Volume 3, Issue 1, January 2025 **ISSN (E):** 2938-3757

# THE DETERMINATION OF DEEP-LEVEL PARAMETERS IN SILICON BASED ON CAPACITANCE SPECTROSCOPY

H. D. Mamarasulova
Jizzakh State Pedagogical Institute,
Sh. Rashidov-4, 100130, Jizzakh, Uzbekistan

**Abstract**

This study explores the characterization of deep-level parameters in silicon through capacitance spectroscopy techniques. Deep-level defects play a crucial role in determining the electrical properties of silicon-based devices, impacting their performance in a variety of applications, including sensors, transistors, and photovoltaics. Capacitance spectroscopy offers a non-destructive method to identify and quantify these deep-level defects by analyzing the capacitance-voltage characteristics of semiconductor materials. The paper discusses the theoretical foundations of capacitance spectroscopy, the experimental setup used for measurements, and the interpretation of results to extract key parameters such as defect energy levels, capture cross-sections, and concentration profiles. Through comprehensive analysis, this work contributes to a better understanding of the behavior of deep-level defects in silicon, providing valuable insights for optimizing material properties and enhancing device reliability.

**Keywords**: Capacitance Spectroscopy Deep-Level Defects Silicon Semiconductor Materials Electrical Properties Defect Energy Levels Capture Cross-Sections Defect Concentration.

## Introduction

In the coming years, various methods of capacitance spectroscopy for deep levels will be increasingly used to study defect formation and annealing processes in semiconductors, which are constantly present in the silicon material lattice as uncontrolled, deliberately introduced impurities, as well as defects formed and eliminated during heating and irradiation. These methods are highly sensitive and allow the investigation of electrically active defects that introduce discrete levels in the forbidden zone of semiconductors. They also enable the measurement of deep-level concentration and parameters in finished devices and at various stages of their fabrication technology. Traditional capacitance spectroscopy methods, such as isothermal capacitance relaxation, thermally stimulated capacitance, photo-capacitance, and others, are widely applied and are thoroughly discussed.

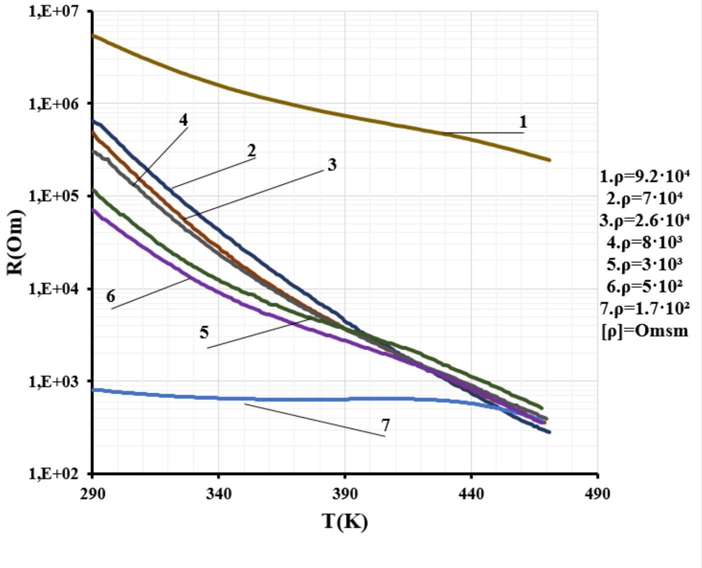
Let us consider the relaxation processes in the p-n junction or Schottky barrier formed on an n-type silicon substrate. Let the reverse electric field strength VVV be much greater than the contact potential difference VkV_kVk across the p-n junction or Schottky barrier. In this case, the concentration of mobile charge carriers in the majority of the volume charge layer (VCL) is usually lower than the concentration of ionized impurities.

Silicon was used as the semiconductor material. A monocrystalline n-type Si<P> sample was selected for this purpose. It was cut from a cylindrical grown state, with the dimensions of the sample being 8 mm in length, 4 mm in width, and 2 mm in thickness. The cut silicon sample was then subjected to mechanical and chemical processing for cleaning. Copper atoms were diffused into the n-type KEF-130 sample at temperatures of 1000°C, 1100°C, 1200°C, and 1250°C for specific periods via diffusion. This diffusion method was primarily used to form thin layers of impurity atoms. The type of the diffused silicon was determined using a four-probe method to measure its resistivity, and the concentration, mobility, and relative resistivity were assessed in the laboratory using the Hall effect.

| Values | **KEF-130** | **Nº1Si<Cu> T=1000ºC** | **Nº2Si<Cu> T=1100ºC** | **Nº3Si<Cu> T=1200ºC** | **Nº4Si<Cu> T=1250ºC** |
|---|---|---|---|---|---|
| **ρ(Omsm)** | 130.3 | 173.6 | 508.7 | 8234.11 | 23718.4 |
| **μ(sm$^2$/V·s)** | 924.8 | 990.8 | 1500.4 | 1148.9 | 1718.8 |
| **n(1/sm$^3$)** | 5.18E+13 | 7.11E+13 | 7.43E+12 | 4.31E+12 | 1.93E+12 |
| **ρ(Omsm) 4-zond** | 131.8 | 178.7 | 534.2 | 8288.9 | 24092.7 |

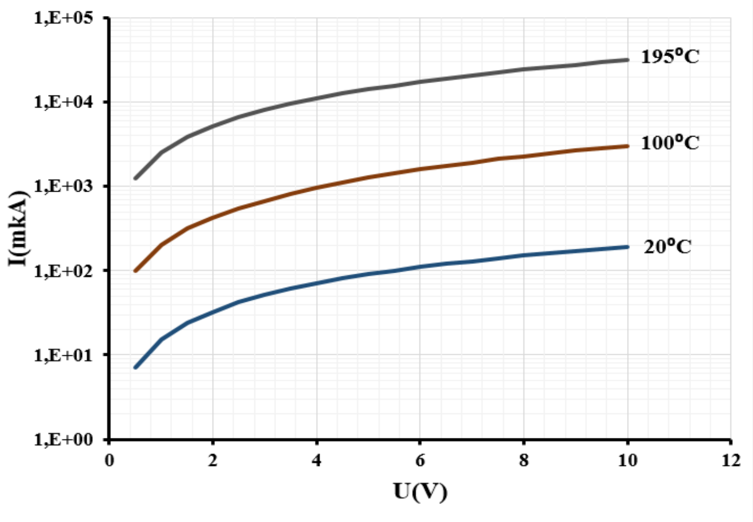
It can be seen from the values obtained as a result of diffusion that the parameters of silicon can be changed over a wide range by introducing impurity atoms into it. The values in the table show that the resistivity of the sample obtained from diffusion varies with different values. This change in values is mainly dependent on the diffusion time and temperature during diffusion. The Si<P,Cu> sample was prepared by three different methods: 1) direct implantation, 2) coating the silicon surface with a selected impurity element via a chemical process, and 3) synthesizing and depositing the impurity element onto the silicon surface. In all three methods, impurity atoms were diffused into the silicon, and the results were compared. By studying previous works, certain aspects of the effectiveness of these new results were identified. When a certain voltage, such as 5V or 3V, is applied to copper-doped silicon, the current value decreases due to the increase in resistivity. When external energy affects the copper-doped silicon, its resistivity and consequently its conductivity change significantly. Since the sensor is intended to measure temperature and humidity, it is measured based on the effect of thermal energy. For this purpose, the copper-diffused silicon sample, which has a resistivity lower than that of the metal probe, is measured using a laboratory device. When temperature affects the sample, its resistance decreases, and its conductivity increases, creating a foundation for the use of multifunctional semiconductors.

In the second chapter of the dissertation, various laboratory instruments for measuring semiconductor parameters are presented. Using the four-probe method and the Hall effect, the measured values of copper-doped silicon parameters are provided in the table. Now, this copper-doped sample was measured in a specially designed laboratory device to determine the temperature dependence of the semiconductor resistance. Si<P Cu> samples with varying resistivities were obtained by diffusing copper atoms into silicon. These samples exhibited resistivities that differed by a factor of 10. The initial parameters of the Si<P> sample had resistivities of 10 Ω·cm, 40 Ω·cm, 50 Ω·cm, 100 Ω·cm, and 130 Ω·cm. During the diffusion of copper atoms into n-type silicon at various temperatures in the furnace, the resistivity increased by a factor of ten to one hundred, resulting in seven different resistivity values. The temperature dependence of these seven resistivity values was measured, and the results were related to each other and expressed in graphical form. The obtained results are presented in Figure 1



Temperature dependence graph of silicon samples doped with copper (Cu) having seven different resistivity values

With the increase in temperature, it can be concluded that the resistivity of silicon decreases, as shown by the different resistivity values. The best values were found in the 3rd and 4th samples, with resistivities of 8 kΩ·cm and 26 kΩ·cm, respectively. These values represent the temperature sensitivity of Si<Cu> with a coefficient of $\beta = 9000$ (K). Using these graphical values, a thermal sensor device was calibrated and programmed accordingly. Based on the graph values shown in Figure 3.1, the voltage-current characteristic of the doped silicon sample was determined. The voltage-current characteristic changed with proportional values. During the measurement of the voltage-current characteristic of the copper-doped sample, the effect of temperature on the change in its properties was also observed.



The voltage-current characteristic (VAX) of Si<Cu> was measured at room temperature, 100°C, and 195°C.

When measuring the voltage-current characteristic, the results obtained at room temperature may significantly differ from those measured at higher temperatures. By introducing impurity atoms into silicon, the electrophysical properties can be significantly improved, which plays a crucial role in obtaining semiconductor materials suitable for devices. The effect of temperature on the voltage-current characteristic is also used to determine the heat resistance level of the material.

## REFERENCE

1. Decree of the President of the Republic of Uzbekistan Shavkat Mirziyoyev "On the development of hydroenergy for 2017-2021."
2. A.T. Mamadalimov, M.N. Tursunov, Physics and Technology of Semiconductor Solar Cells. Educational manual. Tashkent University, 2002. - 94 pages.
3. Neprorzhny P.S., Obrezkov V.I. Introduction to the specialty: Hydroelectric Power Engineering. Moscow, 1990. - 352 pages.
4. Vissarionov V.I., Deryugina G.V., Kuznetsova V.A., Malinin N.K., Solar Energy: A textbook for universities / Edited by V.I. Vissarionov. - Moscow: Publishing House of MPEI, 2008.
5. Meitin M. Photovoltaics: Materials, Technologies, Prospects. Let the Sun Always Shine // Electronics-NTB. - 2000. No. 6. - P. 40-47.