local inhomogeneities.

To determine the distribution of local inhomogeneities along two coordinates $l_i(X_i, Y_i)$, rectifying contacts are created on two opposite side surfaces of the sample, the frequency dependence of the structure's impedance is measured, and the total size of all local inhomogeneities in the entire volume of the sample $(\sum l_i)_0$ is determined. Then, grid ohmic contacts are applied to two opposite sides of the sample through a mask with a width and pitch exceeding the largest size of the inhomogeneities (Fig. 1). After this, a constant voltage is applied alternately to each opposite pair of contacts whose coordinates are known. The magnitude of the voltage is determined from the electric field strength (Muminov R. A., Radzhapov S. A., Sagyndykov N. A. and Nurbaev K. M., 2005) using the formula:

$$E_{кр} \approx 4/3 \cdot [\pi \cdot \rho_\Delta/\varepsilon] \cdot 2R_\Delta$$

Where ρ_Δ is the negative space charge density arising in the p-region; $2R_\Delta$ is the linear size of local impurity atom clusters in the region in the direction of the electric field lines.

Additionally, the frequency dependence of the impedance is measured for each pair (Fig. 1).

Based on the linear diagrams, the total effective size of the inhomogeneities is determined without taking into account the region defined by the coordinates of the contacts to which a constant voltage $\sum l_i$ is applied. The desired distribution of local inhomogeneities along the $l_i(X_iY_i)$ coordinates is determined from the difference in the total effective sizes of the inhomogeneities before and after applying the constant voltage.

$$l_i\,(X_iY_i) = (\sum l_i)_o - \sum l_i$$

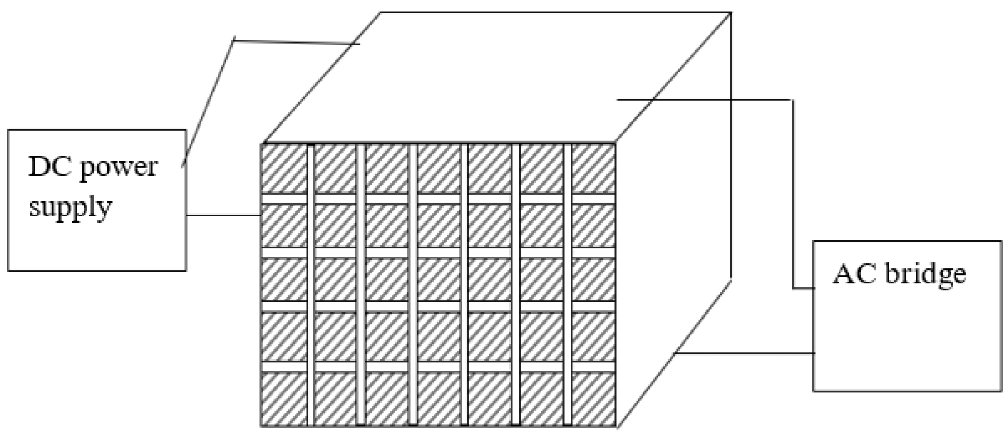
where $(l_i)_0$ is the total effective size of the inhomogeneities before applying constant voltage.

$(\sum l_i)$ is the total effective size of the inhomogeneities after applying constant voltage.

3. Results and discussion

In this example, the method is tested on p-Si with a resistivity of –1000 Ωcm. The sample dimensions are 10 × 8 × 2.5 mm. Nickel contacts are deposited on two opposite side surfaces of the sample using chemical vapor deposition, and grid ohmic contacts are deposited on two opposite sides of the sample using gold sputtering through a mask; the width and length of each cell are 200 µm, and the distance between the contacts is 100 µm.

Figure 1. *Scheme of measurement of coordinate determination of local inhomogeneities*



The frequency dependence of the impedance is measured, and the magnitude of local inhomogeneities in the form of high-resistance layers with a specific resistance and an effective size throughout the sample volume is determined. The sizes and specific resistance of the local inhomogeneities are presented in Table 1. By summing up the sizes of local inhomogeneities, $(\Sigma l_i)_o$, the total effective size of the inhomogeneities in the entire sample, is determined. A constant voltage of $3 \cdot 10^3$ V/cm is then applied alternately to the ohmic contacts. The frequency dependence of the impedance is measured each time, and Σl_i is determined without taking into account the region defined by the coordinates of the contacts to which the voltage is applied. The desired distribution of local inhomogeneities $l_i (X_i, Y_i)$ is determined by the difference in the total effective sizes of the inhomogeneities before and after applying the constant voltage. Table 2 presents the distribution of local inhomogeneities over two coordinates $l_i (X_i, Y_i)$.

Table 1. Dimensions and specific resistance of local inhomogeneities

No.	$r_i \cdot 10^6$ Ωcm	l_i mkm
1.	0.28	4.3
2.	0.65	3.1
3.	1.32	1.6
4.	1.73	2.8
5.	2.3	9.6
6.	2.76	8.3
7.	3.4	4.5
8.	6.4	2.7
9.	7.3	4.2
10.	8.51	6.8
11.	9.6	5.6
12.	11.7	3.2

Table 2. Distribution of local inhomogeneities by two coordinates $l_i (X_i Y_i)$.

No.	l_i, mkm	X_i, mm	Y_i, mm
1.	1.6	0.2	6.5
2.	2.7	0.5	2.0
3.	9.6	0.8	7.4
4.	8.3	2.0	0.2
5.	6.8	2.6	1.1
6.	4.5	3.5	4.7
7.	2.9	4.1	3.8
8.	4.3	5.3	0.5
9.	3.2	5.6	6.7
10.	5.6	6.2	2.3
11.	3.2	6.5	5.9
12.	4.2	7.7	5.0

The use of this method in the preliminary screening of material at an early stage of the technology of manufacturing semiconductor devices, in particular semiconductor nuclear radiation detectors, increases the yield of detectors with improved electrophysical and spectrometric characteristics.

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