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STUDY OF THE MOBILITY AND ELECTRICAL CONDUCTIVITY OF CHROMIUM SILICIDE

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The temperature dependence of the mobility in chromium silicides in the temperature range of 80 ÷ 780 K was studied. The mobility gradually increases to a temperature of 350 K, then it saturates in the temperature range of 350 ÷ 450K, then gradually decreases. It is shown that the mobility depends on the scatter of charge of carriers on a crystal lattice, impurity ions, dislocations, and silicide inclusions. The frequency of collisions is proportional to $T^{3/2}$, and the mobility varies with temperature as $T^{-3/2}$. At high temperatures, phonons may be considered as "frozen" defects and collision frequency with its will proportional to T. The temperature dependences of the electrical conductivity in this temperature range were also studied. Areas with negative and positive temperature coefficients are revealed.
Keywords: *Diffusion; Associate; Lifetime; Film; Acceptor center; Radioactive isotope; Distribution; Mobility, Resistivity; Diffusion coefficient; Enthalpy*
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INTRODUCTION

The use of diffusion-doped single-crystal silicon to produce Schottky diodes, sandwich photoresistors, infrared sensors, thermal sensors, and solar cells is an urgent task today [1-3]. A well-developed technology for growing single-crystal silicon, a fundamentally new technology for creating low-dimensional objects in silicon, modifying properties by various methods, as well as discovering new physical phenomena in the near-surface region that are not typical for bulk silicon, attracts close attention of researchers as an active material for the needs of micro- and nanotechnology [4,5].

Currently, transition metal silicides are becoming the base material for new, promising technological schemes of future generations due to their resistance to aggressive media and high-temperature treatments [6-9]. Therefore, a comprehensive study of the mechanism of the entry of impurities into the bulk of the crystal and their interaction with both the matrix atoms of the crystal and technological impurities is relevant. From this point of view, the study of the formation of silicides in the surface region of silicon during diffusion doping and the development of new semiconductor devices based on them is of particular scientific importance in the context of the creation of new materials for micro- and nanoelectronics.

Therefore, in this work, we investigated the mobility of charge carriers and electrical conductivity, which are necessary in studying the mechanism of current flow through chromium silicides.

MATERIALS AND METHODS

Chromium has a large diffusion coefficient in silicon, so the diffusion method of doping was used. This method has a number of other advantages: 1) relative simplicity of technology; 2) the possibility of studying the influence of annealing temperature on the initial parameters of the crystal; 3) the ability to regulate the concentration of electrically active chromium atoms by changing the temperature. [10, 11]. For doping, single-crystal silicon samples of the KDB-10 and KEF-20 brands grown by the Czochralski method were used. Samples in the form of a parallelepiped with dimensions of $2{\times}2{\times}10$ mm^3, $3{\times}5{\times}16$ mm^3 were cut out from single crystal ingots. The samples were degreased and subjected to chemical etching in a $1HF{:}5HNO_3$ solution for 1÷2 minutes, washed in deposited water, and dried at a temperature not exceeding 373 K.

Ampoules with silicon samples and powders of chromium atoms were evacuated to a vacuum of ~0.133 Pa and sealed. The ampoules were placed in a horizontal furnace and annealed at a temperature of 1123 ÷ 1323 K for 30 ÷ 80 minutes. After annealing, the samples were quenched at a rate of 150 K/s. Using the methods of helium ion back scattering spectrometry [12], X-ray photoelectron spectrometry, the formation of new chemical compounds was proved: mono-, di- higher chromium silicides. Electrical conductivity and mobility were measured by classical methods [13-15].

RESULTS AND DISCUSSION

In Fig. 1 the temperature dependence of the mobility of charge carriers is given. As can be seen from this figure, the mobility increases smoothly up to a temperature of 350 K, then it saturates in the temperature range of 350 ÷ 450 K, then gradually decreases. Mobility is a characteristic that depends on the scattering of current carriers.

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Carriers scatter for various reasons: on vibrations of atoms of the crystal lattice, on impurity ions, when colliding with each other, on neutral impurities, on crystal imperfections, such as dislocations, boundaries of crystal grains, boundaries of silicide inclusions, etc. Thus, the frequency of collisions of carriers with scattering centers will be the sum of the frequencies of collisions with various kinds of defects.

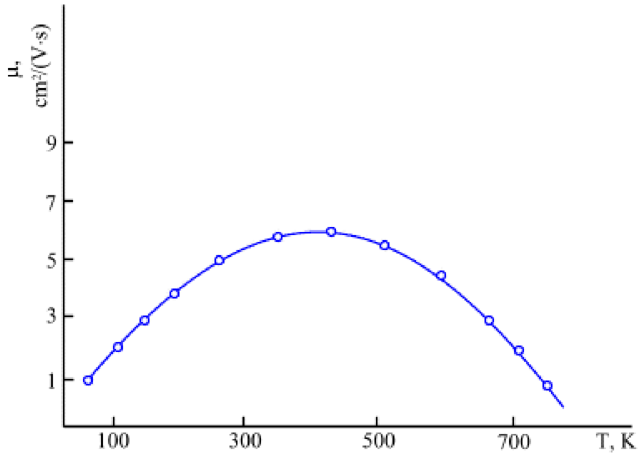

Figure 1. Temperature dependence of mobility in Si<Cr> samples

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In different temperature regions, the role of collisions of various kinds is not the same. Scattering of carriers occurs as a result of thermal vibrations of atoms. The cross section associated with thermal vibrations of atoms and leading to scattering of the carrier is proportional to the square of the amplitude of thermal vibrations, which in turn is proportional to the energy kT. In this case, the effective frequency of carrier collisions will be proportional to the cross section of scattering centers and the velocity of carriers moving between them: $< v_H > \sim\sqrt{T}$. Thus, the frequency of atomic vibrations is proportional to $T^{3/2}$, and the mobility varies with temperature as $T^{-3/2}$. At sufficiently high temperatures, the phonon velocity is 10^5 cm/s, and the current carrier velocity is 10^7 cm/s. Therefore, for current carriers, phonons are practically “frozen” lattice defects. The frequency of collisions with these "frozen" defects will be proportional to their number, i.e. *T*.

In Si<Cr> samples, in the near-surface region with a thickness of 35 μm, when carriers are scattered by impurity ions, the mobility increases with increasing temperature, then it reaches saturation, and at high temperatures, when scattering occurs mainly on phonons, the mobility decreases.

Typical temperature dependences of electrical conductivity for chromium silicides are shown in Fig. 2.

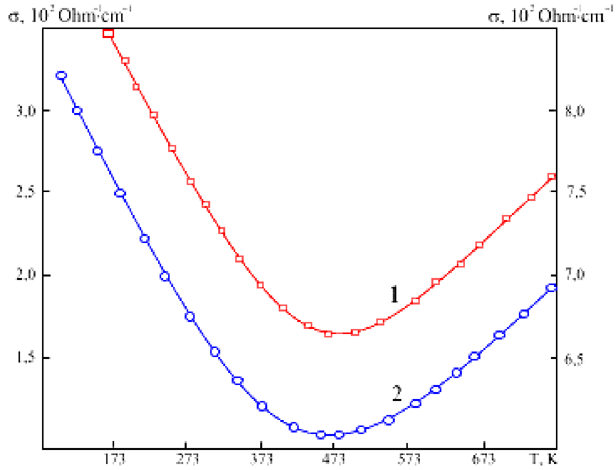

Figure 2. Temperature dependence of electrical conductivity of chromium silicides: 1– for CrSi; 2–for $CrSi_2$

It can be seen from the figure that both for CrSi and $CrSi_2$ there are three regions. The first section is the temperature range 73 ÷ 423 K, where the electrical conductivity decreases linearly with increasing temperature. The second section is the temperature range 423 ÷ 523 K, where the electrical conductivity almost does not change. The third section is the temperature range 523 ÷ 773 K, where the electrical conductivity increases linearly with increasing temperature. In the first region, chromium silicide behaves metal-like, having a negative temperature coefficient.

In the third section, the temperature dependence of chromium silicide is similar to that of a semiconductor (positive temperature coefficient). The electrical conductivity of chromium monosilicide is about 6-7 times greater than that of disilicide, which is explained by the difference in the number of charge carriers.

The decrease in electrical conductivity in the first section is due to the increased scattering of electrons on lattice phonons, on the boundaries of crystal grains, on crystal imperfections, on impurity ions, and so on. It should be noted that the role of collisions of various kinds is not the same in different temperature regions. In our crystals, the main role is played by scattering by vibrations of lattice atoms and by the boundaries of crystal grains.

CONCLUSIONS

Diffusion doping of silicon with chromium revealed a near-surface region 35 μm thick, where chromium silicides are formed. The temperature dependences of the mobility of current carriers and the electrical conductivity of the silicide layer of the crystal were experimentally studied in the temperature range 350 ÷ 780 K. It was shown that the mobility increases smoothly up to 350 K, then saturates, then gradually decreases.

The reasons for this dependence are indicated. Three segments were revealed in the temperature dependence of mobility: the first segment is the temperature range 77 ÷ 423 K, where the electrical conductivity linearly decreases with increasing temperature. The second section is the temperature range 423 ÷ 523 K, where the electrical conductivity does not change. The third section is the temperature range of 523 ÷ 773 K, where the electrical conductivity of the linear increases with increasing temperature, the conductivity increases linearly with increasing temperature. Such a temperature dependence of the electrical conductivity is explained by the difference in the type of scattering in different temperature regions.

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ДОСЛІДЖЕННЯ РУХОМОСТІ ТА ЕЛЕКТРОПРОВІДНОСТІ СИЛІЦИДУ ХРОМУ

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Досліджено температурну залежність рухливості в силіцидах хрому в інтервалі температур 80 ÷ 780 К. Рухливість поступово зростає до температури 350 К, потім насичується в діапазоні температур 350 ÷ 450 К, потім поступово зменшується. Показано, що рухливість залежить від розкиду носіїв заряду на кристалічній решітці, домішкових іонів, дислокацій та силіцидних включень. Частота зіткнень пропорційна $T^{3/2}$, а рухливість змінюється залежно від температури як $T^{-3/2}$. При високих температурах фонони можна розглядати як «заморожені» дефекти, а частота зіткнень з їх волі пропорційна T. Досліджено також температурні залежності електропровідності в цьому діапазоні температур. Виявлено ділянки з негативними та позитивними температурними коефіцієнтами.

Ключові слова: *дифузія; асоціат; час життя; плівка; акцепторний центр; радіоактивний ізотоп; розподіл; рухливість, питомий опір; коефіцієнт дифузії; ентальпія*